EXPLORING MUSICAL COGNITION IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

BY

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ABSTRACT

This aim of this thesis was to investigate musical cognition in children with Specific Language Impairment (SLI) and typical development. The studies carried out utilised a combination of standardised assessments and experimental measures to investigate low-level perceptual to higher-order musical competencies. The theoretical framework motivating the studies comes from three broad theoretical accounts that differentially accentuate the auditory processing, cognitive and linguistic deficits in children with SLI, as well as from neuroimaging and behavioural studies showing that aspects of music and language processing rely on the same cognitive and neural mechanisms. Whilst a number of studies have investigated music perception in SLI, this thesis reports the first systematic and theoretically motivated study of this topic. The results from the studies revealed deficits in auditory short-term memory and procedural processing in SLI, supporting a domain general model of deficits in SLI. On the experiments that tested musical competencies, the children with SLI showed relatively preserved processing of melodic contour, implicit processing of musical harmony and appreciation of the emotional connotations of music. Whilst music perception was strongly associated with auditory short-term memory in typical controls, this was not the case for the children with SLI, and an alternative musical information processing strategy was proposed. The findings from this thesis indicate that although children with SLI demonstrate a range of impairments in language and cognitive functions, there are aspects of musical cognition that are relatively spared, and this has important implications for the development of therapeutic interventions.

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DEDICATION

This thesis is dedicated to those who have gone before; to Michelle Joyce, whose love and ability to see the potential in others has shaped me in so many ways, and to Violet Duffield, whose spark, determination and strength of character is a continued source of inspiration.

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CHAPTER 1

LITERATURE REVIEW: THEORETICAL ACCCOUNTS OF SPECIFIC LANGUAGE IMPAIRMENT (SLI)

ABSTRACT

This chapter will begin with a description of Specific Language Impairment (SLI) outlining the diagnostic criteria and prevalence estimates for SLI alongside the outcomes of children diagnosed with this neurodevelopmental disorder. Following this, theoretical accounts of SLI from within auditory processing, cognitive and linguistic frameworks will be discussed. Finally, the predictions concerning the musical processing abilities of children with SLI, that arise from within each of the theoretical accounts will be considered. This chapter will focus on reviews of each theoretical account of SLI that will be tested in the subsequent chapters. The literature relating to each musical experiment will be reviewed in the introductions for each of the experimental chapters. Throughout this chapter the term ‘speech’ will be used to denote a verbal means of communication and the term ‘language’ will be applied as an overarching term to refer to processes involved in both receptive and expressive communication.

Diagnostic Criteria

Developmental disorders of speech, language, and communication account for 40% of referrals to paediatric services (Harel, Greenstein & Kramer, 1996). Whilst many of these children are referred with early language delay, there are some who demonstrate persistent difficulties with language expression and comprehension despite an absence of apparent neurological damage, hearing deficits, severe environmental deprivation, or mental retardation. These children are given a diagnosis of 'Specific Language Impairment' (SLI) (Lees & Unwin, 1997). SLI is the most frequently diagnosed form of developmental language disorder, affecting up to 7% of 5 year old children (Tomblin et al, 1997). SLI can affect both expressive and receptive language and is associated with an impoverished vocabulary, word-finding problems and difficulty learning new words (Leonard, 1998). Whilst SLI is primarily diagnosed on the basis of language criteria, it should be noted that many children with this disorder also have difficulties in social interaction and deficits in social competence (Farmer 2000).

In the 'Diagnostic and Statistical Manual for Mental Disorders' (DSM-IV, 1994), 'Specific Language Impairment' is diagnosed in children whose language abilities are below what would be expected given their chronological age and non-verbal IQ. The current diagnostic practices involve inclusionary and exclusionary criteria. The inclusionary criterion requires language abilities to be below age expectations and nonverbal cognitive abilities (IQ levels of 85 or higher that can be extended down to include nonverbal IQ levels of 70-85), performance on general language assessments suggests that children in the lower range of nonverbal IQ show the same overall profile of language impairment as children in the range of 85 and above (Tomblin & Zhang, 1999). The exclusionary criteria are used to eliminate any possible related disabilities such as hearing loss, Autism Spectrum Disorder, or Intellectual Disability. Conventional cut-offs for Language Impairment are in the range of 1 to 1.25 standard deviations below the population mean on language assessments. The specifications from the DSM-IV have been described as the DSM-IV was in use when the children included in this thesis were diagnosed with SLI. In the DSM-IV 'SLI' was included under the broader diagnostic classification of 'Communication Disorders', however in the DSM-V 'SLI' has been re-introduced as a separate diagnostic category. The same inclusionary and exclusionary criteria as found in the DSM-IV still apply.

Like many neurodevelopmental disorders, SLI is extremely heterogeneous, encompassing a wide variety of phenotypes within the diagnostic criteria. This means that there is considerable variation in the profile of linguistic deficits observed in individuals diagnosed with this disorder (Bishop, 2001). However, in a large proportion of cases the most obvious difficulties are with grammatical aspects of language, impacting upon the processing of phonology and syntax (Bortolini, Leonard & Caselli, 1998). Given the heterogeneity of impairments typically observed in SLI, it has been proposed that SLI is not a single syndrome, but can be broken down into separate syndromes or subgroups. Typically a distinction between the more linguistic, grammatical impairments and the pragmatic or socially constrained language impairments is drawn. Those with grammatical impairments have been referred to as G-SLI, whilst those with a profile of pragmatic impairments have been given the name P-SLI (Bishop & Norbury, 2002). More recently, it has been proposed that SLI is a syndrome which can be broken down into three separate syndromes: typical SLI, characterized by disproportionate problems with grammatical development; developmental & verbal dyspraxia, characterized by speech output problems due to difficulty in programming movements; pragmatic SLI, characterized by problems using language appropriately in a given context (Parisse and Maillart, 2008).

Outcomes

Around 50 – 90% of children with SLI continue to exhibit language problems through childhood and many go on to have reading difficulties that persist through to adolescence (Catts, 1993; Catts, Tomblin & Zhang, 2002). In cases where language difficulties are mild or specific in form, or the child has a higher IQ, the long-term outcomes are usually better (Bishop & Edmunson, 1987). Children with persistent language difficulties and delay at 5 1/2 years have been found to continue to demonstrate similar language impairments at 15-16 years of age (Bishop & Edmunson, 1987) and even children given an early diagnosis of SLI whose language skills appear to be resolved at 5 ½ years still perform less well than controls on measures of phonology and literacy when aged 15-years (Stothard et al, 1998).

In addition to the heightened risk of late-occurring impairments in literacy, it has been found that the majority of referrals to child psychiatric services are for children with previously undiagnosed language difficulties (Cohen, 1997). It thus appears that a failure to recognize, diagnose, and offer appropriate interventions may be a contributive factor in the development of psychiatric disturbance in children with language disorders. The risk of psychiatric problems is lower for children with difficulties that are restricted to speech production, as compared with children with more pervasive language difficulties (Baker & Cantwell, 1982). One possible reason for this discrepancy is that a language disorder has greater implications for the social development and broader communicative abilities of an individual than a speech disturbance (Marton, Abramoff & Rosenzweig., 2005). Whilst the long-term outcomes for children diagnosed with SLI are quite variable, it has been demonstrated that those with SLI have fewer quality friendships, are at increased risk of psychiatric disturbance and show poorer overall educational achievement than typical children (Conti-Ramsden & Botting, 2008). Investigations of the adult prison population in the UK have observed a much higher incidence of language and communication difficulties than that found in the general population (Bryan, Freer & Furlong, 2007; Snow & Powell, 2004; Bryan, 2004). It has been suggested that whilst the apparent linguistic problems in SLI may resolve over time, this may be an ‘illusory recovery’ and there may be later-emerging problems when academic and social demands are increased (Scarborough & Dorbrich, 1990). Investigations of the long-term outcomes for children diagnosed with language and communication difficulties indicate that these early difficulties can have far-reaching negative consequences on the child’s academic, social and educational success (Conti-Ramsden & Botting, 2008; Stothard et al., 1998).

The language system

The adult language system is multicomponential, and is comprised of a number of specialized sub-systems: phonology, grammar, semantics and pragmatics. Phonology is the system of speech/sound contrasts in words (Joanisse & Seidenberg, 2003). Grammar is the structure governing language and it enables a speaker to produce meaningful utterances and the listener to accurately comprehend meaning in such utterances (Leonard, 1998). Grammar is comprised of morphology and syntax. Syntax is the system of rules that governs how words can be put together to form a coherent sentence, morphology refers to the underlying structure of words and the units of meaning (morphemes) they comprise e.g. boy (morpheme) cowboy (two morphemes: cow and boy). ‘Inflectional morphology’ is the addition of morphemes to change the meaning of a base form (e.g. adding ‘ed’ to ‘camp’) which is commonplace in the English language (Ullman & Gopnick, 1999). Inflectional morphemes are typically used as tense markers (van der Lely, Rosen & McClelland,1998). Semantics refers to the meaning conveyed in language both at the sentence level and the word (lexical) level. Given that the grammatical structure of a sentence (syntax) is usually tied to the sentence’s meaning, there is a strong relationship between syntax and semantics in language. Different grammatical forms take particular semantic roles in a sentence. For example, consider tense markers and inflectional morphology, 'she packed her bags' as opposed to ‘she is packing her bags'. Pragmatics refers to how language is used socially and success in this aspect of language rests upon both the speaker and the listener sharing certain assumptions of what constitutes effective communication.

Typical language development

Typical language development rests upon the ability of the child to tune into the acoustic cues that are relevant to the perception of speech and tune-out those irrelevant auditory cues that are present in the environment. As such auditory processing plays a crucial role in the onset of language. The ability to localize and attend to auditory input is a prerequisite of language acquisition and the perception of speech draws upon the capacity to detect word envelope cues signaled by variations in amplitude (loudness), to discriminate pitch changes, and to perceive gaps between different components of the speech signal (Hulme & Snowling, 2009).

Saffran, Aslin and Newport (1996) have demonstrated that typical infants acquire vocabulary through ‘statistical learning’ in which they track transitional probabilities between phonemes in words. The transitional probabilities within words are low and those between words are high, and this facilitates the infants’ ability to detect word boundaries in continuous streams of auditory input. Similar statistical learning mechanisms have been observed in adults across music and language domains when learning a novel language or learning a new ‘tone language’ (Saffran, Johnson, Aslin & Newport, 1999).

At the earliest stages of language learning, children imitate the sound patterns but will not break words down at the level of individual speech sounds or phonemes, so they are able to learn whole words with very little knowledge of the internal structure or units from which they are derived (Bishop, 2000). Jucszyk (1994) suggested that children become more aware of the phonological units in speech once their vocabulary reaches so significant a size as to necessitate an efficient means of storage and retrieval. It has been suggested that phonological awareness, i.e. the ability to analyse words in terms of their sub-syllabic units, may not develop until the child learns to read, when the alphabet makes the segmental structure of syllables very transparent (Bishop 2000). There is a universal sequence of language learning in which infants initially begin to communicate by using single words that are then later combined into more complex sentences (Bishop, 2000; Leonard, 1998). The onset of grammatical sentence formation is typically seen between the ages of 18 and 24 months when infants begin to combine words into short phrases (Leonard, 1998). However, this combination can only take place if the infant has acquired the vocabulary to combine words effectively and so the development of grammar is intricately linked with that of lexical development (Brown & Fraser, 1964).

The question concerning how children acquire syntax is one that has received much attention in the literature. In an often cited study, Chomsky (1957) observed that when presented with a nonsensical sentence 'colourless green ideas sleep furiously', people readily accept that this sentence is well-formed and grammatically correct even though it is meaningless. This led to the suggestion that grammatical knowledge is innate and could be adapted to enable an infant to learn the language to which they are exposed (Chomsky, 1957). However, Tomasello (2000) argued that young children do not demonstrate any evidence of having abstract grammatical rules when they first start formulating sentences and instead learn whole phrases by imitation and repetition. According to this account, children become aware of grammatical rules in sentences only after a critical mass of language has been acquired. Only then are they able to begin to formulate rules about what constitutes a syntactically correct sentence. Bishop (2000) suggests that there are parallels between Tomasello's account of syntax acquisition and the account of lexical learning described. In both cases, the child begins by learning whole linguistic chunks of either phonological information or word strings, without an awareness of the fact that different words or sentence frames might share the same underlying structure.

Language development in SLI

Children with SLI characteristically exhibit delayed onset of speech and the mean length of utterances (MLUs) in an SLI child's spontaneous speech are on average much shorter than those observed in typical children and have been found to be characteristic of the kinds of utterances produced by typical children one-year younger (Leonard, Bortolini, Caselli, McGrgor & Sabbadini, 1992). In terms of lexical development, the average age of first word production for a child with SLI is much later than that of a typical child (McCune & Vihman, 2001; Trauner, Wulfeck, Tallal & Hesselink, 1995). For example, whilst a typical child may produce their first word at around 11 months, the average age for first word production in a child with SLI is around 23 months (Leonard, 1998). In addition to this slowed lexical development, children with SLI demonstrate particular difficulties in learning verbs (Leonard 1998) and it has been suggested that this may highlight a particular difficulty in processing words that cannot be rote-learned in isolation, but are processed in relation to the sentence in which they appear (Gleitman & Gleitman, 19992). Children with SLI typically manifest difficulties with receptive and expressive grammar problems and a number of theorists have proposed that children with SLI have difficulty learning certain syntactic rules, or acquiring knowledge of linguistic syntax (van der Lely, 1994; van der Lely, Rosen & McClelland, 1998).

Difficulties in producing or perceiving particular phoneme contrasts in SLI may be due to a failure to break down words into their sub-syllabic units. Bishop (1997a) has suggested that these children experience difficulties analyzing speech at the level of the syllable and remain unaware of the sub-syllabic units of which words are composed. Thus the child with SLI adopts an inefficient and cumbersome mode of analysis that fails to utilize prior knowledge when learning new words and which makes the storage and retrieval of words effortful. Support for this notion comes from an observation of the syntactic difficulties observed in SLI, which seem to indicate that these children may learn whole words or phrases without an awareness that they are built from common elements (Gopnick, 1990). Leonard (1998) proposes that children with SLI are aware of linguistic rules and their inability to consistently apply them results from abnormalities in information processing. According to this account, successful application of rules may be observed when the language system is not burdened with other demands, thus whilst syntactic knowledge becomes automatic in typical children it remains effortful to apply in those with SLI. Both accounts seem to indicate that the child with SLI becomes stuck in immature modes of linguistic processing (Bishop 2000).

In one experimental study Evans, Saffran and Robe-Torres (2009) observed impaired statistical learning in children with SLI relative to typical age-matched controls. After 21 minutes of exposure to a novel word stream the participants with SLI failed to track transitional probabilities and performed at chance when tested on items presented during exposure. These results are somewhat consistent with an implicit/procedural learning deficit account of SLI (Ullman & Pierpont, 2005), which proposes that children with SLI will find it difficult to acquire procedural knowledge across domains. Underlying cognitive impairments in these children may trigger atypical learning processes resulting in downstream compensatory processes that give rise to atypical language profiles. Thomas (2006) has suggested that a complex neurodevelopmental disorder such as SLI is likely to be a consequence of a range of atypical learning processes, acting in tandem across development, rather than damage to a specific cortical region.

One suggestion as to the potential etiology of SLI is that genetically influenced abnormal neurological development, occurring early in prenatal life, results in a brain that is not optimally organized for learning language (Bishop, 1999). The question of how genetic influences operate and result in constrained language acquisition in SLI is an interesting one. Galaburda et al (1985) suggested that learning difficulties in general arise as a consequence of abnormalities in prenatal processes of neuronal migration. These prenatal complications lead to distortions in the organization of the cerebral cortex, resulting in a brain that is not optimally organized for learning from the outset.

An alternative theory posits that the primary problem in SLI is a genetically determined impairment of social cognition, which results in poor tuning to communication and subsequent delays in learning vocabulary (Locke, 1994). According to this theory, the social impairment prevents the child acquiring the 'critical mass' of vocabulary that is needed to activate left hemisphere brain mechanisms concerned with analysing the phonological and grammatical aspects of language. Because the left-hemisphere has not been activated, the SLI child persists in using inefficient right-hemisphere mechanisms for language learning. Although SLI has been associated with a range of social difficulties (Marton, Abramoff & Rosenzweig, 2005; Farmer, 2000), it has been argued that these pragmatic-social difficulties co-occur with, as opposed to being causally related to, the language impairments. Support for the notion that SLI may be associated with inefficient processing of language in the left hemisphere comes from one fMRI study reporting that a Finnish family with SLI showed reduced activation in cortical areas that are critical for language processing (Hugdahl et al, 2004).

The Genetic Basis of SLI

Familial clustering and twin-based heritability studies provide strong evidence of genetic influences in SLI (Bishop, 2006). In a review of seven family aggregation studies that measured language impairment in relatives of children with SLI, Stromswold (2008) found that on average a positive family history of language impairment was found in 46% of those with SLI compared to 18% for controls. Similarly, twin studies have demonstrated a higher concordance rate of SLI for MZ twins as compared with DZ twins (Bishop, 2001). Taken together both family aggregation and twin studies indicate genetic influences may contribute to the onset of SLI.

Advances in understanding the potential genetic etiology of developmental language disorders were made upon the discovery that heterozygous disruptions of the FOXP2 gene caused a rare Mendelian speech and language disorder in a three generation family (Hurst et al, 1990). The FOXP2 gene has been found to be directly disrupted in the 'KE family' and an unrelated translocation patient, 'CS'. It has been suggested that the KE and CS phenotypes may be caused by haploinsufficiency of FOXP2 at a key stage of embryogenesis, which results in the abnormal development of neural structures important for speech and language (Lai et al., 2001). Point mutations and chromosomal abnormalities that affect FOXP2 are associated with difficulties in learning and producing sequences of oral movements which impair speech. The affected persons have variable levels of impairment in expressive and receptive language, extending to problems with the production and comprehension of grammar. It has been suggested that since the impairments observed in the KE family include non-linguistic oral apraxia, the primary deficit may be non-linguistic, affecting language processing in a secondary manner (Frederici, 2006).

Although disruptions to the FOXP2 gene have been implicated in some cases of language impairment, further analyses of the FOXP2 gene in persons with typical forms of specific language impairment have not detected etiologic mutations or any evidence of association of this gene with SLI (Newbury et al., 2002). Furthermore, as few as 2% of people with verbal dyspraxia carry etiologic point mutations in this gene (Vernes et al., 2008). It therefore seems that the mutation of FOXP2 itself is unlikely to be a major risk factor for common language impairments. Currently, there is no report of a single gene associated with typical specific language impairment (Newbury, Bishop & Monaco, 2005) and this may reflect the complex nature of the syndrome and the likely multigenic etiology (Skuse & Siegal, 2007). So whilst the genetic influence in SLI has been clearly demonstrated, geneticists are far from isolating a specific language gene that is disrupted in SLI. The FOXP2 gene appears to impact upon the development of a range or organs including the brain networks implicated in speech and language (Fisher, 2005).

Bishop (2001) suggests that genetic factors alone do not seem sufficient to explain the heritability patterns observed in SLI and so it is possible that a single dominant gene may be a risk factor for SLI that is only manifest under certain environmental conditions. However, as previously suggested, it is currently unclear whether SLI is best conceptualized as a single syndrome or an umbrella term for a number of different language disorders, and this hampers attempts to elucidate the role of genes in causing SLI (Bishop, 2001). A 'behavioural' or 'cognitive' phenotype describes a style of behaviour characteristically observed in neurodevelopmental disorders in which a genetic anomaly has been demonstrated. It has been suggested that these ‘phenotypes’ are the observable reflections of dysfunctional neural systems (Skuse & Siegal, 2007). Occasionally, a particular genetic mutation, or deletion, is associated with certain behavioural phenotypes that look like a known disease. However, there is an increasing consensus that complex developmental disorders such as autism and SLI are caused by the interaction of a number of genetic and environmental risk factors (Bishop 2006; Pelphrey, Shultz, Hudac & Vander Wyk, 2011). Thus, although a particular genetic mutation may be associated with the behavioural phenotype of a particular syndrome, it does not necessarily follow that the syndrome is attributable to a single disruption in one gene. Complex psychiatric disorders most likely have a multigenic aetiology with several loci interacting to produce a genetic liability to disease onset (Newbury et al., 2002). The isolation of relevant genetic effects can yield new insights into the potential causes of particular impairments observed in developmental syndromes, which may then lead to improvements in the classification, diagnosis, and treatment of these disorders.

One way to investigate the genetic basis of heterogeneous syndromes such as SLI is to define a measurable biologic marker, or endophenotype, that is present regardless of how the disorder is manifested clinically. An endophenotype is a psychiatric classification or measurable biological marker of a known phenotype. The process of identifying endophenotypes can be a useful way to trace genetic markers and heritable factors in disease onset for complex psychiatric and developmental disorders that have a multigenic etiology (Kendler & Neale, 2010). Given the dynamic nature of a higher cognitive system as complex as language, it may be that genetic influences on endophenotypes are more straightforward to identify and replicate than the impact of genetic variation on behaviour at the level of symptoms (Gottesman & Hanson, 2005). An endophenotype that has been considered in SLI is auditory short-term memory (STM), a cognitive process that is implicated in word learning. auditory STM is typically measured using a non-word repetition task in which participants are asked to repeat back an auditorily presented novel non-word such as 'woogalamic' (Bishop, 2006; Gathercole & Baddeley, 1990). Auditory STM has been linked to specific genetic loci, and might play a role in determining some types of reading impairment as well as some language impairments in SLI (Newbury, Bishop & Monaco, 2005). Identifying those cognitive deficits that work best as indices of heritable phenotypes could help to uncover the etiology of developmental disorders such as SLI and further understanding of the broader neural systems implicated in language cognition. Ullman & Pierpoint (2005) sought to characterize the endophenotypes that were disrupted in SLI and observed that a significant proportion of individuals with SLI demonstrated impairments of a particular brain network implicated in procedural memory. They proposed that disruption to this network leads to impairments of the linguistic and non-linguistic functions that depend on it. According to this account the expressed phenotype in SLI may result from disruption to a particular brain system that does not specifically subserve the language domain.

Although consideration of the expressed endophenotypes may serve to augment current understanding of the genetic etiologies of complex syndromes such as SLI, it is important to proceed with caution since even carefully delineated endophenotypes may have different causes. For example, children with SLI may perform poorly on tests of non-word repetition for a number of different reasons (Vernes et al., 2008). Furthermore, the same genotype can result in different endophenotypes. For example, a person carrying a mutation that affects the coordination of complex oral motor movements could present with difficulties in repeating non-words, with mutism, or selective mutism, or with a tendency to omit phonologically unstressed elements in speech. This individual may then be diagnosed with a grammatical deficit, speech dyspraxia, dysfluency, or stutter (Stromswold, 2008).

Theories of SLI

The studies described in this thesis test four broad theoretical accounts of SLI. These accounts focus upon the linguistic, auditory and/or cognitive deficits that may exist in the disorder.

Linguistic

Although children with SLI do show delayed lexical development (McCune & Vihman, 2001), their language profiles indicate that their language development is atypical rather than just delayed. For example, an investigation of grammatical language processing in children with SLI found that typical 5-year old children used the past tense form of the verb (climb'ed') correctly in 92% of their utterances. Typical 3-year olds also correctly used the past tense form 50% of the time, whereas children with SLI were only correct 27% of the time (Rice et al., 1995). The findings from this study indicate that SLI is associated with particular difficulties in mastering certain aspects of language rather than a simple maturational lag in language acquisition.

Linguistic theories focus on impairments at the behavioural level in children with SLI and attempt to explain the deficits of language within Fodor's (1983) theoretical framework of modularity. A common impairment in SLI is in the use of linguistic grammar, and this has led to the suggestion that SLI may be best explained as an impairment in the underlying, possibly innate, grammatical module for language (Chomsky, 1957). Pinker (1979) suggested that children typically acquire a generative grammar that is distinguishable from other formal grammars by its lexical component. Children create paradigms that are initially word-specific that then contribute to the acquisition of general paradigms and once these general paradigms are implemented, inflections can then be used to efficiently mark new lexical items. Gopnick and Crago (1991) observed that the representation of abstract morphological features is impaired in children with SLI, and suggested that this could explain the many syntactic errors they make. Investigations of the grammatical abilities, non-grammatical language abilities and non-linguistic cognitive abilities of children with SLI, led van der Lely and colleagues to claim that at least a sub-group of children with SLI (G-SLI) have a primary grammar-specific language deficit (van der Lely, 2005; van der Lely, 1994; van der Lely, Rosen & McClelland, 1998).

Research into the comprehension and use of inflectional morphology has shown that the grammatical computations and/or representations underlying regular morphological inflections (e.g. clapped), but not irregular inflections (e.g. flew) are impaired in some children with SLI (van der Lely & Ullman, 1996; Oetting & Horohov, 1997). Thus it seems that SLI is associated with impairments in regular, but not irregular past tense marking, indicating that this disorder r may be characterised by a failure to represent regular inflections normally. Such a failure in regular tense marking may result from the use of an immature imitation-based, rather than rule-based mode of language learning. For example, if a child fails to acquire or consistently apply rules about when to use a regular past tense marker each tense marker will be derived on a case-by-case basis. This would mean that irregular tenses, that do not conform to any standard rule, would be easier to mark than regular tenses.

According to the grammar-specific deficit account of SLI, G-SLI affects hierarchical structural complexity in syntax, morphology and phonology (van der Lely, 2005), with a deficit at the level of grammatical computation underlying the formation of regular morphological inflections (van der Lely & Ullman, 1996). Thus, G-SLI children may store the regular plural forms of nouns in memory in a similar way to irregular plurals, rather than computing the regular plural form using a given morphological rule. Van der Lely & Christianson (2000) investigated a sub-group of children with G-SLI, who were characterized by a persistent grammatical impairment in the comprehension and expression of language. They found that this group of G-SLI children produced fewer correct regular plural nouns than a group of chronological age (CA) matched typical controls. It was also noted that their production of irregular plural nouns did not differ from that of the language age (LA) or chronological (CA) matched controls, showing that children with G-SLI do not experience particular difficulties with all plural forms.

To account for the broad range of syntactic deficits observed in G-SLI, van der Lely and colleagues developed the Computational Grammatical Complexity (CGC) hypothesis, which is a development and extension of the Representational Deficit for Dependent Relations (RDDR) hypothesis (Marshall & van der Lely, 2007). The CGC hypothesis provides a framework for characterizing the deficits in syntax, morphology and phonology that are typically observed in those with SLI. Awareness of different grammatical components in language typically develops between the ages of 3 and 7, and this theory proposes that many school-aged children with SLI do not have the necessary mechanisms to consistently develop grammatical rules for these components (Gallon et al., 2007; Marshall & van der Lely, 2006). The CGC hypothesis claims that the underlying deficit is in the syntactic computational system (representations and/or mechanisms) which leads to particular difficulty with syntactic dependencies (van der Lely, Jones & Marshall, 2011). This deficit prevents children with SLI from building (and parsing) syntactically complex hierarchical structures involving clausal syntactic dependency operations. Investigations of the neural correlates of syntactic processing, have shown that typically developing children show a very fast (around 150–300 ms) neural correlate, known as the Early Left Anterior Negativity (ELAN) that is associated with automatic syntactic structural knowledge. The G-SLI children did not show this response at all, but rather showed a later response at around 400 ms that is typically associated with semantic or pragmatic processing (Fonteneau & van der Lely, 2008). One interpretation of this finding is that the G-SLI children were compensating for their syntactic deficit by processing the semantic meaning of the sentence.

Investigations of wh-questions in children with SLI have revealed that they have significant impairments in the production of syntactic dependencies (i.e. in correctly processing and producing the relations between words in a sentence to reveal the meaning of the sentence) (van der Lely, Rosen & McClelland, 1998). The use of wh-questions has been found to be universally impaired in children with SLI (Deevy & Leonard, 2004; Wong et al., 2007). Although difficulties in syntactic processing have been demonstrated at both behavioural and electrophysiological levels in these children, the deficit could be the result of a domain specific deficit within the syntactic dependency operation itself or from a domain general impairment in working memory or processing capacity (Gathercole, 2006; Wong et al., 2007).

In an attempt to determine whether the syntactic deficits in SLI are a product of impairments at the level of syntactic computation or more generalized memory/processing impairments, van der Lely, Jones and Marshall (2011) asked adolescents with SLI (aged 10-17 years) to make a judgment about whether an auditorily presented wh-question sounded correct (‘‘good’’) or incorrect (‘‘bad’’). Children were presented with wh questions that were either semantically or syntactically incorrect under high or low processing demand conditions, e.g., Which telephone did the sandwich rush? What follow the rabbit? They found that children with G-SLI correctly rejected semantically incorrect questions around 85% of the time but were significantly poorer at identifying syntactic errors than TD controls irrespective of whether the sentences were presented in high or low processing demand conditions. These findings indicate that children with G-SLI show a consistent deficit in grammatical sentence comprehension that is even in evidence when processing demands are relatively low.

One of the criticisms of a grammar-specific deficit account of SLI is that deficits in morphology, observed in SLI are not absolute, but rather children with SLI follow morphological rules less consistently and often than typical controls. Such graded patterns of performance are difficult to capture in a rule deficit theory (Hulme & Snowling, 2009). Another problem with this grammar-specific deficit account is that children with SLI who are learning languages with richer morphologies than English do not demonstrate exaggerated difficulties (Leonard, 2000). Cross-linguistic observations create a challenge for the linguistic accounts of SLI that place the deficit at the level of universal grammatical structures or rules. One more general criticism of any purely linguistic account of SLI is that these accounts cannot explain why a given component in a language system has failed to develop (Thomas & Karmiloff-smith, 2003; Karmiloff-Smith, 2009). The acquisition of language is a dynamic and interactive process and atypical language acquisition and later-occurring language impairments cannot be conceptualized in the same way as the language deficits that result from a lesion to an already developed adult cortex (i.e. in an adult aphasic) (Bishop, 1997).

Auditory Processing Deficit

The auditory deficit account of SLI proposes that the root cause of this disorder is a generalized auditory processing deficit that results in degraded speech input (Tallal, 2000; Tallal & Piercy 1973a, 1973b). This auditory processing account of SLI denotes a particular difficulty in processing the temporal or 'time-based' nature of auditory stimuli, which in turn impacts upon the capacity to effectively perceive, categorise and process sounds in speech. Early support for the idea that language impairments may stem from a low-level deficit in rapid auditory processing came from Lowe and Campbell (1965), who observed that children with SLI needed an inter-stimulus interval (ISI) of around 250 ms duration, to discriminate two tones, of different frequencies. In contrast, typical controls accurately discriminated the tones with an ISI of 40ms. These findings indicate that SLI can be associated with impairments at the level of temporal auditory processing.

Tallal and Piercy (1973) developed the Auditory Repetition Task (ART) modeled after the task used by Lowe and Campbell (1965). Using this task they found that typical children could reliably discriminate between two tones with an ISI of 8 ms, whereas children with SLI required an ISI of 305 ms to make an accurate discrimination. An interesting result from the study was that, in a second condition in which the children were required to make same/different judgments, rather than determine the order of the stimuli, the same pattern of performance was observed. This observation indicated that SLI was not necessarily characterized by impaired ordering of auditory stimuli, but rather by general difficulties in auditory temporal processing (Tallal, 2000). One difficulty with the ART as a measure is that it simultaneously measures frequency discrimination and temporal perception, making it unclear whether difficulties with this task are the result of poor frequency discrimination or impaired temporal processing (McArthur & Bishop, 2004a; Hill et al, 2005). One criticism of the rapid auditory processing deficit account of SLI is that there is little evidence that slowing speech improves the discrimination of speech sounds or the intelligibility of speech (see Rosen, 2003 for a review). For example, Bradlow et al., (1999) found that lengthening the formant transitions of synthesized 'da'/'ga' speech sounds did not improve their discriminability for either control children or those with language problems. A further problem with an auditory processing deficit account of SLI is that the severity of the auditory processing deficit does not seem to predict the severity of the language deficit (Rosen 2003).

It is possible that interference at a low-level of auditory processing may lead to difficulties with a range of higher-order language functions. A deficit in underlying auditory abilities could impact upon the capacity to categorize speech input into phonemes, which in turn could have a knock-on effect on the acquisition of syntax (Leonard, 1998). Thus the grammatical impairments observed in SLI may arise from an impairment in the perception of amplitude and duration cues which signal stressed and unstressed elements in speech. It has been suggested that difficulties in perceiving speech prosody could be linked to many of the impairments of grammatical morphology observed in SLI (Leonard et al., 1997; McGregor & Leonard, 1994). According to this theory, the auditory processing speed of children with SLI is slow and so these processing limitations are exacerbated when morphemes are brief and consequently syllables which are shorter and are of lower amplitude, duration and pitch cause particular difficulties. This notion has received some support, in that children with SLI have been shown to have problems processing non-final weak syllables across different languages (Bedore & Leonard, 2001). However, Corriveau, Pasquini and Goswami (2007) have argued that children with SLI do not have a difficulty with processing speed but have difficulties with processing capacity when acoustic cues are extended over time. They suggest that the grammatical impairments observed across languages in SLI are related to the temporal integration of changes in amplitude across duration (i.e. amplitude envelope onset cues) rather than to slower processing of brief cues. They found that the majority of SLI children tested were within the 5th percentile of performance achieved by control participants for detecting the amplitude envelope rise time and the duration of simple tones, whilst a minority of SLI children demonstrated a rapid auditory processing deficit. The authors suggest that auditory processing difficulties with integrating information over a long duration may underlie language deficits in SLI.

McArthur and Bishop (2004b) investigated both frequency discrimination and temporal processing in children with SLI and found that around one third of children with SLI showed impaired frequency discrimination regardless of the rate of presentation. This impaired group tended to be the younger age group who also experienced particular difficulties with phonological processing. This observation lends support to the notion that phonological development is linked to the capacity to discriminate changes in frequency. Similarly, Mengler, Hogben, Michie and Bishop (2005) found that a group of children with SLI performed consistently more poorly than matched controls on a frequency discrimination task. Taken together these two studies indicated that some children with SLI experience difficulties with frequency discrimination, and may possibly comprise a distinct sub-group. Hill, Hogben & Bishop (2005) addressed the question of whether the apparent impairments in frequency discrimination in SLI were due to developmental lag, or were marked deficits that were stable over time. They measured frequency discrimination in SLI and control children, and then again 3.5 years later and found that the SLI group had significantly higher frequency discrimination (FD) thresholds than controls at both time 1 and time 2. They also observed that whilst frequency discrimination thresholds improved over time for both SLI and control groups, the children with SLI continued to demonstrate significantly poorer FD thresholds than controls.

In a review of the literature, Rosen (2003) noted that typically, only a minority of children with SLI exhibit any auditory processing problems and those difficulties are not linked to the type or severity of the language impairments. Rosen (2003) further pointed out that whilst the presence of selective impairments in certain auditory tasks and not others makes it unlikely that the observed deficits are attributable to an impaired general cognitive mechanism such as attention or memory, it is still possible that some auditory tasks impose a greater cognitive load than others. Thus it may be the processing demands of certain auditory tasks that pose a problem for children with SLI.

Van der Lely et al. (2004) investigated auditory processing for three types of sounds using same/different judgments of pairs of sounds presented with a varying ISI. One pair was a synthesized ba/da contrast, another pair used non-speech sounds with the same formant frequency contrasts present in the ba/da phonemic categories. The third pair were short complex tones that differed in fundamental frequency (modeled after Tallal & Piercy, 1973). The SLI children included in this study were a sub-group who demonstrated persistent and restricted impairments in the use and comprehension of grammar in the presence of normal pragmatic language skills and attention. They found that overall performance on the auditory processing tasks was not significantly correlated with phonological processing, and that around half of the fifteen SLI participants in this study processed rapidly changing non-speech sounds normally for their age. The authors suggest that any auditory processing difficulties that might occur in SLI do not have a direct causal link with the language abilities in this group.

Evidence for auditory processing deficits in SLI yields a very mixed picture. It appears to suggest that some children with SLI do experience difficulties with frequency discrimination in an auditory processing capacity (Mengler et al., 2005; Corriveau et al., 2007). However the extent to which these deficits may play a causal role in the onset of language impairments is far from clear. Bishop et al., (1999) suggest that an auditory deficit is neither necessary nor sufficient to cause SLI, thus it may be that auditory deficits in SLI are not causally related to language disorders but only occur in association with them (Rosen, 2003). It is also possible that degraded auditory processing is just one in a number of causal risk factors associated with the onset of this complex neurodevelopmental disorder.

Cognitive

Although a linguistic approach can afford a useful insight into the nature of behavioural language impairments in SLI, it is limited in the extent to which it can really provide insights into the origins of the disorder and explain any deficits that may exist outside of the language domain. Cognitive theories consider the broader profile of cognitive functions that may be impaired in children with SLI. The advantage of this approach is that it attempts to move beyond the impairments of language observed at a behavioural level, to consider the possible deficits in cognitive mechanisms that sub-serve language. From within this approach it has been suggested that language impairments may be attributed to limitations in cognitive capacities such as procedural memory or auditory short-term memory (Ulman & Pierpont, 2005; Gathercole & Baddeley, 1993).

When considering the nature of the language impairments observed in children with developmental language disorders, it is important to consider the dynamic nature of the developing brain. The developing brain matures and changes throughout infancy and childhood (Karmiloff-Smith, 1992) and therefore cannot be conceptualized as a stabilized system of isolable units that may be independently spared or damaged (Bishop 1997). Whilst acknowledging that modularity of function that may be present in the adult brain, the neo-constructivist approach recognises that the process of brain specialization is steady and continues throughout development. Language comprehension and production is an incredibly complex phenomenon and as such is reliant upon a number of psychological mechanisms and cognitive operations. One such cognitive mechanism that has been widely considered in the context of language processes is auditory short-term memory. The working memory model is a theoretical account of short term memory processes (Baddeley & Hitch, 1974) and has been used to explain success in the production and comprehension of language, as a direct consequence of the ability to actively maintain and integrate linguistic material within the phonological loop component which is responsible for the maintenance of auditory information in short-term memory (Gathercole & Baddeley, 1993).

Throughout development, both short-term and working memory processes undergo a number of changes. The developmental gains in auditory short-term memory can be indexed with a relatively simple measure of auditory digit span which measures the immediate recall of spoken digits. Four-year old children can typically remember between 2 and 3 digits and a typical fourteen year old can remember approximately 7 digits (Gathercole & Baddeley, 1993). Similarly, with working memory measures that rely upon both short-term memory and attentional processes, research has shown that there is an increase in memory performance with age (Hulme, Thompson, Muir & Lawrence, 1984). One suggestion for this improvement is that the rate at which a person is able to rehearse auditory information in the phonological loop increases with age, so that less information is lost due to decay (Gathercole & Baddeley, 1993).

Direct associations between auditory short-term memory-capacity and language abilities have been demonstrated in a number of studies, and research has established a link between auditory STM, as measured by a non-word repetition task, and vocabulary acquisition in young typically developing children (Baddeley, Gathercole & Papagno, 1998; Gathercole & Baddeley, 1990b; Gathercole, Willis, Emslie & Baddeley, 1992). It has been suggested that auditory short-term memory plays a key role in vocabulary acquisition, by generating a brief phonological representation that is then transferred to long-term memory (Baddeley, Gathercole & Papagno, 1998). Children with SLI may have difficulty acquiring vocabulary and learning new phonological forms because their short-term memory representations are inadequate (Gathercole & Baddeley, 1990). A growing body of research has indicated that impairments in language processing, in both children and adults, may be associated with cognitive impairments at the level of memory. Two models of memory, the working memory model (Baddeley & Hitch, 1974) and the limited-capacity model (Just & Carpenter, 1992) have been particularly influential in seeking to explain the role of memory in developmental language disorders. Within the working memory model framework, the focus has been on the role of the phonological loop in language acquisition, processing and retention. The limited-capacity model focuses on a global set of resources that exist to support language computations (including lexical and syntactic processing and storage). It has been proposed that SLI may be characterized by limitations in processing, storage and capacity resulting in an overall impairment in working memory (Bishop, 1992; Montgomery, 1995a; 1996; Lahey & Bloom, 1994).

The 'non-word repetition' task is a measure of auditory short-term memory. The task involves the repetition of non-words comprised of familiar phonological units, that range from 2-5 syllables in length (e.g. woogalamic). Research has shown that children with SLI demonstrate significantly poorer auditory STM than typical controls matched for nonverbal cognitive ability and verbal ability (Gathercole & Baddeley, 1990a; Montgomery, 1995b). It has since been suggested that deficits in non-word repetition provide an endophenotypic marker of SLI (Newbury, Bishop & Monaco, 2005; Newbury et al., 2009). The notion that a cognitive impairment in auditory STM is implicated in SLI is not irreconcilable with Tallal's (2000) suggestion that SLI may be characterized by an auditory deficit in processing rapid, incoming auditory stimuli. It is possible that those with SLI find it difficult to repeat non-words because it necessitates the discrimination of rapid sequences of speech sounds (Bishop, 2001). Bishop (1999) measured temporal processing using the ART and measured auditory STM using the Children's Test of Nonword Repetition (CNRep), (Gathercole et al., 1994) in an SLI twin study. She found that performance on both the cognitive (CNRep) and auditory (ART) measures differentiated the SLI group from the controls. Although the children in the SLI group were markedly worse than controls on the CNRep and the ART, they did not show differential performance on the ART according to the rapidity with which the tones were presented. Importantly, the pattern of twin-twin correlations was different for the two tests. Correlations for MZ twins were significantly higher than for DZ twins on the CNRep task but not the ART task. The findings from the ART task indicated that environmental factors were largely responsible for determining whether or not twin-pairs were impaired on auditory temporal processing. Bishop (2001) notes that in exploring the data further, it becomes apparent that genetic and environmental risk factors are additive, such that those children who performed worst on a range of standardized language tests were those who had both risk factors present (i.e. performed poorly on both the ART and CNRep). Bishop (2001) concludes that auditory and processing and auditory STM impairments are not just different indicators of the same core disorder but are distinct deficits with different origins.

Working memory capacity that incorporates both attention and STM processes may also be impaired in children with SLI. Swanson, Cochran and Ewers (1989) devised a sentence span task in which participants were required to answer questions about a sentence whilst concurrently holding the last word of the sentence in mind, and found that skilled readers had a higher sentence span than unskilled readers. Furthermore, Weismer, Evans and Hesketh (1999) found that in a sentence span task, children with SLI showed the same level of accuracy in determining whether a statement about the sentence was true or false, but showed significantly poorer word recall performance. More recently, Archibald and Gathercole (2006 a & b) carried out a range of verbal and visual short-term and working memory assessments and found that children with SLI were impaired on short-term and working memory tasks in the auditory domain but not the visual domain, indicating that the cognitive impairments in SLI are restricted to auditory information. The observation that the memory impairments in SLI were restricted to the auditory domain presents a challenge to general processing limitation accounts of SLI (Weismer, 1996).

It has been suggested that SLI may be may be associated with general processing or capacity limitations (Leonard, McGregor & Allen, 1992b; Norbury, Bishop & Briscoe, 2001). This theoretical approach can help to account for the range of linguistic and non-linguistic functions that may be impaired in those with SLI and can offer an explanation as to why those with SLI can have difficulties processing both verbal and non-verbal stimuli that are rapidly presented (Leonard, 1998). The observation that SLI may be associated with cognitive limitations in working memory has led to the suggestion that children with SLI may experience difficulties with a range of executive functions (Henry et al., 2012). Henry et al (2012) carried out a comprehensive investigation of higher-order reasoning and thinking or 'executive function' skills in children with SLI. Executive function involves high-level goal directed behaviours and encompasses mental processes that regulate thought and action (Friedman et al., 2006). In the study, a total of ten measures of executive function, assessing working memory, fluency, inhibition, planning and switching, in verbal and non-verbal domains, were administered to children with SLI and matched controls. Significant impairments were observed in the SLI group on measures of both verbal and non-verbal working memory, verbal and non-verbal fluency, nonverbal inhibition and nonverbal planning. This pattern of results persisted even when nonverbal IQ was controlled in the analysis. The authors suggested that the apparent impairment in nonverbal executive functions may indicate that SLI is characterized by domain general cognitive capacity limitations. However, the results could also indicate that executive functions are mediated through verbal self-reminding which may present a challenge for children with SLI. One of the difficulties with a processing limitation account of SLI is that generalized cognitive slowing could explain almost any impairment and so it becomes difficult to generate testable hypotheses about the causal mechanisms implicated in SLI (Ullman & Pierpont, 2005).

The procedural deficit hypothesis (PDH) claims that the profile of linguistic and non-linguistic impairments often observed in SLI are the product of an impaired procedural memory network (Ullman & Pierpont, 2005). The procedural memory system is the network in the brain implicated in the organisation and implicit learning of rule-systems across motor and cognitive domains (Ullman & Pierpont, 2005). Broca's area is implicated within this network in both the learning and online processing of procedural information (Ullman, 2004). According to the PDH, abnormalities in the brain structures underlying procedural memory should lead to impairments in the functions across domains that depend on these structures. Within the language system it has been suggested that procedural memory sub-serves the learning and use of rule-governed aspects of linguistic grammar in phonology, morphology and syntax (Ullman, 2001; 2004; Ullman & Pierpont, 2005).

Working memory is used in the short-term storage and manipulation of information, whereas procedural memory supports long-term knowledge and the storage of information over years. Thus the procedural memory system is one of several brain systems involved in the implicit acquisition, storage and use of knowledge and is the system that underlies the 'sequencing' of information across motor and cognitive domains (Lum et al., 2010). Although procedural memory and working memory may be principally responsible for different aspects of cognitive function and may be sub-served by separate brain networks, there may be an interaction resulting from an overlap in brain structures involved in both systems. Likewise, a similar cognitive function may be adequately performed by a different memory system, so that an impairment in the procedural memory system may result in a compensatory reliance upon a less efficient brain network to support a particular cognitive function (Lum et al., 2010).

Children with SLI have been found to have deficits in the verbal domain for tasks that are reliant upon the procedural memory network (Evans et al., 2009). Non-verbal procedural memory deficits have also been observed in implicit sequence learning tasks (Lum et al., 2010; Tomblin, Mainela-Arnold & Zhang, 2007). Sequence learning deficits have been examined in SLI using implicit visuo-spatial serial reaction time tasks (SRT), in which participants are required to press a button corresponding to the spatial location of a visual target that at first follows a prescribed pattern, before being randomized. Using an SRT task, Tomblin et al (2007) found that children with SLI were slower to learn the sequences than typical children.

Lum et al (2010) examined performance on a range of measures of verbal and visual, declarative, working and procedural memory systems in a group of 51 children with SLI and 51 controls matched for age and non-verbal intelligence. Aspects of auditory STM and working memory were assessed with a range of standardized measures such as forward and backward digit span tasks, in which participants are required to listen to a string of digits and repeat them back in either the same or reverse order. Declarative memory was measured using the Children's Memory Scales (CMS, Cohen, 1997). This assessment was designed to quantify aspects of the learning and retrieval of verbal and non-verbal information in declarative memory. Procedural memory was also assessed using a serial reaction time task. The results from the study showed that the children with SLI were impaired on a visuo-spatial procedural memory task even when working memory had been controlled in the analysis. The results also showed that grammatical abilities were significantly correlated with procedural memory in the typical children, but with declarative memory in the children with SLI. The authors suggested that this pattern of results indicates that children with SLI may rely on declarative memory as a compensatory strategy for grammatical linguistic processing in the face of impairments in the procedural memory system. Drawing all of this evidence together it seems that a cognitive deficit may underlie the linguistic impairments observed in children with SLI.

SUMMARY

The aim of this chapter was to provide an overview of the different theoretical accounts that have sought to explain the auditory processing, cognitive and language impairments characterizing SLI (Tallal & Piercy, 1973; Gathercole & Baddeley, 1990; van der Lely, 1994). The linguistic accounts, such as the 'CGC', argue that at least a sub-group of children with SLI have domain specific impairments in grammatical processing (Marshall & van der Lely, 2008). Whereas the auditory processing deficit accounts, such as the rapid 'temporal processing deficit account' suggest that one contributory factor to the language difficulties in children with SLI is impaired low-level auditory processing, that interferes with the capacity to process changes in speech sounds (Tallal & Piercy, 1973). Alternatively the cognitive accounts of SLI, such as the 'auditory STM impairment' or the 'procedural memory deficit hypothesis' argue that behavioural language impairments can be explained by deficits in underlying cognitive capacities such as auditory STMor procedural memory (Gathercole & Baddeley, 1990; Ullman & Pierpont, 2005).

From each of the theoretical accounts detailed in this review, predictions about the nature of music perception and cognition in children with SLI can be generated. For example if SLI is associated with an impairment in the phonological loop component of auditory working memory (Gathercole & Baddeley, 1990), then it would be expected that children with SLI will show impaired memory for all auditory information including both musical and verbal novel information. Similarly, if SLI is associated with a domain general cognitive impairment in the procedural memory network then this should disrupt the capacity to process hierarchical, structural information across domains (Ullman & Pierpont, 2005). Alternatively, if the grammatical impairments in SLI are specific to the language domain then the hierarchical processing of musical structure should be typical (van der Lely, 2005). Furthermore, if SLI is characterized by domain general limitations in auditory processing this should impact upon a range of musical perceptual abilities in this group (Tallal & Piercy, 1973).

The investigation of musical processing in children with SLI can serve to inform debates about the extent to which the language impairments are domain specific or are symptomatic of domain general cognitive and/or auditory processing impairments. The following seven chapters of this thesis will explore different aspects of musical cognition in children with SLI, from simple pitch-interval direction discrimination through to the implicit and explicit processing of hierarchical structure and emotional meaning in music. The experimental paradigms were designed to test different deficit accounts of SLI within the musical domain, and background data from standardized tests of cognitive and language ability were included in the analysis of the experimental data. The aim of this was to gain insight into the complex interplay between cognitive and musical development in children with impaired language.

The following chapter will outline the methodology, it will begin with the ethics and recruitment procedure and a description of the participants recruited, followed by a breakdown of the materials and assessments used to determine verbal and non-verbal abilities in the SLI sample. Finally the testing procedure and the design and statistical analysis methods will be described.

CHAPTER 2

METHODOLOGY

ABSTRACT

The aim of this chapter is to provide a detailed summary of the methods, measures and procedures employed in the thesis. The chapter is divided up into the following main sections: recruitment and ethics, participants, materials, procedure, design and statistical analysis.

RECRUITMENT AND ETHICS

Ethical approval was sought and granted from Goldsmiths College Departmental Ethics Committee.

The decision was taken to recruit the SLI sample from within NHS Speech and Language Therapy services which involved completing the necessary NHS ethical procedures. Firstly, ethical permission was sought from the NHS Research Ethics Committee (REC) at Great Ormond Street Hospital. Once the NHS REC had granted ethical approval, permission was then sought from the appropriate Research and Development (R&D) department to recruit children with SLI from within a particular NHS Primary Care Trust. Once NHS approval had been given, the clinical lead for Speech and Language Therapists working in mainstream primary schools was approached and a request made for her involvement in this project. The clinical lead then contacted the relevant Speech and Language Therapists (SLTs) in four separate language resource units to request their involvement. Mainstream 'language resources' are units attached to primary schools that are there to support children who can cope with the demands of mainstream schooling, but are in need of additional support as a result of their particular difficulties with speech and language.

Permission was then sought from the headteachers of each of the primary schools with language resource units attached, to work in the schools to test those children with SLI who had taken up placements in the language resources. Once permission was attained from both the headteachers and the SLT's working in the mainstream language resourced primary schools, parental consent forms were then sent home with the children diagnosed with SLI. Those children who returned the signed parental consent forms were invited to participate in the study.

The children in the typically developing control groups were recruited from within two different mainstream primary schools, in a similar geographical location to the language resourced schools that the SLI sample were recruited from. Permission was sought from the headteachers of two primary schools to work in the schools to recruit and test a total of 17 children from within each school. Once permission from the headteachers of each of the schools was granted, parental consent forms and information letters were sent home with the children in the relevant classes. Those children who returned parental consent forms were invited to participate in the study. For the CA-matched controls, the school arranged for participant information letters and consent forms to be sent home with all children in years 3 – 6 (aged approximately 8-11 years). Of those who returned consent forms, the children that were most closely matched to the SLI sample for age and gender were invited to participate in the study. For the VMA-matched controls, the school arranged for consent forms to be sent home to all children in years 1 and 2 (aged approximately 5-7 years). Of those who returned consent forms, the children that were most closely matched on gender and chronological age to the verbal mental age of the children in the SLI group, were invited to participate in the study.

All data collected was stored securely in a locked file in a locked office in accordance with the ESRC guidelines for the protection and storage of data. The data was anonymised and all participants given a number that was used in later analyses.

PARTICIPANTS

Group 1: children with SLI

The SLI group included 10 males and 7 females aged 7 years 3 months to 10 years 11 months (*M* = 9 years and 4 months; SD = 1 year and 2 months). All children were over 7 years of age and had received a clinical diagnosis of 'Specific Language Impairment' prior to taking part in this study. Children had been assessed by a variety of professionals (e.g., paediatricians, educational psychologists and speech and language therapists). Diagnoses were carried out using standardised assessments, for example CELF-4 (Semel, Wiig & Secord, 2000), TROG-2 (Bishop, 2003b) and BPVS-II (Dunn, Dunn, Whetton & Burley, 1997). Behaviour checklists and school observations had also been used in some cases. SLI is identified in the DSM-IV using both inclusionary and exclusionary criteria (American Psychiatric Association, 1994). The inclusion criterion requires there to be a discrepancy between the child's language abilities and non-verbal intellectual abilities, so that language abilities fall below age expectations and nonverbal cognitive abilities are at or above age expectations. In order to be given a diagnosis of SLI, the children showed a significant impairment (1.25 SD below the mean) on one or more standardised language tests, and their non-verbal abilities were greater than 75 as measured on a standardised non-verbal IQ test (e.g. Raven's Progressive Matrices, Raven, Court, & Raven, 1988). Children with any neurological, motor or articulation (e.g. dyspraxia) or psycho-social deficits (e.g. pragmatic impairment or attention deficits) were excluded from the study.

All of the children in the SLI group attended mainstream schools at the time of participation in the study, and had taken up placements in language resource units attached to the schools.

Group 2: CA typically developing matched controls

This group consisted of 9 males and 7 females aged 7 years and 6 months to 10 years and 11 months (*M* = 9 years and 3 months; *SD* = 1 year and 2 months). All of these children were recruited from mainstream school, were of average academic ability (according to teacher's verbal reports) and were not receiving any additional targeted academic support. None of the children presented with developmental or psychological disorders or had prior diagnoses of audiological, neurological or educational problems. The CNRep was administered to all typically developing children in group two to screen for difficulties in non-word repetition that could be indicative of underlying language difficulties (Bishop, 1996). All of the children in the

CA-matched control group showed close to ceiling performance on this measure (M=35.81; SD=3.37). Taken together, the spared non-word repetition capacity along with the average academic ability as identified by class teachers, and the lack of any previous diagnoses of developmental disorders means that the likelihood of any children in this group having impaired language ability was very low. This group of typically developing control children were matched to the SLI children on an individual basis for gender, chronological age ($t(31) = .086$, $p>.05$) and non-verbal IQ, as assessed using the Raven's Progressive Matrices ($t(31)=-1.744$, $p = .09$. Although the groups were not statistically significantly different in their scores on the Ravens measure of non-verbal IQ, it is important to note that with a p-value of .09, they are not perfectly matched. This information is presented in table 2-1.

Group 3: VMA typically developing matched controls

A second control group was matched to the SLI group for their 'verbal mental age' (VMA) which was derived on the basis of their level of receptive vocabulary. This group included 8 males and 9 females aged 6 years and 1 month to 6 years and 10 months (*M* = 6 years and 7 months; *SD* = 3 months). The CNRep was administered to all typically developing children in group three to screen for difficulties in non-word repetition that could be indicative of underlying language difficulties. All of the children in the VMA-matched control group showed close to ceiling performance on this measure (M=32.65; SD=5.45). All of these children were recruited from mainstream school, were of average academic ability (according to teacher's verbal reports) and were not receiving any additional targeted academic support. None of the children presented with developmental or psychological disorders and had no prior diagnoses of audiological, neurological or educational problems. This group of typically developing control children were matched to the SLI children on an individual basis for performance on the BPVS-II ($t(32)= -1.297$, $p>.05$). Table 2-1 presents this information.

	SLI Group 1 (N=17) Mean (SD)	**CA Group 2 (N=16)** Mean (SD)	**VMA Group 3 (N=17)** Mean (SD)
Age (years)	9:4 (1.2)	9.3 (1.2)	6.7 (0.3)
Range	7:3-10:11	7:6-10:11	6:1-6:10
BPVS-3			
Raw Score	86.06 (15.01)	N/A	96.64 (8.18)
Standard Score	72.8 (10.56)		96.64 (1.37)
Age equivalent	5.11 (0.1)		6.3 (0.8)
Ravens Matrices			
Raw score	23.38(8.8)	32.56 (7.5)	N/A
Standard Score	88.61 (11.9)	96.6 (14.2)	
CNRep [a]			
Raw score	20.31 (8.35)	35.81 (3.37)	32.65 (5.45)
Range	7-29	28-40	21-39

Table 2-1. Participant details for the SLI group, the first typical control group (CA) matched for chronological age and non-verbal IQ and the second typical control group (VMA) matched for verbal metal age.

MATERIALS

The decision was taken to administer the following language assessments to children with SLI so that it would be possible to match a typically developing control group to the SLI group on the basis of their level of language development. These particular tests were selected as they provided measures of language comprehension that would be important for comparisons with performance on the music cognition tasks.

Cognitive Measure 1

Raven's Progressive Matrices

Raven's Progressive Matrices **(**Raven, Court, & Raven, 1988) are non-verbal multiple choice measures of the reasoning or 'meaning-making' component of Spearman's G which is often referred to as general intelligence. The Raven's Matrices were designed as a measure of Spearmans G factor and were devised to provide measures of the ability to deduce relationships and correlates. The easier items on the test require accuracy of discrimination and the more difficult items require analogies, permutations and alternations of patterns and other logical relations. Factorial analysis of tests suggests that they are heavily loaded with a factor common to most intelligence tests (Spearmans G), but that spatial aptitude, inductive reasoning, perceptual accuracy and other group factors also influence performance.

The tests were originally developed by John C Raven in 1936. In each test item, the testee is asked to identify the missing element that completes a pattern. Many patterns are presented in the form of a 4x4, 3x3, or 2x2 matrix and the test is administered with no time limit. The test is divided into five sets of twelve items, each set starts out very simple and it develops a theme which becomes progressively more difficult.

A part of the diagnostic criteria for SLI is a discrepancy between non-verbal intelligence and language abilities, this measure of non-verbal intelligence is especially important in eliminating generalised poor intelligence or mental retardation in the SLI sample. Performance on the Ravens Matrices will also be used to match a second typically developing control group to the SLI group on non-verbal intelligence. The inclusion of a typically developing control group, matched to the children in the SLI group for non-verbal intelligence, will allow for the identification of those areas of musical cognition in which the children with SLI show a different performance to typically developing children of the same chronological age and non-verbal abilities.

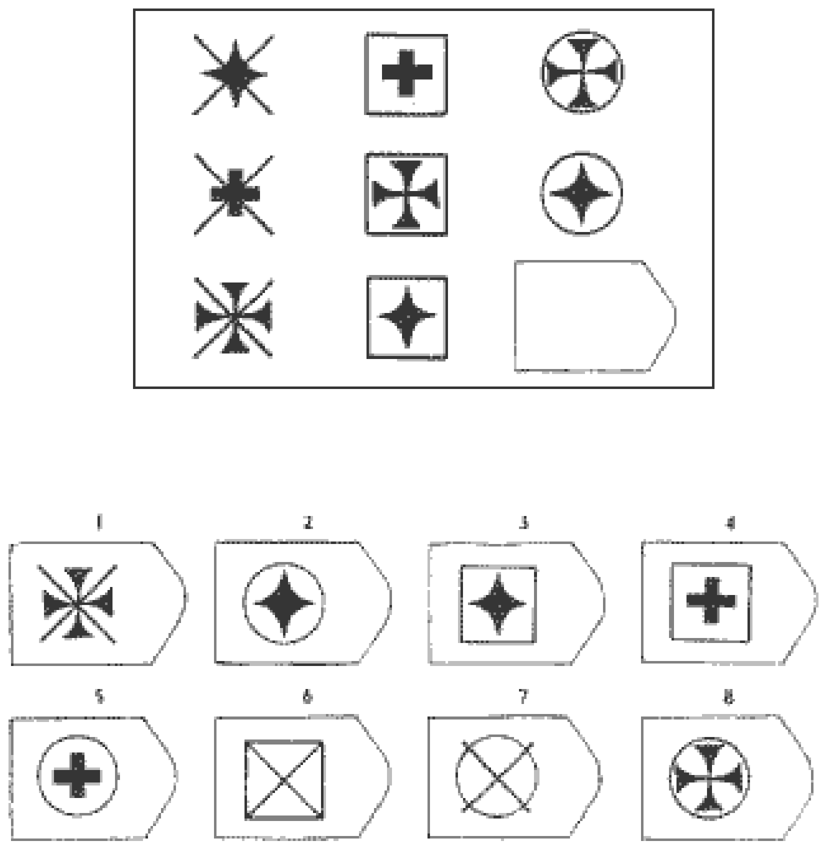


Figure 2-1. Example of a test item from the Ravens Progressive Matrices.

Cognitive Measure 2

The Wechsler Intelligence Scale for Children (WISC-IV)

The WISC-IV (Wechsler, 2003) began with the original Wechsler-Bellvue that was based on the notion that intelligence is both a global entity, characterising the individual's behaviour as a whole, and also specific because it is comprised of elements or abilities that are distinct from each other. Wechsler selected and developed subtests that highlighted the cognitive aspects of intelligence he thought were important to measure: verbal comprehension, abstract reasoning, perceptual organisation, quantitative reasoning, memory and processing speed. All of these areas have been confirmed as important aspects of cognitive ability in more contemporary theories and measures of intelligence.

In this thesis, this standardised intelligence test will be used to assess 'working memory' and 'processing speed' in the children with SLI and the typically developing controls.

Working Memory (WMI) Subtest

The WMI is composed of subtests measuring attention, concentration, and working memory. Working memory is the ability to actively maintain information in conscious awareness, perform some operation with it, and produce a result. Contemporary research has shown that working memory is an essential component of fluid reasoning and other higher order cognitive processes, as well as being closely related to achievement and learning.

Digit Span is a core Working Memory subtest composed of two parts: Digit Span Forward and Digit Span Backward. Digit Span Forward requires the child to repeat numbers in the same order as read aloud by the examiner and Digit Span Backward requires the child to repeat the numbers in the reverse order to that presented by the examiner. This subtest is designed as a measure of auditory short-term memory, sequencing skills, attention and concentration. The Digit Span Forward task involves rote learning and memory, attention, encoding and auditory processing. Digit Span Backward involves working memory, transformation of information, mental manipulation, and visuospatial imaging. The shift from the Digit Span Forward to the Digit Span Backward task requires cognitive flexibility and mental alertness.

This Digit Span subtest will be used to assess auditory short-term and working memory in children with SLI and typically developing controls.

Processing Speed (PSI) Subtest

The PSI is composed of subtests measuring the speed of mental and graphomotor processing. The speed of information processing is dynamically related to mental capacity, reading performance and development of working memory for higher-order fluid tasks. Processing speed has been identified as an important domain of cognitive functioning in studies of cognitive abilities. Clinical research in developmental cognitive neuropsychology suggests a dynamic interplay between working memory, processing speed and reasoning, e.g. more rapid processing of information may reduce demands on working memory and facilitate reasoning (Kail, 1994).

Coding is a core Processing Speed subtest in which the child copies symbols that are paired with simple geometric shapes or numbers. Using a key, the child draws each symbol in its corresponding shape or box within a specified time limit. In addition to processing speed, the subtest measures short-term memory, learning ability, visual perception, visual-motor coordination, visual scanning ability, cognitive flexibility, attention and motivation. It may also involve visual and sequential processing.

This Coding subtest will be used to assess processing speed in children with SLI and typically developing controls.

Cognitive Measure 3

The Children's Test of Non-word Repetition (CNRep)

The CNRep (Gathercole & Baddeley, 1996) is a measure of phonological short-term memory (PSTM) that has been standardised with children between 4-8-years in mainstream primary schools in England. This method of assessing short-term verbal memory involves the child attempting to repeat single unfamiliar spoken items (‘non-words’) such as “blonterstaping” or “woogalamic”.

The test contains a total of 40 non-words comprised of 2,3,4, or 5 syllables, presented on an audio cassette tape. The child listens to each non-word and then is required to repeat it back immediately in the silent interval that follows the spoken presentation of the word on the tape. The test administrator scores each of the 40 repetition attempts as either correct or incorrect and calculates a single score at the end of the test which corresponds to the total number of correct repetitions. The duration of the tape is approximately 3 minutes. The words are comprised of phonemes that are typically used in the English language. So although the words are novel (e.g. woogalamic) they abide by the phonological rules governing language and as such conform to the same rules as ‘real’ words in terms of their structure and pronunciation. They are given two practice trials before the test begins. The responses are scored by the experimenter as either ‘correct’ or ‘incorrect’.

The CNRep will be used to assess phonological short-term memory in children with SLI and typically developing controls. Given that poor non-word repetition has been found to be a clinical marker of SLI (Bishop et al., 1996), it will also be used to screen for language difficulties in the typical children. This test has only been standardised for children up to the age of 8-years and 11-months. Many children in this PhD were older than 8-years and 11 months and so raw scores, as opposed to scaled scores, will be used in the analyses.

No. Syllables	Example non-word
2	pennel
3	glistering
4	contramponist
5	defermication

Table 2-2. Example of 2-5 syllable non-words in the CNRep task.

Language Measure 1

The British Picture Vocabulary Scale (BPVS-II)

The British Picture Vocabulary Scale, second edition (BPVS-II) (Dunn, Dunn, Whetton & Burley, 1997) is a measure of acquired receptive vocabulary and is designed to show the extent of English vocabulary acquisition. Vocabulary knowledge is important for many aspects of psycholinguistic processing and many complex oral language skills are dependent upon vocabulary. For example, a child with strong grammatical knowledge but limited vocabulary would find it difficult to comprehend a text or to write a meaningful narrative.

BPVS-II is an individually administered, norm referenced test of receptive vocabulary for Standard English that is suitable for use with children aged 2 years 6 months to 16 years 11 months. This test is comprised of 168 pages of multiple-choice items and each item in the test consists of a two-by-two array of coloured illustrations arranged as fourteen sets of 12 test items. For each item, the examiner reads aloud a stimulus word and the child is required to point to the picture that is the best representative of the word spoken. The sets become progressively more difficult as the test goes on, with each successive set being more difficult than the one before. The BPVS can be used to assess language development in non-readers and is especially suitable for use with children with expressive language impairments because no spoken response is required.

Normative scores allow comparison of an individual's performance with well-defined reference groups. By means of age norms, an individual's score can be compared with a large cross-section of people of the same chronological age on whom the test was standardised. The *standardised* score indicates the degree to which an individual's score deviates from the average score for people of the same age. The scale is based on the normal distribution of scores that would be expected within the population, and is calculated on the basis that the overall mean standardised score is 100 and the standard deviation is 15, so that around 68% of people will score between 85 and 115. Very low (lower than 70) and very high (higher than 140) standardised scores are printed in the norm table as '***'. This means they will be either lower than 70 or higher than 140. They cannot be given with any greater degree of accuracy because too few people in the standardisation sample had very low or very high scores. The *percentile* rank indicates the percentage of people of the same age in the standardisation sample who scored equal to or below the individual's score. The *age-equivalent* indicates the age at which a given raw score is an average accomplishment for the group on whom the test was standardised.

Caution is needed when interpreting scores from the BPVS-II as all psychometric measuring devices provide only an estimate of a person's ability in the attribute being tested, and influences such as fatigue, practice, general health, concentration level etc. can affect an individual's performance on a particular testing occasion. The limits within which an individual's true score might lie can be statistically estimated from the tests reliability and can be used to define a confidence band around the individual's score.

The BPVS-II will be used to assess receptive vocabulary development and the ‘age equivalent’ score will be used to gain a ‘verbal mental age’ for this ability in the children with SLI. One of the typically developing control groups will then be matched to the SLI group on the basis of the ‘verbal mental age’ score for receptive vocabulary derived from this measure. This matching will allow for the performance of the SLI group on the experimental tests of music cognition to be compared with typically developing children at the same level of language development. This comparison will enable the performance the SLI group to be characterized as either developmentally delayed (i.e. at the same level as this verbal mental age-matched control group) or atypical in relation to this younger typically developing group.

Language Measure 2

Test for Reception of Grammar (TROG-II)

The TROG-II (Bishop, 2003b) is a measure of linguistic receptive grammar. This test assesses understanding of grammatical contrasts marked by inflections, function words and word order and is intended to be a relatively pure measure of understanding of grammatical contrasts, rather than a test of comprehension in everyday situations. In an everyday situation there are numerous sources of information that can be used to interpret a sentence, including the meaning of words in sentences, the context in which a sentence is spoken, and knowledge of what is likely and unlikely (Bishop, 1997). TROG-II is designed to test grammatical comprehension under conditions when these cues have been taken away. The purpose of TROG-II is to help to tease apart possible reasons for comprehension failure and to identify the difficulties with grammar that present a major obstacle to understanding language.

Once again it is important to note that it is not possible to create a totally pure measure of grammatical comprehension that is not influenced by other factors. A child could do poorly on TROG-II, for a number of factors such as weak attention or poor short-term verbal memory. However, the TROG-II enables the tester to use the pattern of errors made to identify when non-grammatical factors are exerting an influence on performance. The early items in TROG-II contain both grammatical and non-grammatical foils, allowing one to note whether the child's errors are concentrated on the grammatical foils. Because TROG-II is designed to provide qualitative information about which aspects of grammatical comprehension the child finds difficult, as well as an overall score, TROG-II items are grouped in blocks of four. The probability of getting any one item correct simply by guessing is one in four. It follows that the probability of getting all four correct by guessing is much lower: close to 1 in 250. This means that if a person gets all four items in a block correct, then it is likely that they understand the grammatical contrast being tested. Blocks are passed only when all four items in that test block are answered correctly. Testing is discontinued after failing five consecutive blocks.

This measure can be used as part of an assessment battery to aid in the diagnosis of language impairment. The test is comprised of 80 pages of four-choice items arranged into twenty blocks, with each block assessing a particular grammatical construct. Blocks are arranged in order of increasing difficulty, so that the most complex grammatical sentences are in the final block e.g. centre embedded sentences: "The sheep the girl looks at is running" (see table 2-3). Each page of the stimulus manual has a two-by-two array of coloured illustrations. The testee is shown a page with four pictured choices, and must point to the picture that matches a sentence that has been read aloud by the experimenter. The TROG-II will be used to assess the linguistic grammatical comprehension abilities of children in the SLI sample. This will allow for the identification of children within the SLI sample who have particular difficulties processing particular grammatical constructs.

Block	Construction	Example of Construction
A	Two elements	The sheep is running
B	Negative	The man is not sitting
C	Reversible in and on	The cup is in the box
D	Three elements	The girl pushes the box
E	Reversible SVO	The cat is looking at the boy
F	Four elements	The horse sees the cup and the book
G	Relative clause in the subject	The man that is eating looks at the cat
H	Not only X but also Y	The pencil is not only long but also red
I	Reversible above and below	The flower is above the duck
J	Comparative/absolute	The duck is bigger than the ball
K	Reversible passive	The cow is chased by the girl
L	Zero anaphor	The man is looking at the horse and is running
M	Pronoun gender/number	They are carrying him
N	Pronoun binding	The man sees that the boy is pointing at him
O	Neither nor	The girl is neither pointing nor running
P	X but not Y	The cup but not the fork is red
Q	Postmodified subject	The elephant pushing the boy is big
R	Singular/plural inflection	The cows are under the tree
S	Relative clause in object	The girl chases the dog that is jumping
T	Centre-embedded sentence	The sheep the girl looks at is running

Table 2-3. The grammatical constructs assessed in each block of the TROG

Speech Processing Measure 1

Test of Auditory Analysis Skills (TAAS)

The TAAS (Rosner, 1993) is a measure of children's auditory perceptual skills. This test assesses a child's ability to sort and to analyse the individual sounds within a spoken word and to engage in fine-grained analysis of spoken words into phonemes. The capacity to isolate and represent the individual sounds in speech is important for spoken language comprehension and also has implications for the child's ability to read and spell. In learning to read the child must learn to 'map' individual speech sounds onto letters.

The test is comprised of two practice items and thirteen test items totaling fifteen familiar words. The test begins with the two demonstration items that are designed to show the child what is expected. The administrator reads aloud a word and the testee is asked to listen to each word and then to repeat it back with a part missing. For example, in the first demonstration item the child is asked to repeat the word 'cowboy' and is then asked to say it again without the 'boy'.

Once the child has successfully completed the first two demonstration items the administrator moves onto the test items. The test administrator is instructed to read aloud each word distinctly, without stressing any sounds and without giving any hints. The testing is stopped after two consecutive errors and the number of the last correct item before the two errors is the TAAS score.

Background Questionnaire 1

Participants

The first background questionnaire is designed to assess the musical competencies and interests of all of the participants. It is orally administered by the experimenter in the test session and is comprised of 6 questions relating to the musical background of the participants (i.e. number of years of formal musical training). This questionnaire can be found in appendix one.

Background Questionnaire 2

Parents/ Carers

The second musical background questionnaire is designed to assess the musical competencies and interests of the parents/carers of each of the participants. It is attached to the parental information and consent form and given to parents to complete on their own. The questionnaire is comprised of 6 questions relating to the musical background of the participants (i.e. number of years of formal musical training, amount of time spent listening to music). The questionnaire also includes questions relating to the child's medical and educational background and asks specifically for information concerning previous diagnoses of developmental disorders or hearing difficulties in the child. This questionnaire can be found in appendix two.

PROCEDURE

Participants in all three groups were tested individually in a quiet room at their school during school hours. Of the 17 children with SLI, each child completed the testing over eight test sessions. Each testing session lasted no longer than 30 minutes. Testing sessions were arranged to take place on a weekly basis over a period of eight weeks until all of the tasks were completed. The length of each test session varied depending on the pace at which children felt comfortable working. It was found that some children required a number of breaks per session whereas others were keen to work continuously without stopping. All of the tasks were presented as short games and structured activities. The language assessments were completed first followed by each of the experimental tasks. The order in which the experimental tasks were presented was randomised. The testing sessions were arranged to take place on a weekly basis so as not to interfere with regular speech and language therapy that the children were receiving and so that there would be minimal disruption to the children's class teaching.

The typically developing comparison children in group 2 and group 3 received a less intensive test battery (e.g. they did not complete the TROG-II and only completed the necessary standardized assessments needed to match them to the SLI group) and so these 33 children were tested over a period of 5 sessions each of around 30 minutes duration. These test sessions were scheduled to take place over a 2 week period and although each session was scheduled to last around 30 minutes, this was dependent upon the speed at which the children felt comfortable working. As with the SLI group, the standardised assessments were administered first followed by the experimental tasks which were randomised.

Standardised instructions were adhered to for all published tests and similar standardised instructions were developed and used for all experimental tasks. Children were informed at the start of each session that they could stop at any time should they wish and were then asked at regular intervals throughout the tests sessions if they were happy to keep going. All testing sessions (approx. 291 in total) were conducted by the author of this thesis.

DESIGN AND STATISTICAL ANALYSIS

The thesis employed a mixed-methods approach. Standardised assessments were used in conjunction with new experimental paradigms. Group differences were investigated using both ANOVAs and t-tests. Relationships between performance on the experimental tasks and the standardised assessments were investigated using both correlation and regression analyses. The data was analysed using the Statistical Package for the Social Sciences (SPSS) (version 17) mostly using mixed ANOVAs for data comparing performance on different conditions of an experiment across the clinical SLI group and the two matched-control groups.

For all parametric inferential statistical tests the necessary assumptions were checked. Before conducting either ANOVAs or parametric correlational analyses the data was checked for the normality of the distribution and also for equality of variances across the groups. The power of the statistical procedures used was an important issue. The power of a statistical test is the ability to detect an effect if an effect genuinely exists and is important to avoid making a Type II error. If a test has low statistical power this may mean that it fails to detect an effect even if that effect genuinely exists. A primary factor that affects statistical power is sample size. The following guidelines from Cohen (1988) indicate that if the standard alpha level of .05 is taken and requires the recommended power of .8, then 28 participants are needed to detect a large effect size (r=.5). With the standard alpha of 0.5 and a sample size of 17 per group, tests of between-group differences between means had a power of 0.738 to detect a large effect size (d = 0.8). Conventionally a test with power greater than .8 is considered statistically powerful (Field, 2000).

The present study included 17 children in the SLI sample, 16 children in the age and non-verbal IQ-matched control group and 17 children in the control group matched for verbal-mental age. Other studies have carried out similar analyses with smaller samples (e.g. van der Lely, Rosen & Adlard, 2004 had a sample of 15 SLI participants and 14 typical chronological age-matched controls; Mengler et al., 2005 had 15 SLI participants). Therefore it was considered that the sample size in the present studies was appropriate.

Another important issue when conducting statistical tests is how large the effect size for that test is. Effect sizes provide a measure of the importance and meaningfulness of an effect. For example, effect sizes contain information about how much of the variance is explained and can therefore inform as to whether a statistically significant effect is very meaningful in real terms. The most common measure of effect size are Cohen's d and Pearson's correlation coefficient r (lies between 0 (no effect) and 1 (perfect effect). A correlation coefficient of 0 would indicate no effect and a coefficient of 1 would indicate a perfect effect. Cohen (1988) suggested that a coefficient of .1 constitutes a small effect since it only explains 1% of the variance, a coefficient of .3 explains 9% of the variance and constitutes a medium effect. Finally a coefficient of .5 explains 25% of the variance and so constitutes a large effect.

CHAPTER 3

CHARACTERISING THE LANGUAGE, COGNITIVE AND MUSICAL PROFILES OF CHILDREN WITH SLI

ABSTRACT

The theoretical accounts of SLI outlined in chapter one offered explanations for the language impairments and broader cognitive and auditory processing limitations that are sometimes observed in children with SLI. The aim of this chapter is to provide a detailed summary of the individual verbal and non-verbal abilities of children with SLI, and to compare the SLI group performance on measures of cognitive and speech processing with typically developing CA and VMA-matched controls. Characterising the cognitive profiles of the SLI group and typically developing controls allows for the identification of patterns of deficit and delay in the children with SLI. Finally, this chapter will also provide a summary of the musical backgrounds of all children participating in this study.

The Diagnostic and Statistical Manual for Disorder (DSM-IV; American Psychological Association, 1994) states that a child is diagnosed with SLI when they demonstrate a discrepancy between their scores on standardised assessments of language ability and their non-verbal cognitive abilities. Scores for the SLI group on measures of language and non-verbal intelligence are shown in table 3-1.

SLI GROUP ANALYSES

A summary of SLI group cognitive and language profiles can be seen in table 3-1.

	Raw	Percentile	Standard
Ravens Matrices	23.05(9.02)	27.64 (23.98)	88.53 (12.22)
BPVS-II	87.63 (15.23)	3.18 (2.35)	73.0 (8.65)
TROG-2	8.7 (3.35)	9.85 (14.47)	69.59 (13.57)

Table 3-1. Means and SDs for raw scores, standardised scores and percentile ranks for the BPVS-II, TROG-2 and the Ravens Matrices.

For the Ravens Matrices, a standard score of 88.53 with a percentile rank of 27.64 is considered a ‘low average’ score that is not below 1 SD from the typical population mean. Therefore, non-verbal intelligence test scores were within the normal range for the SLI group. Consistent with diagnostic criteria for this disorder, at the group level the SLI participants show markedly poorer performance on the BPVS-II measure of receptive vocabulary and the TROG-II measure of receptive grammar, than would be predicted on the basis of their chronological age and non-verbal intelligence. For the BPVS-II the SLI group achieved a standard score of 73.0 with a percentile rank of 3.18 which is below 1.25 standard deviations from the mean for the typical population (close to 2 SD below the mean). For the TROG-II, the SLI group achieved a standard score of 69.59, with a percentile of 9.85. This is below 1.25 standard deviations from the mean and indicates that less than 10% of children in the general population obtain such a low score on this test.

INDIVIDUAL ANALYSES

Given diagnostic heterogeneity and the suggestion that SLI may include a grammatically impaired subgroup, individual data from the BPVS-II, TROG-II and Ravens Matrices are shown in table3-2.

Participant	Chronological Age	Ravens Standardised Score	BPVS-III (Standardised Score)	BPVS-II **Age Equivalent**	TROG- II Standardised Score	TROG-II Age Equivalent
8	7;3	100	70-***	4:2 (2:11-4:10)	69	4;11
9	8;3	100	70-***	3:11 (2:8-4:8)	55	4;0
10	10;8	75	70-***	5:2 (4:7–5:10)	74	6:2
11	10;8	110	70-***	3:11 (2:11-4:8)	69	5:11
12	10;1	110	75	7:1 (6:5-7:8)	92	9:0
13	9;8	90	72	6:7 (5:11–7:2)	99	9:0
14	9;10	90	70-***	5:11 (5:4-6:8)	55	4:5
15	8;4	90	73	5:7 (4:11-6:1)	62	4:11
16	8;9	90	70	5:8 (5:1-6:2)	85	9:0
17	8;0	100	70-***	3:11 (2:8-4:8)	83	5:11
18	10;3	75	70-***	6;7 (5:11-7:2)	55	4:5
20	8;6	80	70	4:10 (4:2-5:5)	62	4:11
21	10;7	75	70	5:8 (5:2-6:4)	74	6:2
22	8;10	80	106	6:11 (6:4-7:7)	62	4:11
23	8;10	75	71	5:10 (5:2-6:5)	55	4:5
24	8;6	90	74	6:2 (5:8-6:11)	72	5:6
25	10;11	75	70	6:5 (5:11-7:2)	60	5:3

Table 3-2. Individual standardised scores for the Ravens Progressive Matrices, the British Picture Vocabulary Scales (BPVS-II) and the Test of Reception of Grammar (TROG-II).

Visual inspection of the individual data demonstrated that all but one of the children in the SLI group performed at a level that was 1 SD below the general population mean on the BPVS-II assessment of receptive vocabulary. Although participant number 22 showed an average score on the BPVS-II, investigation of this participants' performance on the TROG-II assessment of receptive grammar revealed a marked impairment with a score that was 1 SD below the typical population mean. The individual analyses therefore confirmed that all of the children in the SLI group showed a discrepancy between their non-verbal abilities as assessed by the Ravens Matrices and performance on at least one of the measures of receptive language ability.

TROG-II

The TROG-II is comprised of 17 blocks and each block is designed to test certain grammatical and non-grammatical comprehension abilities. Visual inspection of performance across the blocks indicated that there was a linear decrease in the number of children who passed the blocks as the test went on. All of the children failed the final block 'T' which tested the 'centre-embedded sentence' construct (e.g. 'the sheep the girl looks at is running') and all but one participant also failed block 'S' which tested the 'relative clause in object' construct (e.g. 'the girl chases the dog that is jumping') (see table 3-3 and figure 3-1). If a child performs poorly on blocks A, D and F, that may indicate more general difficulties with remembering words, or integrating information from different parts of a sentence, rather than problems with grammatical comprehension (Bishop, 2003). As can be seen from table 3-3 and figure 3-1, the majority of children passed blocks A, D and F and there were no children who failed on all three blocks. Thus it seems that the poor performance on the TROG-II cannot be solely explained by poor vocabulary but reflects a difficulty with sentence comprehension. The association between memory and information processing and performance on the TROG-II will be further investigated.

	TROG-2. Blocks passed																				
Participant	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	TOTAL
8	1	1	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	7
9	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
10	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	1	0	0	11
11	0	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0	1	0	10
12	1	1	1	0	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	0	15
13	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	0	0	15
14	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6
15	1	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	7
16	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	12
18	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6
20	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	7
21	1	1	1	1	1	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	11
22	1	1	1	0	0	1	1	0	0	0	1	0	0	1	0	1	0	0	0	0	7
23	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
24	1	1	1	1	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	9
25	1	1	0	1	1	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	8
																				0	

Table 3-3. Individual profiles on the TROG-II standardised assessment of linguistic grammatical comprehension.

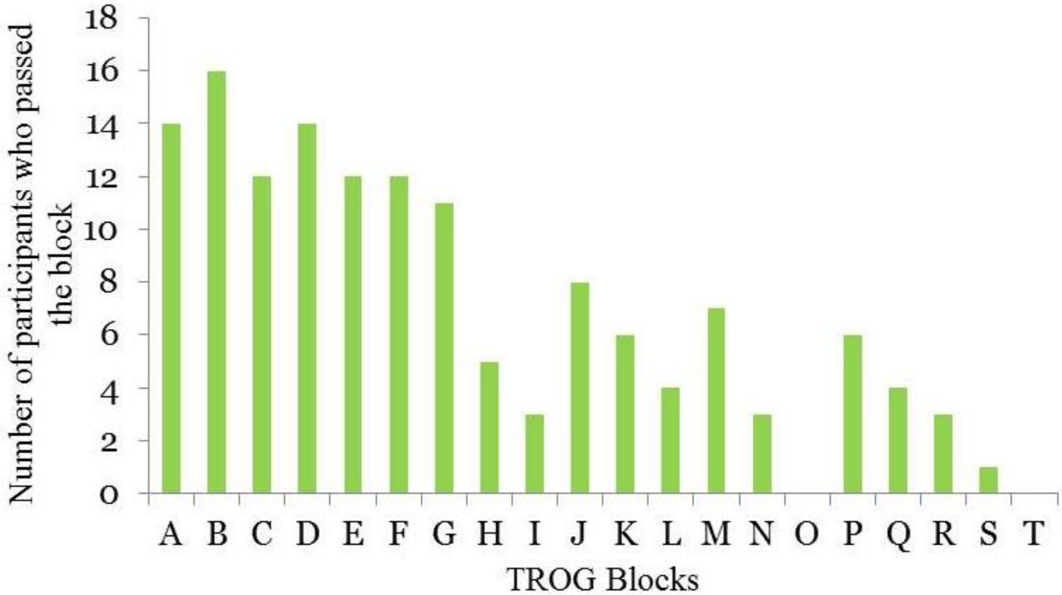


Figure 3-1. Breakdown of the number of children in the SLI group who passed each of the TROG blocks.

One way to determine if a child is performing poorly on the TROG-II due to lack of grammatical knowledge or more general processing difficulties is to count the total number of errors in the last five blocks. The grammatical constructs tested in the TROG-II become increasingly complex as the test progresses, therefore examining performance across the most complex blocks will demonstrate whether the child is absolutely failing to process those constructs or is showing a more variable response pattern. If the total number of errors is less than twelve then the testee is performing better than chance, and so their performance corresponds to a pattern of sporadic responses which may indicate a processing problem. However, if the testee makes thirteen or more errors over the last five blocks this is compatible with random guessing and indicates a genuine lack of knowledge of the meaning of the grammatical constructs being tested. Investigation of the error pattern demonstrates that all except one of the children with SLI show a sporadic error pattern indicating that there may be a processing problem mediating the comprehension difficulties identified in the TROG-II (see table 3-3). To investigate the relationship between auditory STM and performance on the TROG-II, the single participant who showed a ‘random’ error pattern was excluded and a correlational analysis was carried out with the Digit Span measure of auditory STM and the total number of TROG-II blocks passed. It was found that Digit Span and total number of TROG-II blocks passed were positively correlated at a level approaching significance ($r(15)=.384$, $p=.07$). The observation that Digit Span was related to the total number of blocks passed lends further support to the notion that the poor performance on the TROG-II may be due to limitations in processing rather than absence of knowledge of the grammatical constructs being tested.

In summary, the analysis of the data from the SLI participants confirmed a discrepancy between performance on measures of verbal and non-verbal ability. Analysis of performance on the TROG-II measure of grammatical comprehension demonstrated that the poor performance was most likely due to processing limitations rather than a concrete absence of grammatical knowledge.

Criteria for inclusion in the typically developing (TD) control groups stated that children should have no prior histories of language or hearing abnormalities, and should have verbal and non-verbal intelligence scores within the normal range (see chapter two). Theoretical accounts of SLI, described in chapter one explain SLI in terms of deficits and delays in a range of cognitive and auditory processing abilities. For this reason, cognitive assessments were carried out on all children in the SLI group and typically developing control groups and the data obtained are detailed in the next section.

Digit Span

The Digit Span subtest from the Wechsler Intelligence Scale for Children (WISC-IV) tests forward and backward digit recall and provides measures of auditory STM and WM. The raw scores for the composite Digit Span (DS) subtest of the WISC-IV were compared using a univariate ANOVA with group (SLI, CA, VMA) as a between subjects factor. This analysis revealed a significant effect of group ($F(2,46)=22.971$, $p<.001$, $n_p^2= .505$). Tukey HSD post-hoc comparisons revealed that the Digit Span score was significantly lower in the SLI group than the CA matched controls score ($p<.001$) and the VMA group score ($p<.05$) and the VMA group score was significantly lower than the CA group score ($p<.001$).

Group	DS Raw	DSF Raw	DSB Raw	DS Scaled
SLI	10.8 (1.8)	6.19 (1.9)	5.19 (1.04)	6 (2)
CA	17.13 (3.16)	10.19 (2.13)	6.94 (1.57)	11.75 (2.77)
VMA	13.19 (2.79)	8.18 (1.47)	4.88 (1.69)	11.31 (2.94)

Table 3-4. Means and *SDs* of scores for digit span forward (DSF) and digit span backward (DSB) and the raw and scaled scores for the composite digit span (DS) score.

Digit Span discrepancy scores

In children, the digit span forward is a measure of auditory short-term memory, as success on this task relies upon an ability to retain and to repeat back auditory information. The digit span backward task involves both the retention and manipulation of information in short-term memory and places additional demands on attentional resources within working memory and as such is considered to be a measure of auditory working memory in children (St Clair-Thompson, 2010).

Visual inspection of the mean scores attained on the digit span forwards and digit span backwards components of the digit span task indicate that the typically developing controls achieved higher scores on the digit span forwards than the digit span backwards task. In contrast, this difference appeared to be far smaller for the participants with SLI. A discrepancy score for performance across these two components of the digit span measure was derived by subtracting the digit span backwards score from the digit span forwards score for each participant. The data from these discrepancy scores are shown in figure 3-2.

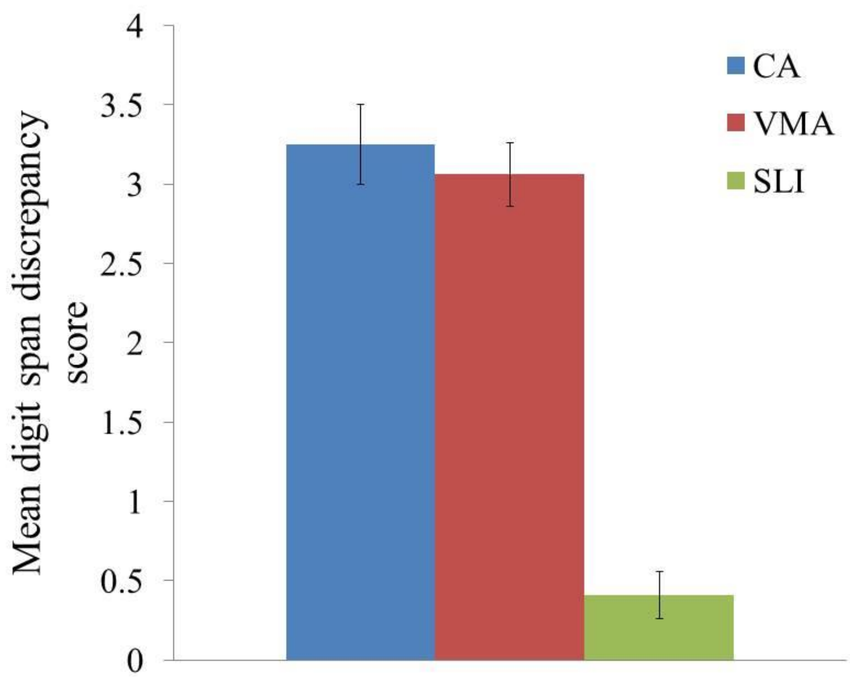


Figure 3-2. Mean and Standard Error of the Means (*SEMs*) of discrepancy scores for the digit span forwards and digit span backwards subtests.

Discrepancy scores were analysed using a univariate ANOVA with Group (SLI, CA, VMA) as a between-subjects factor. There was a significant difference in discrepancy scores across the SLI-group, the CA-matched controls and the VMA-matched controls ($F(2,49)=15.269, p<.001, n_p^2=.394$). Tukey HSD post-hoc comparisons revealed that the children with SLI obtained a significantly smaller Digit Span difference score than the CA-matched controls ($p<.001$) and the VMA-matched controls ($p<.001$). The difference scores for the older CA-matched controls and the younger VMA-matched were not significantly different ($p>.05$).

This analysis showed that the typically developing children show a much better forward than backwards digit span. The high discrepancy score indicates that in typical development digit span forwards matures more quickly than digit span backwards and this is likely to reflect development of the different components within auditory working memory.

Working memory is a synergy between both attention and short-term memory; short-term memory involves storage and rehearsal processes whereas attentional processes are employed to reactivate memory traces and inhibit irrelevant information. A discrepancy between STM and WM may be more apparent in children than in adults because routine STM tasks may require additional attention resources (St Clair-Thompson (2010). For example, changing the order of digits involves executive or attentional resources in children and so the backwards digit recall becomes a working memory task, whereas in adults this task is less attentionally demanding and so draws primarily upon short-term memory resources (Rosen & Engle, 1997). The magnitude of the difference scores in both the older and younger typically developing control groups indicates that auditory short-term memory matures more rapidly than working memory, meaning children are able to accurately repeat back information before they are able to manipulate the same amount of information in working memory (St Clair-Thompson, 2010).

The pattern of performance in the SLI group was very different to that of controls. They obtained poorer composite digit span scores than the CA-matched and the VMA-matched controls and this is consistent with earlier work showing a cognitive deficit in auditory short-term memory in children with SLI (Gathercole and Baddeley, 1990a). Investigation of the discrepancy scores for the digit span forwards and digit span backwards components revealed that, in the SLI group, the discrepancy in performance on the digit span forwards and the digit span backwards tasks is very small and is significantly smaller than the discrepancy scores found in both the older and younger typically developing controls. This finding seems to indicate that SLI is associated with a deficit in auditory short-term memory, which results in equally poor retention and manipulation of auditory information within a short-term memory store.

Coding

It has been suggested that SLI may be associated with a generalised slowing of processing speed (Leonard, 1998). The Coding task from the Wechsler Intelligence Scale for Children (WISC-IV) is a measure of global processing speed. The scaled scores from the Coding (CD) subtest of the WISC-IV were compared using a univariate ANOVA with group (SLI, CA, VMA) as a between-subjects factor. This analysis revealed a significant effect of group ($F(2,42)=9.933$, $p=.001$). Tukey HSD post-hoc comparisons showed that the SLI group score was significantly lower than the VMA-matched control groups score ($p<.01$) but was not significantly different to the CA-matched control score ($p>.05$) (see table 3-5). This indicates that the younger VMA-matched control group showed better processing speed than the CA-matched and the SLI groups.

	Coding Raw	Coding Scaled
Group	Mean (*SD*)	Mean (*SD*)
SLI	34 (2.44)	7.94 (2.84)
CA	37.87 (8.08)	8.5 (3.22)
VMA	47.24 (9.1)	12 (2.52)

Table 3-5. Means and SDs for the Coding subtest of the WISC-IV.

The observation that the SLI group performance on the measure of processing speed was not significantly different to that of the CA-matched TD controls indicates that this sample of SLI children do not show a domain general deficit in processing speed.

Discrepancy scores for the digit span and coding subtests of the WISC-IV

Analysis of the mean scaled scores for the digit span and coding subtests of the WISC-IV across groups demonstrated that on the coding task the SLI group obtained higher scores on the measure of processing speed than auditory short-term memory. To further investigate how processing speed relates to auditory short-term memory in children with SLI and typically developing children, the discrepancy scores for performance on the subtests measuring each of these cognitive functions were calculated. The discrepancy scores for auditory short-term memory and processing speed were derived by subtracting the composite scaled scores for the digit span task from the scaled scores for the coding task. A positive discrepancy score therefore indicates better performance on the coding measure of generalised processing speed, and a negative score indicates better performance on the digit span measure of auditory memory. These discrepancy scores were then compared across the SLI-group, the CA-matched controls and the VMA-matched controls using a univariate ANOVA with group (SLI, CA, VMA) as a between-subjects factor. There was a significant difference in discrepancy scores across the SLI-group, the CA-matched controls and the VMA-matched controls ($F(2,43)=12.324$, $p<.001$, $n_p^2=.364$). Tukey HSD post-hoc comparisons showed that the SLI group discrepancy score was significantly higher than the CA-matched control groups score ($p<.001$) but was not significantly different to the VMA-matched control score ($p>.05$).

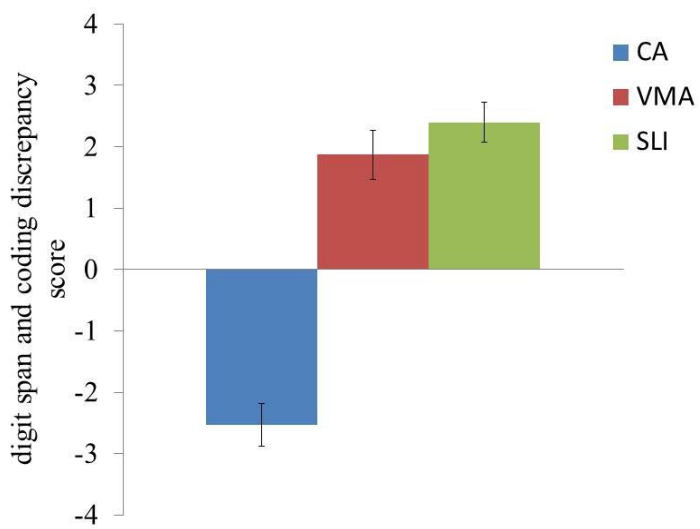


Figure 3-3. Mean and *SEMs* of discrepancy scores for the scaled composite digit span and the scaled coding subtests of the WISC-IV.

Looking at the difference in standard scores attained for the coding measure of processing speed and the composite digit span measure of auditory memory, it is apparent that the SLI group show a different profile to the CA-matched controls but are very similar to the younger VMA-matched controls. The higher discrepancy scores indicate that both the younger VMA-matched controls and the SLI group show a better performance on the measure of processing speed than auditory STM whereas the older CA-matched controls show a difference in the opposite direction. The observation that the younger typically developing controls show better processing speed than auditory memory may indicate that these two cognitive functions develop at different rates. It has been suggested that increases in processing speed could facilitate the development of auditory memory by reducing the demands placed on working memory (Carpenter, Just & Shell, 1990; Fry & Hale, 1996; Kail & Salthouse, 1994). As age increases so does the speed with which information can be processed, meaning that typical children are able to perform tasks more quickly as they get older (Fry & Hale, 1996). It is also apparent that over the course of development children are able to retain more items in working memory (Gathercole & Baddeley, 1993). It is possible that this developmental change in processing speed facilitates the rate at which information in the articulatory loop component of working memory is rehearsed and so drives improvement in auditory memory (Fry & Hale, 1996). In a cascade model of development, age-related changes in processing speed lead to changes in working memory which then contribute to improvements in reasoning and associated changes on measures of intelligence (Kail & Salthouse, 1994).

This cascade model could offer an explanation as to why the younger typical VMA-matched controls show such a large discrepancy score for auditory short-term memory and processing speed whereas the older CA-matched controls do not. It may be that in typical development, age-related increases in global processing speed drive improvements in working memory. Looking at the difference in standard scores attained for the measures of processing speed and auditory short-term memory, it is apparent that children with SLI show processing speed that is typical for their age but show a deficit in auditory STM. Thus, although the children with SLI are showing typical development of processing speed, this developmental gain is not associated with concomitant improvements in auditory STM.

For children with SLI, the combination of preserved global processing speed and poor auditory memory may lead to the adoption of a compensatory strategy for processing auditory information. For example, rather than relying on the retention of auditory information in STM and the subsequent processing of that material in the phonological loop, there may be a rapid search for the most salient and meaningful auditory cues. Support for this notion comes from studies of the importance of different cues in speech processing. Nittrouer and Lowenstein (2007) found that preschool children and older listeners use different cues when making phonetic discriminations in speech so that children show a tendency to attend to the global, slowly changing aspects of speech and through experience they learn to use the finer details in sound to make discriminations. Sussman (2001) suggested that younger children adopt a different strategy for the processing of speech and place a greater emphasis on the distinctiveness or informativeness of the cues than older children and adults. It may be that children with SLI persevere in processing the most salient auditory cues, in a similar way to younger typically developing children, in order to compensate for limitations in auditory STM.

The Children's Test of Non-word Repetition (CNRep)

The CNRep is a measure of phonological STM. It has been suggested that this test is a more accurate measure of the phonological loop component of working memory than the digit span task, as this test relies upon the representation of novel words in a phonological store that cannot be re-described with words taken from a long-term lexical store (Gathercole, 2006). Children with SLI show particular difficulty with this task in comparison to both chronological age-matched controls and younger controls matched for verbal-mental age and show a particular pattern of performance that is characterised by a steep decline as the syllable lengths of the non-words increase (Gathercole & Baddeley, 1993). Data from the SLI group, the CA-matched controls and the VMA-matched controls on the CNRep are shown in table 3-6 and figure 3-4.

	CNRep Total	2 syllable	3 syllable	4 syllable	5 syllable
Group	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean SD)
SLI	20.31 (8.35)	8 (2.37)	5.69 (2.47)	3.69 (2.82)	2.81 (2.4)
CA	35.81 (3.37)	9.81 (0.4)	9.38 (0.5)	8.25 (1.73)	8.25 (1.88)
VMA	32.65 (5.45)	9.41 (1.06)	8.24 (1.82)	7.29 (2.23)	6.88 (2.47)

Table 3-6. Means and standard deviations (SDs) for the different syllable lengths in the CNRep.

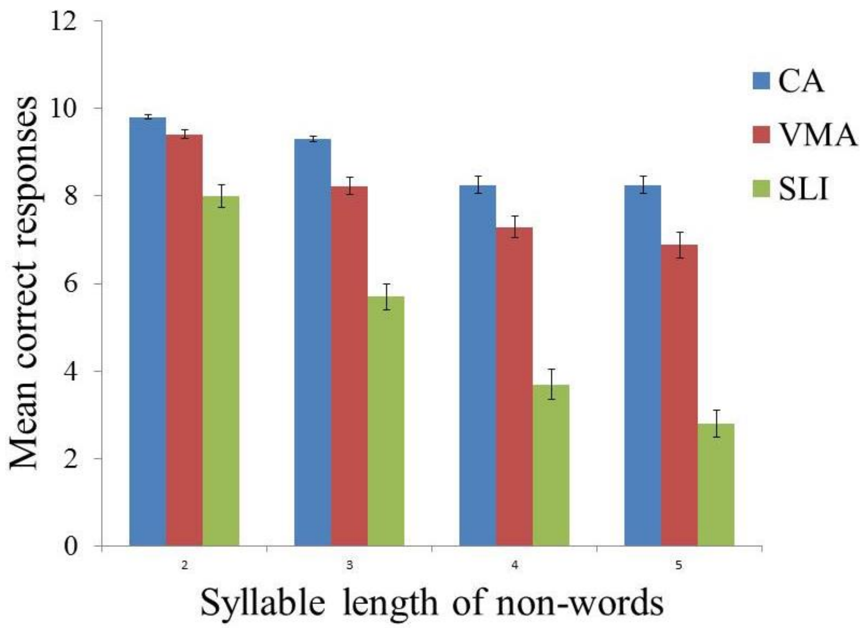


Figure 3-4. Means and standard error's (*SEMs*) of the total correct resposnes for each syllable length in the CNRep.

The data were analysed using a univariate ANOVA with group (SLI, CA, VMA) as a between-subjects factor. This analysis revealed a significant effect of group $F(2,46) = 29.303, p<.001, n_p^2 =.56$). Tukey HSD post-hoc comparisons revealed that the SLI group score significantly lower than the VMA ($p<.001$) and CA group scores ($p<.001$) on the CNRep (see table 3-6). The results from the analysis were consistent with the WISC-IV digit span subtest analyses, in demonstrating a clear cognitive deficit in auditory short-term memory in children with SLI.

Test of Auditory Analysis Skills (TAAS)

Impaired phonemic awareness has been observed in some younger children with SLI (Coady et al., 2005). One measure of phonemic awareness is phoneme deletion in which the child is asked to say a word without a particular phoneme (e.g. 'say coat without the 'c') (Zourou et al, 2010). It has been suggested that phoneme identification tasks in which the target sound is embedded in a phonetic context, pose a particular problem for some children with SLI, so that vowels that are rapidly presented in isolation are readily distinguished and yet are not distinguishable when they are embedded in a phonetic context (e.g. da-bi-ba: da-bu-ba) (Leonard et al, 1992; Sussman, 2001; Coady et al, 2005). This apparent impairment in phonemic awareness may be due to a more generalised impairment in auditory processing associated with SLI. It has been proposed that impoverished phonemic awareness may be a contributory factor to the characteristically poor performance of children with SLI on measures of non-word repetition (Vance, 2008; Gathercole 2006). In an attempt to tease apart the relative contributions of speech perception and memory load to performance on the Children's Test of Non-word Repetition (CNRep; Gathercole & Baddeley, 1996), Loucas, Riches, Charman, Pickles, Siminoff, Chandler and Baird (2010) tested adolescents with and without SLI on a measure of non-word discrimination and found that SLI was associated with residual impairments in auditory STM but not phonemic awareness. The findings from Loucas et al., (2010) seem to indicate that limitations in phonemic awareness and deficits in auditory STM are separable in children with SLI.

The Test of Auditory Analytic Skills (TAAS) measures the ability to breakdown an incoming spoken word into its constituent phonemes and as such is a measure of auditory perceptual skills. Data for the three groups on the TAAS are shown in table 3-7.

	TAAS Raw
Group	Mean (*SD*)
SLI group (1)	9 (3.39)
CA group (2)	12.19 (3.15)
VMA group (3)	12.12 (2.67)

Table 3-7. Means and SDs for the TAAS measure of auditory analysis skills.

The data were analysed using a univariate ANOVA with group (SLI, CA, VMA) as a between subjects factor. This analysis revealed a significant effect of group $F(2,46)= 5.237$, $p<.01$, $n_p^2=.185$). Tukey HSD post-hoc comparisons revealed that the SLI group score on the TAAS was significantly lower than the CA-matched controls ($p<.05$) and the VMA-matched controls scores ($p<.05$).

The poor performance of the SLI group on the TAAS, relative to typical CA-matched and VMA-matched controls, indicates that SLI may be associated with impaired auditory processing that impacts upon the capacity to discriminate between phoneme contrasts in speech. One of the difficulties in attributing the poor performance to difficulties in auditory perception is that the task itself also relies upon auditory STM.

CORRELATIONAL ANALYSES

To investigate the relationships between performance on the linguistic measures of receptive vocabulary (BPVS-II), grammatical comprehension (TROG-II) and speech processing (TAAS) and cognitive measures of auditory STM (DS), phonological STM (CNRep), processing speed (coding) and non-verbal reasoning (Ravens Matrices) in the SLI group, correlational analyses were carried out. The raw scores from the BPVS-II, digit span, CNRep, coding and Raven's tests and the total number of TROG-II blocks passed were included in the analysis. These analyses revealed that the composite digit span score (DS) was significantly positively correlated with the coding measure of processing speed and the Ravens measure of non-verbal reasoning in the SLI group. This indicates that auditory short-term memory is related to processing speed and non-verbal intelligence in the children with SLI. Whilst coding was also significantly positively correlated with the Raven's measure, partial correlations revealed that the correlation between coding and Raven's was no longer significant when digit span was controlled ($r(15)=.047$, $p>.05$). Thus it seems that digit span was mediating the apparent relationship between coding and performance on the Raven's measure of non-verbal reasoning. Performance on the TROG-II was significantly positively correlated with performance on the TAAS, the BPVS-II and the Raven's matrices, indicating that this measure of grammatical comprehension in language was related to speech processing skills, vocabulary knowledge and non-verbal reasoning in the children with SLI (see table 3-8).

SLI group	**BPVS**	**TROG**	**TAAS**	**CNRep**	**DS**	**Coding**	**Ravens**
Age	.203	.313	.269	-.041	.027	.379	.278
BPVS	1.00	.426*	.465*	-.053	.146	.043	.039
TROG		1.00	.509*	.097	.384	.121	.582**
TAAS			1.00	.265	.318	.390	.567*
CNRep	.			1.00	.153	-.064	.302
DS					1.00	.559*	.563*
Coding						1.00	.505*
Ravens							1.00

*p<.05 **p<.001

Table 3-8. Correlation matrix showing the relationships between linguistic and cognitive measures in the children with SLI.

Musical Background

It has been suggested that in children with SLI, limitations in auditory short-term memory may have a genetic origin whereas auditory processing abilities may be environmentally mediated (Bishop, 2001). Given the proposed environmental influence on auditory processing, it is possible that musical enrichment may be related to the auditory perceptual abilities of both the TD children and those with SLI. Therefore, the musical backgrounds of all of the participants were assessed with questionnaires administered directly to the participating children and their parents/carers. The findings from the questionnaires revealed that none of the children had received more than 1 year of formal musical training or achieved any grades on a musical instrument and the majority of children across all three groups listened to music regularly during the week. There was some variation in the broader musical backgrounds of the children. It was found that in the CA-matched controls, six of the children (38%) played a musical instrument; three of them (19%) had parents who played an instrument and one child (6%) attended regular dance lessons. Similarly in the VMA-matched controls, two of the children (12%) played an instrument and four of the children had parents who played an instrument (24%). In the SLI group there was only one child (6%) who played an instrument and the same child also had a parent who played an instrument (see figure 3-5).

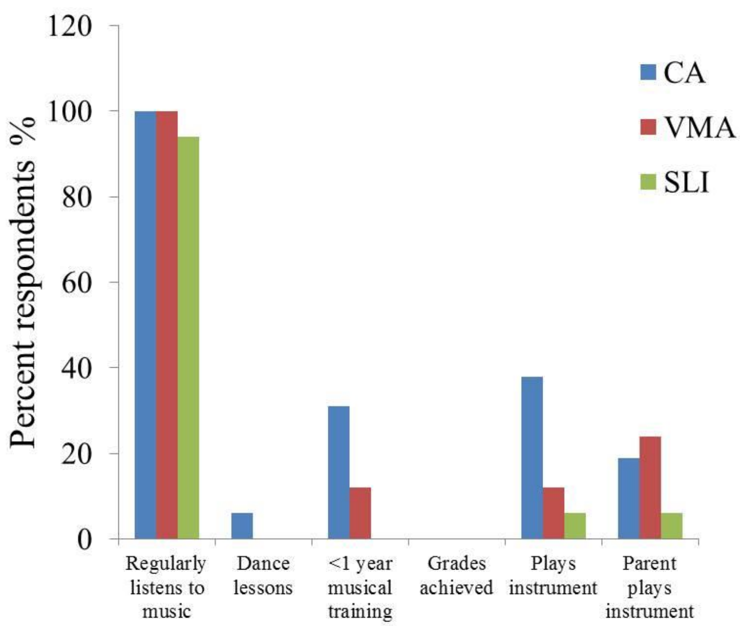


Figure 3-5. Summary of the child and parental musical background questionnaires.

The musical background data demonstrates that although none of the children included in this study had received more than one year of formal musical training, some children within the typical control groups may have come from slightly more enriched musical environments. It is also possible that the level of informal exposure to music may therefore have varied between the groups and this will be further considered in the discussion of the experimental findings.

SUMMARY

This chapter described the background measures that were used in this thesis and contextualised them in the context of existing theories of SLI. It was found that all children included in the SLI group showed a discrepancy between verbal and non-verbal skills with impaired performance on measures of vocabulary and grammatical comprehension. Further analysis of performance across the blocks of the TROG-II revealed that the majority of children with SLI showed a sporadic pattern of response, suggesting that low global scores did not reflect a failure to acquire specific grammatical constructs. The results therefore do not provide clear evidence that the sample included children who would meet criteria for G-SLI (van der Lely, 1994).

Testing of specific cognitive functions using both the digit span and the CNRep indicated that the children in the SLI group were characterised by a deficit in auditory STM. This poor performance on auditory memory was not simply a feature of delayed language development, but rather was deviant as compared with the younger VMA-controls who were matched to the SLI group for their level of receptive vocabulary. In terms of processing speed, the SLI group were not significantly different to the CA-controls who were matched to the SLI group for chronological age and non-verbal intelligence. The observation that the SLI group did not differ from the chronological age-matched controls on this measure indicates that generalized processing speed is not impaired in this group of children with SLI. The discrepancy scores for processing speed and auditory memory revealed that the SLI group showed a profile that was similar to the younger VMA-controls. One interpretation of this finding is that processing speed drives age-related improvements in auditory memory in TD children but not in those with SLI. Finally, a measure of auditory perceptual skills demonstrated that the SLI group showed atypical performance which may indicate additional limitations in auditory perceptual processing. Thus it may be that in the children with SLI, limitations in both auditory processing and auditory short-term memory were present and contributed to the linguistic impairments observed (Bishop, 2001).

CHAPTER 4

EXPERIMENT ONE: PITCH INTERVAL DISCRIMINATION

ABSTRACT

The experiment described in this chapter investigated pitch-interval direction discrimination in children with SLI and typically developing CA and VMA-matched controls. Participants were presented with a range of sequential pitch-intervals and asked to judge whether the second tone in the interval pair was higher or lower than the first. The pitch intervals varied in size and were categorised as either small (ranging from 1-4 semitones) or medium (ranging from 5-8 semitones). The findings demonstrated that all groups showed above-chance discrimination accuracy on the small pitch-interval condition and significantly increased levels of accuracy on the medium pitch-interval condition. Although the SLI group obtained significantly lower correct discrimination scores than CA matched controls, their discrimination performance did not differ from that of VMA matched controls. However, correlational analyses revealed that auditory STM was related to pitch-interval discrimination in TD children but not in children with SLI and this suggested that pitch discrimination relies on different cognitive mechanisms in SLI.

INTRODUCTION

Pitch can be defined as "that property of a sound that enables it to be ordered on scale going from low to high" (Acoustical Society of America Standard Acoustical Terminology, cf. Randel, 1978). In Western music, pitch information is organized in octaves which are themselves divided into 12 equal-sized intervals or 'semitones' (Dowling & Harwood, 1986; Patel, 2008). These 12 semitones comprising the octave are the "tonal material" upon which musical scales and musical patterns, or melodies are constructed (Dowling, 1978). Whilst perception of western music rests upon a capacity to differentiate pitch change of at least one semitone, musically untrained adults can readily distinguish changes in the order of around 0.25 of a semitone (Hyde & Peretz, 2004) and musically untrained children can detect changes in pitch that are smaller than 0.5 of a semitone (Fancourt, Dick & Stewart, 2013).

In addition to the ability to detect changes in pitch, the ability to discriminate the direction of changes in pitch is also crucial for melody discrimination (Patterson et al, 2002; Cuddy & Cohen, 1976). Heaton (2005) tested pitch-interval direction-discrimination in a group of children with autism and typically-matched controls, aged between 7 and 14-years, and found that typically developing children showed that discrimination accuracy improved as the intervals between the two tones comprising the interval increased. Lowest levels of performance were observed in the small interval condition where the difference between tones ranged between one and four semitones. Thus it seems that for typical children, pitch-interval direction discrimination is facilitated when the perceptual distance between the two tones is larger.

The capacity to perceive and to discriminate changes in pitch has been linked to both musical and language abilities in typically developing children (Lamb & Gregory, 1993; Anvari, Trainor, Woodside & Levy, 2002). Loui, Kroog, Zuk, Winner and Schlaug (2011) investigated the relationship between pitch perception and production and the ability to manipulate phoneme contrasts in speech in 7-9 year old children. They found that phonemic awareness skills were positively correlated with pitch perception and production skills. Furthermore, Anvari et al., (2002) found that both speech processing and auditory short-term memory were related to musical skills in typical 4 and 5-year old children. Similarly, Chobert, Marie, François, Schön, and Besson (2011) reported that children who had received formal musical training showed better passive mismatch negativity (MMN) and active (discrimination) processing of syllable contrasts in speech. Taken together these findings appear to support the view that aspects of music and language processing depend on shared auditory and cognitive processing mechanisms, and that musical training can facilitate speech processing (Patel, 2011).

Poor speech processing skills have been reported in a number of studies of SLI (Tallal, 2000; Tallal & Piercy, 1973; Lowe & Campbell, 1965) leading researchers to conclude that the disorder may, in part, be characterised by an auditory perceptual deficit that leads to difficulties with sound discrimination (Ziegler, Pech-Georgel, George, Alario & Lorenzi, 2005). However, a number of these studies have used the Auditory Repetition Test (ART) (developed by Tallal & Piercy, 1973 and discussed in chapter one), which measures frequency discrimination and temporal perception simultaneously. The results then become difficult to interpret as it is impossible to determine whether impaired performance is the result of poor frequency discrimination or impaired auditory temporal processing (McArthur & Bishop, 2001).

A number of studies have investigated frequency discrimination in children with SLI and found evidence to suggest that poor frequency discrimination is implicated in both developmental language disorders and reading disabilities (McArthur, Atkinson & Ellis, 2009; Wright, Bowen & Zecker, 2000). McArthur and Bishop (2004b) investigated both frequency discrimination and temporal processing in children with SLI and found that around one third of the SLI group showed impairments in frequency discrimination regardless of the rate of presentation. In a further study, Hill, Hogben and Bishop (2005) addressed the question of whether the apparent impairments in frequency discrimination in SLI were due to developmental lag or a marked deficit that was stable over time. They measured frequency discrimination in children with SLI and control children and then again 3.5 years later, and found that the SLI group had significantly higher frequency discrimination thresholds than controls at both time 1 and time 2. They also observed that although the frequency discrimination thresholds for both SLI children and controls improved over time, the children with SLI continued to demonstrate significantly poorer thresholds than controls. McArthur, Atkinson and Ellis (2009) measured passive auditory ERPs to a number of different sounds in children with SLI and children with reading impairments. They found that around 38% of the children with SLI or reading problems showed atypical flattened ERPs to sounds in general, lending support to the notion that a generalised impairment in auditory processing may be a causal risk factor for both SLI and reading difficulties.

One of the characteristic impairments observed in children with SLI is a deficit in auditory STM (Gathercole & Baddeley, 1993). However, measures of auditory STM, such as the non-word repetition task, also rely on auditory processing skills, so it is difficult to determine whether language difficulties in SLI result from deficits in cognitive and/or auditory processing mechanisms (Vance, 2008; Dollaghen et al;., 1995; Leitao et al., 1991). Montgomery (1995) found that children with SLI were poorer at non-word discrimination than language-age matched controls, indicating that SLI may be characterised by a speech processing deficit that is not simply a feature of delayed language development. Archibald and Gathercole (2006a) studied a group of children with language impairments who were more impaired at non-word repetition than other STM tasks, and concluded that the non-word repetition deficit observed in SLI may reflect a combination of impairments at different levels of auditory and cognitive processing.

The extent to which auditory processing abnormalities in SLI may be related to other cognitive abilities is the subject of debate. Mengler et al., (2005) measured frequency discrimination, non-word repetition and reading ability in a group of 15 children with SLI and TD age and non-verbal IQ matched controls. They used a three-interval, two-alternative-forced-choice AXB in which each trial involved the presentation of three 100 ms pure tones with an ISI of 300 ms. For each trial one of the tones varied and the child was asked to indicate whether the second sound was the same as the first or last sound by pressing a corresponding button on the computer keyboard. Mengler et al., (2005) found that the SLI group showed significantly poorer frequency discrimination, non-word repetition and reading as compared with the typically matched controls. However performance across each of these measures was not significantly correlated in either the SLI group or the controls. This finding seems to indicate that although SLI may be associated with impaired frequency discrimination this may not necessarily be related to poor performance on measures of auditory short-term memory.

To address the question of whether deficits in non-word repetition and auditory processing were part of the same heritable disorder, Bishop et al (1999) conducted a twin study. They used the ART and the CNRep to measure auditory processing and auditory STM and found that whilst both tests discriminated between language-impaired and control children, the SLI group showed markedly poorer performance on the CNRep than the ART. Crucially, Bishop et al., (1999) observed that the pattern of twin-twin correlations was different for the two tasks. The correlations were substantially higher for MZ than DZ twins for the CNRep indicating significant heritability, whereas MZ and DZ twins tended to resemble one another for the ART and the twin-twin correlations did not differ. Interpreting these findings, Bishop (2001) suggested that auditory processing and phonological short-term memory impairments are not just different indicators of the same disorder they are distinct deficits with different origins. Bishop (2001) suggests that in addition to genetic factors, environmental risk factors may play a causal role in the aetiology of SLI. One implication of this account is that, if auditory processing is environmentally mediated, there may be a specific link between formal and informal exposure to music and auditory processing competencies in children with SLI.

Contrary to a number of studies reporting impaired frequency discrimination in some children with SLI (Mengler et al., 2005; Hill et al., 2005; McArthur & Bishop, 2004b), Bishop et al., (2005) investigated auditory discrimination in children with SLI and impaired speech perception, and failed to find group differences in the capacity to discriminate frequency glides. The authors suggested that their finding may indicate that SLI is associated with a primary linguistic impairment and any additional difficulties in auditory processing are incidental and not causally related to speech processing abnormalities. One possible explanation for the apparent spared glide discrimination in children with SLI is that the use of pitch glides rather than discrete tones may have reduced the cognitive demands of the task, since glides can be represented as contours and can be successfully discriminated by comparing the end of one glide with the start of the next, rather than necessitating the representation and retention of three isolated tones in memory.

Studies directly investigating frequency discrimination have reported impairments in low-level frequency discrimination of simple sine tones in SLI (Hill et al., 2005; Mengler et al., 2005; McArthur & Bishop 2004b). One potential implication of these findings is that a low-level impairment in frequency discrimination would most likely disrupt higher-order musical abilities in affected individuals. Pitch discrimination is an important musical “building block” upon which perception of melody, musical mode (e.g. major and minor) and cadences within harmony depend. The experiment described in this chapter addressed the important question of whether children with SLI show evidence of disrupted musical processing at a simple level of discriminating the direction of pitch-intervals.

PILOT STUDY

A pitch-interval discrimination task, previously used to measure pitch discrimination in children with autism and typical development (Heaton, 2005) was adapted for use in experiment one. In order to ensure that the paradigm was suitable for use with children with SLI, a pilot study was conducted. A total of 8 participants were included in this pilot study: 4 male children diagnosed with SLI (age range 7-10-yrs; mean age 9yrs) and 4 typical control children who were matched to the children with SLI on age, gender and non-verbal IQ using the Raven's standard progressive matrices.

The experimental stimuli consisted of 18 small (1-4 semitones) and 18 medium (5-8 semitones) pitch intervals that were presented through headphones connected to a laptop computer. Children were asked to determine whether the second of the pair of tones comprising the interval rose or fell and to indicate their responses by pressing a button on a purpose-built button box that was also connected to the laptop computer.

Analyses of the individual data sets revealed that all children, in both the SLI and typically-matched control groups, were able to accurately discriminate the direction of both small and medium pitch intervals at levels that were better than chance. For small intervals the SLI group had a mean hit rate of 15; the controls had a mean hit rate of 16. For the medium intervals the mean hit rate for the SLI group was 15 and the mean hit rate for the controls was 16. Therefore, it was concluded that the task was suitable and so was used to measure pitch-interval discrimination in a larger sample of participants.

Experiment one: Testing pitch interval discrimination and its cognitive and perceptual correlates in children with SLI and typical development.

Research has shown that some children with SLI may have difficulties discriminating between changes in frequency (Mengler et al., 2005). Low-level difficulties discriminating between changes in frequency may have negative consequences for higher-order musical processing in SLI. Therefore this first experiment addressed the question of whether or not children with SLI are able to reliably determine the direction of a relative pitch interval. It was hypothesized that children with SLI would show poorer discrimination of both small and medium pitch intervals as compared with chronological age-matched controls.

Abnormalities in both short term memory and auditory perceptual processing have been described in SLI (McArthur et al., 2009; Mengler et al., 2005). Whilst research has revealed associations between musical ability and auditory short-term memory in typically developing children (Loui et al., 2011; Anvari et al., 2002), Bishop (1999;2001) has suggested auditory processing and poor auditory short-term memory represent distinct deficits in SLI. For this reason, the second aim of this first experiment was to investigate that extent to the ability to discriminate the direction of pitch-intervals is related to cognitive abilities in typically developing children and children with SLI. Based on previous research, it was hypothesized that pitch-interval direction discrimination would be significantly correlated with auditory short-term memory in typically developing children.

The ability to process changes in pitch is important for both music and language processing, e.g. enhanced pitch processing may have implications for processing syllable contrasts in speech (Chobert et al., 2011). Bishop (2001) has suggested that auditory processing difficulties in SLI may be environmentally mediated and so it would be expected that children with more enriched musical backgrounds may show better pitch-interval discrimination. Therefore a third aim of this experiment was to address the question of whether or not musical background, pitch-interval discrimination and language abilities were related in children with SLI and typically developing children.

METHOD

Participants

Two of the CA-matched controls and four of the VMA-matched controls did not complete the pitch-interval discrimination task. Data from a total of 17 children with Specific Language Impairment, 14 CA-matched controls and 13 VMA-matched controls were included in the analysis. The CA-matched control group were matched to the SLI group for non-verbal IQ using the Ravens Matrices ($t(29) = -1.681$, $p>.05$) and the VMA-matched controls were matched for verbal-mental age using the BPVS ($t(29) = -1.347$, $p>.05$).

Stimuli

A total of 32 pairs of successive tones (16 ascending and 16 descending) were digitally recorded in piano voice, using Sibelius version 6. For each interval, tone 1 was presented followed by a 500 ms inter-stimulus interval (ISI), followed by tone 2 (1st tone 500 ms, ISI 500 ms, 2nd tone 500 ms). The size of the relative interval between the tones varied from 1 – 8 semitones. A total of 4 trials for each interval size were included. Testing was conducted in a quiet room within the children's school environment, using a laptop computer. Sound delivery was via an external sound card (Edirol UA-4FX) and Sennheiser HD265 headphones. The volume was set at a comfortable listening level, and the program for stimulus presentation and the collection of data was written in E-Prime.®

Design and procedure

The design was mixed factorial, with Group as the between-subject factor (SLI, CA and VMA) and interval size (2 levels: small and medium) as the within-group factor.

Picture Training

In line with previous work on interval discrimination in children with developmental disorders (Heaton, 2005), participants were shown pictures of people and objects that were either rising or falling (e.g. a man climbing a staircase or a child descending a slide in a playground, see figure 4-1). The children were asked to indicate if the people and/or objects in the pictures were ascending by pressing a button with a blue up arrow on it and to indicate if the people and/or objects were descending by pressing a button with a picture of a red down arrow on it. After 100% accuracy on 4 picture trials (2 up and 2 down) participants progressed to the auditory training.

Figure 4-1. Examples of pictures used to demonstrate 'up' and 'down' in the pre-test picture training session.

Auditory Training

Participants were played two tones comprising a downward relative interval of 12 semitones (1st tone 500 ms, ISI 500 ms, 2nd tone 500 ms) and the experimenter explained that the second tone was lower than the first, so the sound went down. Participants were then played two tones comprising an upward interval of 12 semitones and the experimenter explained that as the second tone was higher than the first, the sound went up. Participants were then presented with four auditory training trials (2 up and 2 down) and asked to indicate whether the sounds went up or down by using the same buttons they had used in the picture training. If participants gave an incorrect response on any of the four training trials, the training was repeated. Participants proceeded to the task once 75% criterion was reached on the auditory training trials.

Pitch interval discrimination task

The task comprised four blocks of trials plus a practice block. The practice block consisted of 6 picture trials (3 up, 3 down) and 6 auditory trials (3 up, 3 down). In the practice block participants were required to make judgments about the direction of the objects in the pictures and the second tones in large (above 9 Semitones) pitch intervals by pressing the 'up' or 'down' buttons. In order to consolidate the pre-test training, the picture trials always preceded the auditory trials and matched the direction (e.g. an up picture was always followed by an up interval). Once 75% performance criterion had been achieved on the practice block, participants began the first test block.

A total of 32 pairs of successive tones (16 ascending and 16 descending with interval sizes varying between 1 and 8 tones) were randomised into 4 test blocks. Participants were presented with an interval and were asked to indicate whether the second tone in a pair went up or down using the same buttons as used in the pre-test training. Responses ("up" or "down") were recorded via a purpose-built button response box that was directly connected to the computer that ran the experimental paradigm. Visual feedback, in the form of a smiley face appeared after each correct response.

RESULTS

The correct responses for small (1-4 semitones) and medium (5-8 semitones) pitch intervals were summed and the means and standard deviations *(SD)* calculated for each group (see table 4-1).

	Small		**Medium**	
Group	Mean	*SD*	Mean	*SD*
CA controls (*n=14*)	13	3	14	1.8
VMA controls (*n=13*)	10.3	3.6	11.4	3
SLI (*n=17*)	10.5	3.1	11.1	3.1

Table 4-1. Means and *SD*s for correct identification of small and medium pitch intervals.

One-sample t-tests revealed that performance on the small interval condition was significantly above chance for the SLI group (t(16)=3.403, p=,004, *d*= 1.7), the CA control group (t(13) = 6.253, p=.000, *d* = 3.4) and the VMA control group (t(12) = 2.287, p=.041, *d* = 1.3).

A mixed ANOVA with interval type (small or medium) as the within-subjects factor and group (SLI, CA or VMA) as the between-group factor was carried out on the data. This revealed a significant main effect of interval type (F(1,41)=8.133, p=.007, n_p^2=.166) with higher discrimination scores on the medium pitch interval condition. The analysis also revealed a significant main effect of group (F(2,41)=5.078, p=.011, n_p^2=.199), although the group by interval interaction was not significant (F(2,41)=0.436, p=.650, n_p^2 =.021). Tukey HSD post-hoc comparisons revealed poorer discrimination accuracy in the SLI group compared with the CA control group (p<.05) but not the VMA control group (p>.05). The VMA control group showed poorer discrimination accuracy than the CA control group (p<.05). This pattern of performance is demonstrated in Figure 4-2.

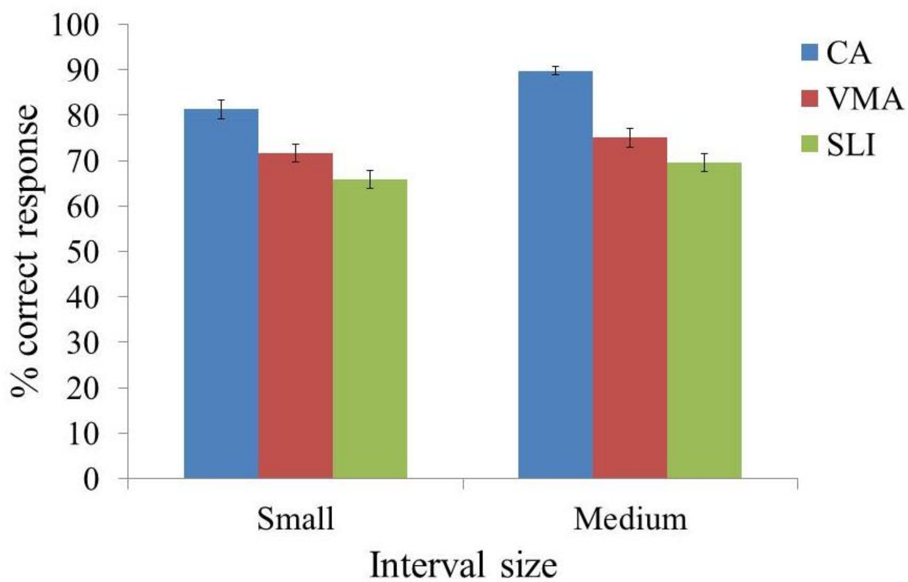


Figure 4-2. Mean percentage correct discrimination of small and medium pitch-intervals for the SLI group and the two control groups matched for chronological age (CA) and verbal mental age (VMA).

To investigate the relationship between cognitive ability and performance on the pitch-interval discrimination task, the correct responses for small and medium intervals were summed to form a single 'total correct response' score. As the pattern of performance was similar across the two TD groups, the control data were collapsed in the subsequent analyses. Separate correlational analyses were carried out for the SLI group and the typically developing controls with scores from the CNRep and digit span measures of auditory short-term memory and the TAAS measure of auditory analytic skills along with the total pitch interval discrimination scores. These data are shown in table 4-2.

	Pitch interval		**Digit Span**		**Digit Span**		**TAAS**	
Group	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
CA	27.34	4.5	17.21	3.3	36.29	3.3	13.23	1.3
VMA	21.69	6.4	11.46	4.5	33.28	5	12.8	2.1
SLI	21.6	5.6	10.81	1.9	20.31	8.3	9.6	2.5

Table 4-2. Mean and standard deviation of total correct responses for the pitch-interval direction discrimination task, the CNRep, the Digit Span and the TAAS.

The correlational analysis of these data showed that for the SLI participants performance on the pitch interval task did not significantly correlate with performance on either the digit span or the CNRep tasks, although it did significantly correlate with performance on the TAAS measure of speech processing (see table 4-3).

SLI group	**Pitch Interval**	**digit span**	**CNRep**	**TAAS**
Age	-.427*	.027	-.041	.269
Pitch Interval		.273	-.159	.447*
Digit Span			.153	.318
CNRep		.		.265

*p< .05 **p< .01

Table 4-3. Correlation matrix for pitch interval discrimination, age, digit span, CNRep and TAAS in the SLI group.

The analysis of the TD data showed that pitch interval discrimination was significantly positively correlated with performance on the digit span measure of auditory short-term memory but not the TAAS measure of speech processing (see table 4-4).

TD Controls	**Pitch Interval**	**digit span**	**CNRep**	**TAAS**
Age	.482**	.599**	.298	.179
Pitch Interval		.589**	.046	.299
Digit Span			.368*	.340*
CNRep				.513**

*p< .05 **p< .01

Table 4-4. Correlation matrix for pitch interval discrimination, age, digit span, CNRep and TAAS in the TD controls.

In order to further investigate the potential influence of musical background on performance on the pitch-interval discrimination task, the data from the musical background questionnaires administered to both parents and children was included in further analysis. Three dichotomous variables were calculated based on 'yes/no' responses to the following questions: Does the child play a musical instrument? Do the parents play a musical instrument? Has the child received any formal musical training?

Two separate hierarchical regression analyses with age and digit span alongside the three musical background variables as predictor variables and the total pitch-interval discrimination score as the dependent variable were carried out for the SLI and TD control groups. Only one child from the SLI group reported that a parent played a musical instrument and so only this variable was included as a 'musical background' predictor variable in the regression analysis. This hierarchical regression analysis revealed that in the SLI group age, digit span and musical background did not significantly predict performance on the pitch interval discrimination task (see table 4-5).

SLI group	R^2	B	R^2 change	F	P
Step 1					
age	.153	-.392	.153	2.538	>.05
Step 2					
age		-.399			
digit span	.234	.283	.080	1.983	>.05
Step 3					
age		-.312			
digit span		.272			
parent instrument	.349	.351	.115	2.146	>.05

Table 4-5. Hierarchical regression predicting interval discrimination scores from age, digit span and musical background in children with SLI

The regression analyses demonstrated that for the TD controls, auditory short-term memory accounted for significant variance after age had been entered. The inclusion of the musical background variables into the model only accounted for a further 5.5% of the variance in total pitch-interval discrimination. All three models were significant (see table 4-6).

TD Controls	R^2	B	R^2change	F	P
Step 1					
age	.245	.495	.245	8.118	<.01
Step 2					
age		.228			
digit span	.373	.446	.127	7.125	<.01
Step 3					
age		.230			
digit span		.460			
child instrument		.135			
parent instrument		-.168			
music lessons	.425	-.306	.053	3.109	<.05

Table 4-6. Hierarchical regression predicting interval discrimination scores from age, digit span and musical background in TD controls.

A final research question concerned the relationship between pitch-interval direction discrimination and language abilities in the SLI group and correlational analyses were carried out on these data and the total raw scores from the BPVS-II and the total blocks passed on the TROG-II measure of grammatical comprehension. This analysis failed to reveal any association between pitch-interval direction discrimination and performance on the measures of receptive vocabulary or grammatical comprehension in this group (see table 4-7).

SLI group	**Pitch interval**	**TROG-II**	**BPVS-II**
Age	-.391	.313	.213
Pitch interval		.206	.089
TROG			.426*
*p< .05	**p< .01		

Table 4-7. Correlational analyses for age, pitch-interval scores, number of blocks passed on the TROG-II and the raw scores from the BPVS-II in the children with SLI.

DISCUSSION

The research questions tested in this first experiment were motivated bv research showing impaired frequency discrimination in children with SLI (McArthur & Bishop, 2004; Mengler et al., 2005; Hill et al., 2005) and outstanding questions about the musical, language and memory correlates of such a deficit. Whilst it was hypothesized that SLI children would show an impairment in pitch-interval discrimination, this was only partially supported by the results, as these showed that SLI children discriminate pitch intervals as well as VMA-matched controls. Although impaired frequency discrimination have been reported in a number of studies of SLI

(Wright, Bowen & Zecker, 2000; McArthur & Bishop, 2004b; Hill, Hogben & Bishop, 2005; McArthur, Atkinson & Ellis, 2009) the result from experiment one suggest delayed pitch-interval discrimination that is similar to that observed in younger TD children. The SLI children could discriminate small pitches at a level that was higher than chance and like TD controls, discrimination performance improved when pitch-intervals were large.

Considering these results within an auditory processing deficit account of SLI, it is important to note that the children with SLI showed impaired performance on the TAAS measure of speech perceptual abilities (see chapter 3), and these data positively correlated with scores from the pitch-interval task. The observation that phonemic awareness may be related to pitch-interval direction discrimination in children with SLI is interesting given findings from Chobert et al., (2011) showing better active and passive discrimination of syllable contrasts in speech in musically trained children. Thus it may be that musical training could facilitate speech perception through training and strengthening generalised auditory processing networks implicated in both music and speech discrimination (Patel, 2011). However, whilst performance on the pitch-interval task was positively correlated with the measure of auditory speech processing it did not significantly correlate with the scores from the BPVS-II or the TROG-II for the SLI group. Therefore it appears that the capacity to discriminate the direction of pitch-intervals in music is not related to vocabulary acquisition and grammatical sentence comprehension in children with SLI.

The results from the analysis exploring the correlates of pitch-interval discrimination showed that for TD controls, digit span was significantly positively correlated with performance on the pitch-interval direction discrimination task whereas the TAAS measure of phonemic processing was not. This finding is consistent with other work demonstrating a relationship between measures of musical ability and auditory short-term memory (Loui et al., 2011; Anvari et al., 2002) and further supports the notion that there may be shared mechanisms implicated in the processing of musical and verbal information within auditory short-term memory (Williamson, Baddeley & Hitch, 2010). However, the absence of a correlation between the TAAS measure of speech processing and performance on the pitch-interval discrimination task is counter to that observed in Anvari et al's (2002) study. One possible explanation for this apparent discrepancy may be that the children included in Anvari's (2002) study were much younger than the typical controls in the present study, and it may be that the relationship between phonemic awareness and pitch-interval discrimination is more prominent at an earlier stage of language acquisition.

This observation that performance on the pitch-interval direction discrimination task was not significantly correlated with performance on the digit span or CNRep measures of auditory STM in the SLI group supports the notion that impairments in auditory STM and delays in auditory processing observed in SLI are separate deficits with distinct origins (Bishop, 1999; 2001). One other possibility is that this lack of a correlation in the SLI group between measures of auditory STM and pitch-interval discrimination may reflect the choice of stimuli. Using gliding stimuli within an 'odd one out' paradigm, Bishop et al., (2005) found that children with

SLI were able to discriminate the direction of glides as accurately as typically developing control children, suggesting a degree of spared processing of frequency glides in SLI. In the present task, participants were required to discriminate the direction of pitch-intervals and this relied upon a capacity to represent and retain information about pitch contour, rather than about discrete pitches within STM. One possibility is that pitch-interval direction discrimination is not related to auditory STM in children with SLI because they utilize a strategy that circumvents the need to represent sequences of discrete pitches within a phonological store. For example, they may rely on their relatively spared visuospatial processing abilities (Archibald & Gathercole, 2006) and represent the shape of a melody in a visuospatial form. Questions about the extent that musical contour processing is preserved will be further investigated in chapter five.

The extent to which any possible impairment in auditory processing are causally related to the language problems in SLI remains unclear. The observation that the SLI group showed similar pitch-interval discrimination accuracy as the younger typically developing controls supports a maturational lag account of auditory processing difficulties in SLI (McArthur & Bishop, 2004). However the observation that pitch-interval discrimination was positively correlated with auditory short-term memory in the typically developing children but not the children with SLI, may indicate that there is a qualitative difference in the way that children with SLI are processing music as compared with typically developing children.

Finally, to test the suggestion that auditory processing capabilities may be environmentally mediated and related to the level of musical exposure in the home, measures of musical background were included as predictors in a hierarchical regression analysis. These regression analyses revealed that whilst age and digit span were significant predictors of performance in the typical controls, musical background only accounted for a further 5.5% of the variance in pitch-discrimination. In the SLI group neither age, digit span or musical background significantly predicted pitch-interval discrimination. However, the large majority of the children included in this study did not come from enriched musical backgrounds and these findings need to be interpreted with caution.

CONCLUSION

The findings from experiment one demonstrate that children with SLI showed significantly poorer pitch-interval direction discrimination than CA-matched controls. The pattern of performance on this task resembled that of younger VMA-matched controls, which may indicate that pitch-interval discrimination is delayed and reflects generalized immaturity in auditory processing in children with SLI. However, it was observed that whilst auditory STM was related to pitch-interval direction discrimination in the typically developing controls, this was not the case for the children with SLI which may indicate that children with SLI process music in a qualitatively different way to typically developing children. The observation that pitch-interval direction discrimination is relatively preserved and is not related to auditory STM in children with SLI may reflect a qualitative difference in the way that children with SLI process music. It may be that children with SLI are able to compensate for limitations in auditory short-term memory by relying upon a visuo-spatial representation of contour when processing music. The finding from experiment one motivated the second experiment that tested melody processing over a longer duration.

CHAPTER 5

EXPERIMENT TWO: MELODY DISCRIMINATION

ABSTRACT

The experiment described in this chapter investigated melody discrimination in children with SLI and typically developing CA and VMA-matched controls. The findings from experiment one revealed that pitch-interval direction discrimination is related to auditory short-term memory in typically developing children but not children with SLI. Furthermore, it was found that although SLI is characterized by marked cognitive limitations in auditory short-term memory, pitch-interval direction discrimination appears to be relatively spared in this group. One possibility is that children with SLI show spared pitch interval discrimination because of a preserved ability to represent musical contour. Thus it may be that limitations in auditory short-term memory lead children with SLI to adopt qualitatively different music processing strategies to those adopted in typically developing children. In this second experiment, musical processing was investigated over a longer duration using a same/different melody discrimination task. Participants were asked to listen to two novel melodies that were either the same or differed at local (pitch interval) or global (contour shape) levels and to indicate whether they thought the melodies were the same or different.

INTRODUCTION

The auditory processing deficit account suggests that low-level difficulties with auditory processing negatively impact upon higher-order processing abilities in children with SLI (Tallal & Piercy, 1973). Experiment one tested the auditory processing deficit account and demonstrated that children with SLI show poorer pitch-interval discrimination than CA-matched controls but perform at a similar level as younger typical VMA-matched controls. One possible interpretation of the findings from experiment one is that SLI is characterized by a developmental delay or maturational lag in auditory processing (Bishop, 2005). However, the observation that pitch-interval direction discrimination was related to auditory short-term memory in the typically developing children, but not in the children with SLI, may reflect a qualitative difference in the way that musical information is processed in this group.

Melody is one of the most salient characteristics of music and includes both pitch-interval and contour information (Trainor et al., 2002; Liegeois-Chauvel, Peretz, Babaie, Laguitton, & Chauvel, 1998). The ability to process changes in contour is universal; it is one of the first aspects of music to be discriminated by infants (Trehub et al., 1984; Trainor & Trehub, 1992; Trehub, Schellenberg & Hill, 1997) and young children accurately reproduce contour before they are able to reproduce intervals (Dowling, 1982; 1999). It has been suggested that this early processing of contour provides a ‘scaffold’ that is gradually replaced with culturally defined interval-based tonal schemata (Patel, 2008; Bartlett & Dowling, 1980; Cuddy & Cohen, 1976).

EEG studies have reported cortical responses to violations of contour even when the absolute distance between the relative pitch intervals comprising the contour are not processed (Tervaniemi et al., 1994). Trainor et al (2002) investigated contour and interval processing in adult non-musicians and found that MMN responses during contour processing were faster than for during interval processing, suggesting that more time is needed to extract interval information than to process contour.

Melody processing in adults and children has been investigated using a melody discrimination task in which pairs of novel melodies are either the same or differ at the level of contour (globally violated) or interval (locally violated) (Dowling, Lung & Herrbold, 1987). Investigations of melody discrimination have demonstrated that typical children show much better discrimination accuracy for globally violated melodies (Deruelle et al., 2005; Heaton, 2005). Deruelle et al., (2005) presented a group of children with Williams syndrome and a group of typical chronological age-matched controls with two melodies that were either the same or different. The 'different' melodies involved a manipulation of contour or interval. In the global contour manipulated melodies, one melody was identical to the other apart from one single pitch that was altered so that the direction of the surrounding intervals, and melody shape was modified. The interval modification changed a single pitch in one of the melodies but maintained the original direction and melody shape of the surrounding intervals. The results demonstrated that the typically developing children showed significantly better discrimination accuracy for contour-violated melodies than interval-violated melodies. Interestingly, children with Williams syndrome failed to show this global processing advantage for musical structure.

Using a similar methodology, Heaton (2005) also found that both children with autism and typically-developing matched controls showed better discrimination accuracy for global contour-violated melodies with the majority of participants performing at chance when discriminating local interval-violated melodies.

In adults and typically developing children, musical ability has been linked to auditory short-term memory (Roden et al., 2013; Loui et al., 2011; Anvari et al., 2002). It has been suggested that the phonological loop component of working memory may be implicated in the maintenance of verbal and musical information within short-term memory (Williamson, Baddeley & Hitch, 2010). Support for the notion that there may be shared mechanisms within auditory short-term memory for the processing of both musical and verbal information comes from Roden et al., (2013) who report that after 18 months of musical training, typical 7-8 year olds show improved performance on measures of auditory short-term and working memory. One prediction that arises from a model of shared speech/music rehearsal mechanisms is that developmental increases in the rate of rehearsal in the phonological loop will be reflected in improvements in memory for novel musical information and that disruption to the phonological loop component of working memory should lead to difficulties maintaining novel musical information in STM (Baddeley et al., 1998; Gathercole & Baddeley, 1990). The results from experiment one showed that auditory short-term memory is involved in pitch-interval processing in typical children but not in children with SLI. However, these children performed at levels that were significantly better than chance and showed a typical processing advantage when pitch intervals were large. It thus appears that qualitatively different cognitive mechanisms are implicated in musical processing in this group.

The contour pattern within a melody can be represented in both auditory and visual modalities, pitch can be mapped spatially and pitch relations can be described as moving 'up' and 'down' (Prince et al., 2009). When listening to music, the cognitive system automatically maps pitch onto an internal representation of space (Rusconi et al., 2006). In one experiment Rusconi et al. (2006) demonstrated that when asked to determine whether a reference tone was higher or lower than a probe tone, listeners' performance was faster and more accurate when responding to high frequency pitches with a key on a computer keyboard that was spatially higher and a key that was on the right hand side of the keyboard. Thus it seems that the 'up' 'down' pattern of pitch changes that comprise a melodic contour can be mapped spatially. Furthermore, activation in the visual cortex has been reported in both musicians and non-musicians while attending to melodic contour (Zatorre, Evans, & Meyer, 1994). Prince et al. (2009) presented participants with two melodic contours, one represented visually and one auditorily (the order of presentation was counterbalanced) and were asked to rate the similarity of them. They found that similarity ratings were significantly higher for matched than mismatched contour pairs, demonstrating that listeners were able to map contour across visual and auditory modalities.

Processing intervals within melodies rests upon a capacity to represent and compare individual tones as they unfold in auditory short-term memory. Therefore, impairments in auditory short-term memory are likely to disrupt interval processing within melodies to a greater extent than contour processing since the global melodic contour shape can also be represented visuo-spatially. One study of short-term and working memory abilities in children with SLI demonstrated that SLI is associated with a deficit in auditory short-term memory but spared visuo-spatial short-term memory (Archibald & Gathercole, 2006). Therefore it would be predicted that deficits in auditory short-term memory would result in impaired interval-processing in novel melodies, whereas contour processing will be relatively spared due to a compensatory reliance upon visuo-spatial representation.

Experiment two: Testing melody discrimination in children with SLI and typical development.

Melodic information is encoded in two forms: interval and contour (Dowling, 1984). The contour of a melody describes the pattern of ups and downs over time and can be represented in both visual and auditory modalities (Prince et al., 2009). Previous studies have indicated that typical children show more robust representation of contour than relative intervals within melodies (Deruelle et al., 2005; Heaton 2005). In typically developing children musical ability has been linked to auditory working memory (Roden et al., 2012; Ancari et al., 2002), indicating that there may be shared mechanisms involved in rehearsing musical and verbal information within auditory short-term memory (Williamson et al., 2010). SLI is charactersed by marked deficits in auditory short-term memory (Gathercole & Baddeley, 1990), and therefore it would be expected that aspects of musical processing that are more heavily reliant upon auditory short-term memory (e.g. interval processing) would be impaired in this group. The findings from experiment one indicate that the ability to represent pitch contour is not impaired but delayed in children with SLI and therefore may indicate that children with SLI show relatively spared processing of musical contour, possibly through a compensatory reliance upon a visual representation of this musical feature.

The present experiment investigated contour and interval processing of melodies. It was hypothesized that melody processing would be related to auditory short-term memory in typically developing children but not children with SLI. It was also hypothesized that limitations in auditory short-term memory would result in a deficit in interval processing but not contour processing of melodies in children with SLI.

PILOT STUDY

A melody discrimination task with a similar methodological design to that adopted in prior investigations of melody processing in children with Williams syndrome and autism (Deruelle et al., 2005; Heaton, 2005), was developed and used in experiment two. In order to ensure that the paradigm developed was suitable for use with children with SLI a pilot study was conducted. A total of 10 participants were included in this study: 5 children diagnosed with SLI (age range 7-10-yrs; mean age 8yrs) and 5 typical control children matched for chronological age, gender and non-verbal IQ.

Pairs of novel melodies varying in length between 3-5 tones were digitally recorded in piano voice, using Sibelius version 6. Tempo was set at 120 crotchet beats per minute. For each sequence length there were 27 trials: 9 the same, 9 'different interval' and 9 'different contour'. For the 'different interval' pairs, in one of the melodies there was a displaced piano tone that did not vary the overall shape of the contour. In the 'different contour' pairs, in one of the melodies there was a displaced piano tone that altered the shape of the contour. In both of the different conditions, the displaced piano tone maintained the harmonic structure of the melody and occurred in the middle of the melody. The trials were randomly interleaved into 4 blocks. For each trial, the experimenter played a recording of one of the melodies followed by a 500ms ISI and then the second melody. Children were asked to listen to the two melodies and to say whether they thought they were the same or different.

Some difficulties with the stimuli were encountered during pilot testing. Firstly, the children in both the SLI and TD groups were reluctant to indicate verbally whether they thought the melodies were the same or different. Secondly, it was found that the time taken to complete the task was too long for children at this stage of development. To counter these problems the task was computerised to create a game of musical 'spot the difference', in which the children were asked to listen to two melodies and to indicate via button press whether they thought they were the same or different. The use of E-prime for stimulus presentation increased the speed with which participants were able to progress through the trials and the introduction of a button box and visual characters helped to alleviate boredom and to maintain the children's attention on the task.

METHOD

Participants

Seventeen children with Specific Language Impairment (SLI) and thirty-three typically developing (TD) controls completed the experiments. In the younger VMA-matched control group, five of the children failed to complete the task. Therefore, an additional five TD children matched to the SLI group for receptive vocabulary (using the BPVS-II) were recruited to complete this task and this substituted data was included in the analysis. An independent samples t-test confirmed that the BPVS-II performance did not differ significantly between this group of typically developing control children and the SLI group ($t(32) = -.675$, $p>.05$).

Table 5-1. Participants' psychometric data.

	SLI Group 1	**CA Group 2**	**VMA Group 3**
	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	9:4 (1.2)	9.3 (1.2)	6.1 (0.8)
BPVS-3			
Raw Score	86.06 (15.01)	N/A	96.64 (8.18)
Standard Score	72.8 (10.56)		96.64 (1.37)
Age equivalent	5.11 (0.1)		6.1 (0.7)
Ravens Matrices			
Raw score	23.38(8.8)	32.56 (7.5)	N/A
Standard Score	88.61 (11.9)	96.6 (14.2)	
DS (WISC) [a]			
Raw Score	10.8 (1.8)	17.13 (3.16)	13.19 (2.79)
Standard Score	6 (2)	11.75 (2.77)	11.31 (2.94)
DSF (WISC) [a]			
Raw Score	6.19 (1.9)	10.19 (2.13)	8.18 (1.47)
DSB(WISC) [a]			
Raw Score	5.19 (1.04)	6.94 (1.57)	4.88 (1.69)
CNRep [a]			
Raw score	20.31 (8.35)	35.81 (3.37)	32.65 (5.45)
Range	7-29	28-40	21-39

SLI, Specific Language Impairment; CA, chronological age-matched controls; VMA, verbal mental age-matched controls; BPVS-3, The British Picture Vocabulary Scales; DS, Digit Span Composite subtest of the Wechsler Intelligence Scale for Children; DSF, Digit Span Forward subtest; DSB, Digit Span Backwards subtest; CNRep, The Children's Test of Non-word Repetition.

[a] Group difference significant at p<.0.001

Stimuli

A total of 54 pairs of novel melodies, either 3 or 5 tones in length comprising both large and small pitch intervals were digitally recorded. The melodies were recorded in piano voice using Sibelius 6, had a set tempo of 120 crotchet beats per minute and were varied across keys. For each sequence length (3 or 5 tone conditions) there were 27 trials: 9 the same, 9 'different interval' (DI) and 9 'different contour' (DC).

The second melody of a pair in the 'different interval' (DI) condition included a single tone alteration that maintained the contour. In the 'different contour' (DC) condition the tone alteration changed the shape of the contour. In both of the 'different' conditions the altered tone maintained overall harmonic structure and occurred in the middle of the melody. For each trial, one melody was presented, followed by a 500ms inter-stimulus interval (ISI) and then by the second melody. Examples of the three conditions for 3-tone melody pairs are shown in Figure 5-1.

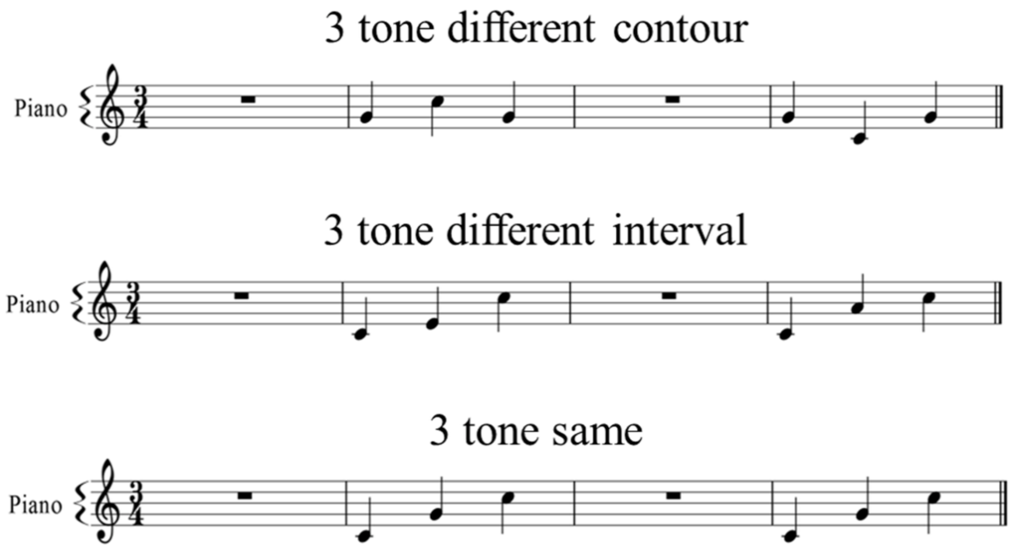


Figure 5-1. Examples of 3 tone ‘different contour’ (DC), ‘different interval’ (DI) and ‘same’ melody pairs.

For each of the ‘different’ conditions a SDA parameter d-prime (*d’*) was computed alongside the ‘same’ condition. The parameter *‘d’* is a measure of the perceived difference between the conditions being compared and is distributed around 0. A large d score indicates successful recognition of melody pairs as the same in the ‘same’ condition and as different in the two ‘different’ conditions. Conversely, a small *d’* parameter indicates a failure to distinguish between same and different melodies.

Design and procedure

The design was mixed factorial, with group as the between-subject factor (SLI, CA and VMA) and melody length (2 levels: 3tone and 5tone) and manipulation (2 levels: Interval and Contour) as the within-group factors.

The children were initially presented with nine cartoon picture pairs for same/different discrimination. This practice was used as an introduction to the experiment and to the concept of discrimination. The picture trials were not related to the auditory task in any way, this was simply used as an introduction to the concept of discriminating between two stimuli that may share certain features e.g. the same characters. The use of graphic illustrations in pre-test training for an auditory discrimination task is in line with previous developmental investigations of auditory processing (e.g. Stalinski, Schellenberg & Trehub (2008); Heaton, 2005). In three pairs of practice trials the pictures were the same; in three pairs the pictures were ‘slightly different’ (e.g. the same character with a change of orientation) and in three pairs the pictures were ‘very different’ (e.g. a change of character). The children were asked to indicate whether the pictures were the same or different by pressing either a same button or a different button (e.g. the button with two pictures that were different on it). Once participants had achieved 100% accuracy on the picture training they proceeded to a practice block. All participants achieved 100% accuracy on this picture training.

The melody discrimination task was comprised of 54 trials randomly interleaved into 4 blocks. Each block took around 5 minutes to complete. A break was offered between blocks and stickers were given to maintain interest in the task. A separate practice block comprised of nine 3-tone melodies, was presented at the start of the task. Once participants achieved 75% accuracy on the practice block they proceeded to the task. Practice and test trials were presented in the form of child-friendly computer games in which the children were invited to play musical ‘spot the difference’. Each trial was visually cued and then the first melody was presented followed by a 500 ms inter-stimulus interval (ISI) and the second melody. Once both melodies had been presented a visual prompt appeared on the screen asking participants to determine if the melodies were the same or different. Participants were asked to respond by pressing the ‘same’ or ‘different’ button on the purpose-built button box that was used in the training. Visual feedback, in the form of a smiley face appeared after each correct response and following an incorrect response the screen remained blank.

RESULTS

Signal Detection Analysis (SDA)

For each child the SDA d-prime (*d’*) was computed on the response data for the ‘same’ and ‘different contour’ (DC) and the ‘same’ and ‘different interval’ (DI) pairs. Responses on ``different" trials were classified as hits if an alternate comparison melody was correctly judged as ``different" and responses on ``same" trials were classified as false alarms if an identical comparison melody was incorrectly judged as ``different". In line with previous work (Mottron, Peretz & Menard, 2000) for each of the 'different' conditions a SDA parameter d-prime (*d'*) was computed alongside the 'same' condition. The parameter *'d'* is a measure of the perceived difference between the conditions being compared and is distributed around 0. A large *d'* score indicates successful recognition of melody pairs as the same in the 'same' condition and as different in each of the 'different' conditions. Conversely, a small *d'* parameter indicates a failure to distinguish between same and different melodies. One of the limitations of calculating *d'* is that if the standard deviations for the hits and false alarms are not equal then this can impact upon the reliability of the *d'* score (Stanislaw & Todorov, 199), in which case the *A′* nonparametric version may be a more accurate estimate of sensitivity (Donaldson, 1993). The means and standard deviations of the Hits and False Alarms (FAs) were calculated for each group across all conditions. It was found that with the exception of the CA-matched controls on the 3-tone DI and 3-tone DC conditions, the standard deviations of the hits and false alarms were close to equivalent across the conditions and groups, and therefor *d'* scores were calculated (see table 5-2).

	SLI		CA		VMA	
	HITS	FA	HITS	FA	HITS	FA
3 Tone DC	6.38 (2.29)	4.5 (2.37)	7.81 (2.02)	1.19 (0.87)	7.5 (1.87)	1.74 (1.25)
3 Tone DI	4.79 (1.82)	4.5 (2.37)	5.5 (1.75)	1.18 (0.87)	3.62 (1.9)	1.74 (1.25)
5 Tone DC	7.5 (1.87)	5.15 (2.5)	6.75 (1.48)	2.5 (1.59)	4.3 (1.9)	2.9 (1.77)
5 Tone DI	5.74 (2.1)	5.15 (2.5)	6.75 (1.48)	2.5 (1.59)	4.3 (1.9)	2.9 (1.77)

Table 5-2. Means (SDs) of the Hits and False Alarms (FA) for each group across each of the conditions

The proportion of hits and false alarms for the different contour and different interval melodies were calculated and a loglinear approach was used to correct for extreme values (Hautus, 1995). The loglinear correction involved adding 0.5 to the number of hits and false alarms and adding 1 to the total number of same and different trials before calculating the hit and false alarm rates.

The confidence intervals around the *d'* scores for each participant were calculated and it was considered that if the confidence intervals for participants on any condition crossed zero then this could indicate a degree of random responding. Nine of the children in the SLI group had confidence intervals that crossed zero on every condition of the task. A breakdown of performance across conditions revealed that for the 3-tone 'different interval' (DI) melodies fourteen of the SLI participants had confidence intervals that crossed zero and for the 5-tone DI melodies thirteen had confidence intervals crossing zero. For the globally violated melodies, eleven participants had confidence intervals that crossed zero for the 3-tone ‘different contour’ (DC) melodies and twelve had confidence intervals that crossed zero for the 5 tone DC melodies. In the VMA and CA-matched control groups none of the children had confidence intervals that crossed zero on every condition of the task. Investigation of the confidence intervals for each condition revealed that in the CA-matched controls four participants had confidence intervals that crossed zero for the 3-tone DI condition and five participants had confidence intervals crossing zero for the 5-tone DI melodies; two participants had confidence intervals crossing zero for the 3-tone DC melodies and three participants had confidence intervals crossing zero for the 5 tone DC melodies. In the VMA-matched controls the profile was very different with thirteen of the participants with confidence intervals crossing zero for the 3-tone DI melodies and fourteen participants with intervals crossing zero for the 5-tone DI melodies. On the 3-tone DC melody condition only two participants’ confidence intervals crossed zero and this rose to three participants for the 5-tone DC melodies. Individual *d’* scores across each of the conditions are shown in table 5-3.

Participant	Group	Three DC	Three DI	Five DC	Five DI
1	SLI	-0.39	-0.18	0.2	-0.54
2	SLI	0.18	0.36	0.64	-0.36
3	SLI	-0.18	0	0.64	0.39
4	SLI	1.21	0	1.44	0.18
5	SLI	0.89	0.89	0.89	0.46
6	SLI	0.26	-0.75	-0.69	-1.25
7	SLI	2.33	1.44	1.9	1.9
8	SLI	1.47	0.46	1.07	0
9	SLI	1.9	0.64	1.01	0.75
10	SLI	0.57	0.57	1.9	1.44
11	SLI	0	0.18	0.46	0.2
12	SLI	-0.46	-0.64	-0.26	0
13	SLI	0.95	0.39	-0.54	-0.18
14	SLI	-0.36	-0.36	0.18	-0.18
15	SLI	-0.36	-0.57	-0.57	-0.2
16	SLI	0	-0.39	0.39	0.39
17	SLI	-0.36	-0.36	0.57	-0.64
1	CA	1.9	0.46	1.9	1.25
2	CA	1.44	1.25	0.18	0
3	CA	0.69	0.69	0.57	0.2
4	CA	1.25	0.69	0.95	0.57
5	CA	1.9	1.01	1.64	0.75
6	CA	0.75	0.54	1.25	0.82
7	CA	1.9	1.21	1.64	1.64
8	CA	1.9	1.25	1.64	0.95
9	CA	1.9	1.44	1.9	1.01
10	CA	1.25	1.64	1.64	1.44
11	CA	1.9	1.01	1.9	1.47
12	CA	1.9	1.25	0.82	1.21
13	CA	1.01	0.26	0.36	0.18
14	CA	1.47	1.01	1.01	0.82
15	CA	1.64	0.75	1.44	0.75
16	CA	2.33	1.44	1.9	1.21
1	VMA	1.47	1.01	1.64	0.95
2	VMA	0.82	0.26	0.54	0.18
3	VMA	1.01	0.36	0.46	-0.18
4	VMA	1.9	0.26	1.01	0.18
5	VMA	0.46	0.26	1.07	0.69
6	VMA	0.95	0.2	1.07	0.18
7	VMA	1.44	0.43	1.01	0.64
8	VMA	2.33	1.07	2.33	0.43
9	VMA	1.47	0.64	1.01	0.36
10	VMA	1.47	0.26	1.21	0
11	VMA	1.25	0.43	0.95	0.2
12	VMA	0.64	-0.43	1.44	-1.07
13	VMA	1.9	0.89	1.47	0.64
14	VMA	1.07	0	1.07	0.18
15	VMA	1.01	0.26	1.21	0.46
16	VMA	1.9	0.64	1.64	0.2
17	VMA	0.95	0.95	1.47	1.01

Table 5-3. Individual *d'* prime scores for the discrimination of interval and contour violated melodies that were 3-tones and 5-tones in length.

Inspection of the subject-wise data indicated a large degree of variability in *d'* scores screening revealed that within each of the groups across all conditions, however it appeared that there were no single clear outliers that could be identified in any of the groups that may have biased the data. The means and standard deviations of *d'* scores attained on each condition are shown in table 5-4.

	Interval change		**Contour change**	
Group	3-tone	5-tone	3-tone	5-tone
SLI	0.1 (0.6)	0.14 (0.18)	0.45 (0.9)	0.54 (0.8)
CA	0.99 (0.4)	0.89 (0.12)	1.57 (0.47)	1.3 (0.58)
VMA	0.44 (0.39)	0.3 (0.48)	1.3 (0.5)	1.2 (0.4)

Table 5-4. Means (SDs) of *d'* prime scores for the discrimination of interval and contour violated melodies that were 3-tones and 5-tones in length.

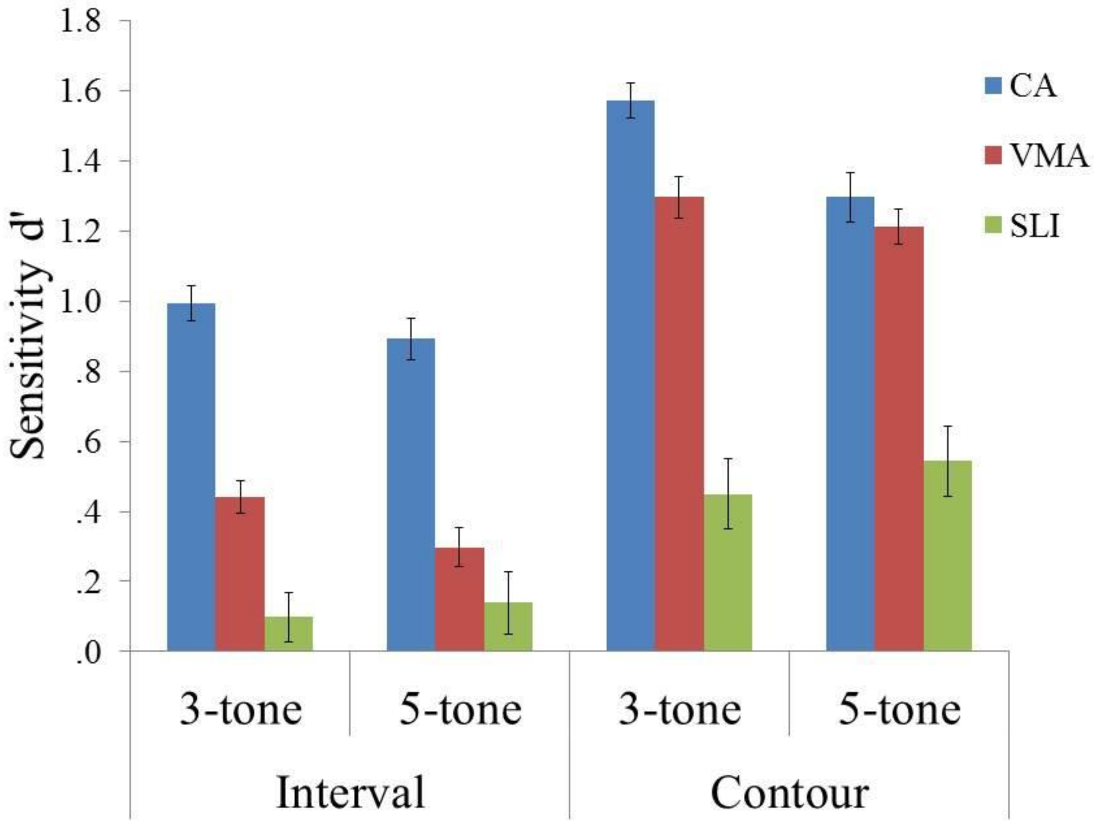


Figure 5-2. Mean *d* scores and standard errors for the SLI group and the typically developing CA-matched and VMA-matched control groups on the melody discrimination task.

D' scores for melody discrimination were compared across the three groups. These data were screened and found to be normally distributed. The performance of the SLI group was compared to the CA and VMA-matched controls with a 3x2x2 ANOVA with group (SLI, CA, VMA) as a between-subjects factor and Manipulation (interval, contour) and Length (3tone, and 5tone) as within-subjects factors. There was a significant main effect of Manipulation ($F(1,47)=117.737$, $p<.001$, $n_p^2=.715$), indicating that discrimination accuracy was better for melodies that varied in global contour versus those varied at the local interval level. There was also a significant main effect of Group ($F(2,47)=13.351$, $p<.001$, $n_p^2=.362$), indicating that there was a significant difference in discrimination accuracy across the three groups. Further Tukey HSD post-hoc comparisons revealed that overall the SLI group showed significantly poorer discrimination accuracy than the CA-matched controls ($p<.001$) and the VMA-matched controls ($p<.05$) and the VMA-matched controls showed poorer discrimination than the CA-matched controls ($p<.01$).

There was a significant interaction between Manipulation and Group ($F(2,47)=8.299$, $p=.001$, $n_p^2=.261$), pairwise comparisons with a Bonferonni adjustment (0.05/6) whereby the criterion value for statistical significance was set at $p<.008$ were carried out. The TD matched control groups showed significant differences between the DC and DI conditions for 3-tone (CA: $t(15)=5.370$, $p<.001$; VMA; $t(16)=8.623$, $p<.001$) and 5-tone (CA: $t(15) = 4.718$, $p<.001$; VMA: $t(16) = 6.589$, $p<.001$) melodies. The SLI group showed a significant difference between DC and DI conditions for the 5 tone melodies ($t(16)=3.199$, $p<.001$) and at a level approaching significance for the 3-tone melodies ($t(16)=2.739$, $p=.015$).

To control for the effects of variability in verbal auditory short-term memory on melody discrimination performance, a second 3x2x2 mixed-ANOVA was carried out with digit span scores entered as covariates. This analysis revealed that after controlling for variability in auditory short-term memory there was still a main effect of manipulation $F(1,46)=119.004$,

$p<.001$, $np2=.721$ and a significant Manipulation by Group interaction $F(2,46)=7.625$, $p=.001$, $np2=.225$).

To further investigate the effect of length, the discrepancy scores for length were calculated for both interval-violated and contour-violated melodies. The length discrepancy scores were calculated by subtracting the 5-tone *d*' scores from the 3-tone d scores for contour-violated and interval-violated melodies, yielding two separate length discrepancy scores for interval and contour-violated conditions. The relationships between length discrepancy scores and age and auditory memory were investigated by collapsing the data to form one typically developing control group and carrying out correlational analyses. The correlational analyses revealed that there was a significant negative correlation between the length discrepancy score for interval-violated melodies and digit span. This indicates that in the typically developing group, those children with good digit span scores showed the smallest discrepancy in discrimination accuracy for three and five tone interval-violated melodies (see table 5-5). However, it is important to note that this findings must be interpreted with caution since this is a weak correlation that is only approaching significance once a Bonferonni correction for multiple comparisons is applied ($p=0.05/4$).

TD Controls	Interval	Contour	Digit Span	CNRep
Age	.260	-.142	.592**	.338*
Interval		-.024	-.297*	-.278
Contour			-121	-.215
Digit Span				.340*

Table 5-5. Correlational analyses between discrepancy scores for interval and contour violated melodies and digit span and CNRep in the typically developing controls.

To investigate the extent to which auditory short-term memory predicted the size of the length discrepancy score for interval-violated and contour-violated melodies in the typically developing children, two separate hierarchical regression analyses were carried out with interval discrepancy scores and contour discrepancy scores as dependent variables. This analysis revealed that neither age, nor digit span were significant predictors of the size of the length discrepancy score for interval-violated melodies (see table 5-6) or the contour-violated melodies (see table 5-7).

Contour	R^2	β	R^2 change	F	P
Step 1					
Age	.088	-.297	.088	2.898	>.05
Step 2					
Age		-.186			
Digit Span	.111	-.187	.023	1.806	>.05

Table 5-6. Hierarchical regression with age and digit span entered as predictors of the length discrepancy scores for the interval-violated melodies.

Interval	R^2	β	R^2 change	F	P
Step 1					
Age	.011	-.103	.011	.322	>.05
Step 2					
Age		-.269			
Digit Span	.061	.280	.051	.949	>.05

Table 5-7. Hierarchical regression with age and digit span as predictors for the length discrepancy scores for the interval-violated melodies.

The analysis of the data from the typically developing children indicates that there is a different relationship between length and manipulation and discrimination accuracy for interval and contour-violated melodies. The length discrepancy scores for interval-violated melodies were negatively correlated with auditory short-term memory whereas the length discrepancy scores for contour-violated melodies were not. This finding may indicate that children with good auditory short-term memory showed a smaller discrepancy in the discrimination accuracy scores for interval-violated melodies that were either 3-tones or 5-tones in length, whereas auditory short-term memory was not related to the size of the discrepancy scores for 3 and 5-tone contour-violated melodies.

The length discrepancy scores for the interval-violated and contour-violated melodies across the SLI, CA and VMA-matched controls were compared with two Univariate ANOVAs. For the contour-violated melodies the length discrepancy scores were not significantly different across the three groups ($F(2,49)=2.508$, $p>.05$, $n_p^2=.051$). For the interval-violated melodies the length discrepancy scores were significantly different across the three groups ($F(2,49)=3.986$, $p<.05$, $n_p^2=.145$), Tukey HSD post-hoc comparisons demonstrated that the SLI group showed significantly different discrepancy scores than the VMA-matched controls ($p<.05$) (see figure 5-3) .

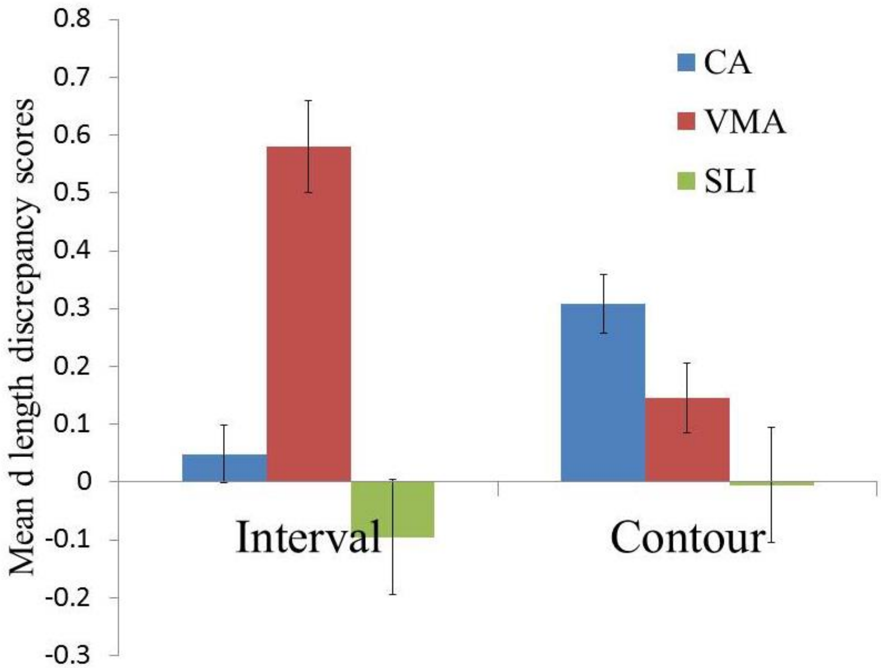


Figure 5-3. The impact of sequence length on discrimination of interval and contour violated melodies in the SLI group and the CA and VMA-matched controls.

Correlational analyses carried out on the SLI data failed to real significant correlations between length discrepancy scores for interval-violated and contour-violated melodies and performance on the digit span measure of auditory STM in this group (see table 5-8).

SLI Group	Interval	Contour	digit span	CNRep
Age	-.137	-.099	-.517*	-.383
Interval		.053	.326	.176
Contour			.281	.046
digit span				.295

*p<.05 **p<.01

Table 5-8. Correlational analyses between length discrepancy scores for interval and contour violated melodies and digit span and CNRep in the children with SLI.

Response bias

To investigate potential response bias for each of the melody discrimination conditions across the three groups, the c' measure of response bias was also calculated. Inspection of the mean c' scores across conditions and groups indicated that the SLI group showed a tendency towards identifying the melodies as sounding the 'same' (as indicated by the negative c' scores) (see Table 5-9).

	SLI	CA	VMA
3 Tone DC	-0.15 (0.39)	0.17 (0.48)	0.12 (0.44)
3 Tone DI	0.1 (0.48)	0.58 (0.34)	0.72 (0.45)
5 Tone DC	-0.4 (0.48)	-0.14 (0.4)	0.42 (0.47)
5 Tone DI	-0.11 (0.49)	0.13 (0.37)	0.42 (0.47)

Table 5-9. Means (SDs) of c' measures of response bias for each group across conditions

A 3x2x2 ANOVA with group (SLI, CA, VMA) as a between-subjects factor and Manipulation (interval, contour) and Length (3-tone, and 5-tone) as within-subjects factors was carried out on the c' scores. There was a significant main effect of Length ($F(1,47)=36.819$, $p<.001$, $n_p^2=.439$), indicating that overall the tendency towards biased responding differed according to the length of the stimuli. There was a main effect of Manipulation ($F(1,47)=121.181$, $p<.001$, $n_p^2=.721$), indicating that response bias differed significantly across depending upon whether the melodies were varied at the interval or contour levels. There was also a significant main effect of Group ($F(2,47)=5.806$, $p=.006$, $n_p^2=.198$), indicating that there was a significant difference in response bias across the three groups. Further Tukey HSD post-hoc comparisons revealed that overall the SLI group showed significantly greater response bias than the CA-matched controls (p=.045) and the VMA-matched controls (p=.006).

The analysis of the c' measure of response bias indicates that the SLI group showed greater response bias than the CA and VMA-matched controls with a tendency towards reporting that the melodies were the 'same'.

Reaction Time (RT)

The RTs for responses to same (S), different interval (DI) and different contour (DC) melodies were calculated (see table 5-10) and compared across the three groups. A 3x3x2 mixed-ANOVA Group (SLI, CA, VMA) as a between-subjects factor and Melody Type (DC, DI and S) and Length (3tone, and 5tone) as within-subjects factors was carried out. There was a significant main effect of Length ($F(1,47)=26.69$, $p<.001$, $n_p^2=.378$), indicating that overall there was a significant difference in reaction times for processing melodies that were either 3- or 5-tones long. The main effect of melody-type was not significant ($F(2,94)=.961$, $p=.386$, $n_p^2=.021$) and the main effect of Group was not significant ($F(1,47)=2.69$, $p=.071$, $n_p^2=.109$).

Pairwise comparisons with a Bonferonni adjustment (0.05/9) whereby the criterion value for statistical significance was set at $p<.005$ were carried out. The SLI group showed a significant difference between RTs for 3-tone and 5-tone melodies for the DC condition ($t(16)=-3.248$, $p=.005$) and the DI condition ($t(16)=-4.489$, $p<.001$. The TD controls did not show a significant difference in RTs for 3-tone and 5-tone DC or DI melodies. The findings indicate that the length of the melodies was significantly related to RTs for processing interval and contour violations in the SLI group only.

	SLI	**CA**	**VMA**
3 Tone DC	836 (294.5)	788.49 (411)	912.6 (367.6)
3 Tone DI	823.22 (368.7)	896.6 (595.1)	705.5 (460.6)
3Tone S	871.54 (271.9)	651.7 (335.9)	1134.7 (608.6)
5 Tone DC	1154.23 (544.3)	947.8 (404)	1234.5 (541.2)
5 Tone DI	1306.82 (549.9)	950.6 (455.9)	1248.18 (703.67)
5 Tone S	1443.09 (825.4)	911.6 (427.5)	1342.2 (609.1)

Table 5-10. Means (SDs) of RTs for Same, Different Contour (DC) and Different Interval (DI) melodies of each length across groups.

Correlational analysis

In a final analysis of the data, correlations were carried out on the separate conditions of the experiment and digit span scores for the TD and SLI groups, a Bonferonni adjustment (0.05/6) whereby the criterion value for statistical significance was set at $p<.008$ was applied. Correlations for the TD group are shown in table 5-11.

TD Group	**digit span**	**3 tone DI**	**3 tone DC**	**5 tone DI**	**5 tone DC**
age	.465*	.572*	296	.562**	.156
digit span		.372	.170	.420*	.299
3 tone DI			.604*	.733*	.386
3 tone DC				.472	.590*
5 tone DI					.499

*P<.01

Table 5-11. Correlations between each condition of the melody discrimination task, age and digit span in the typically developing children.

For the TD controls *d'* scores for the 5-tone interval-violated melodies were significantly positively correlated with digit span. Partial correlations revealed that once age was controlled this correlation was no longer significant, showing that age-related improvement across both interval-discrimination and digit span was underlying the relationship between digit span and discrimination for interval-violated melodies.

The correlations for the SLI group demonstrated that digit span was not significantly correlated across any condition of the melody discrimination task (see table 5-12).

SLI Group	**Digit Span**	**3 tone DI**	**3 tone DC**	**5 tone DI**	**5 tone DC**
age	-.331	-.254	-.339	.-.045	-.357
Digit Span		.-.289	.-.239	-.118	-.364
3 tone DI			.803*	.745*	.728*
3 tone DC				.592	.606*
5 tone DI					.772*

*p<.01

Table 5-12. Correlations between each condition of the melody discrimination task, age and digit span in the typically developing children.

DISCUSSION

The aim of the experiment described in this chapter was to investigate interval and contour processing using a same/different melody discrimination task. Melody discrimination was investigated in children with SLI and two TD control groups matched for chronological and non-verbal IQ (CA) and verbal mental age (VMA). Melodies varied in length (three or five semitones) and at the level of manipulation (different interval or different contour). The results of the data analysis showed significantly poorer overall discrimination accuracy in the SLI group compared with both the CA and VMA-matched controls.

For each of the groups melody discrimination was poorer for interval-violated melodies than for contour-violated melodies. These findings are consistent with previous child studies showing that melody discrimination is more accurate when different melodies include globally violated contours than when they maintain the contour shape but vary at the local interval level (Deruelle et al., 2005; Heaton, 2005). Inspection of the *d* scores and confidence intervals around the *d* scores demonstrated that there were a number of children in the SLI group who showed consistently poor discrimination for both interval and contour-violated melodies. The analysis of the TD child data showed that there were a greater number of younger VMA-matched controls who showed poorer discrimination of locally violated melodies than global contour violated melodies, whereas in the older CA-matched controls there were similar numbers of children showing poor discrimination accuracy for both locally and globally-violated melodies. This observation may indicate that in typical development there is an initial global bias in processing musical structure that becomes less dominant as age increases. The large number of younger VMA-controls with confidence intervals crossing zero for the local interval-violated melodies, may demonstrate that a number of children in this group were unable to reliably discriminate between interval-violated melodies. These findings are consistent with those of Heaton (2005) who found that the TD participants were only able to correctly discriminate the interval-violated melodies 46% of the time.

Investigation of the manipulation by length by group interaction demonstrated that the length and manipulation of the melodies interacted and influenced melody discrimination accuracy in different ways in the older and younger typically developing children. The older typical CA-matched controls were able to accurately discriminate between both the interval- and contour-violated melodies, whereas the younger VMA-matched controls showed very poor discrimination accuracy for 5-tone interval-violated melodies. The VMA-matched controls continued to show significantly better discrimination accuracy for contour-violated melodies than interval-violated melodies after controlling for variability in digit span scores. One potential interpretation of this finding is that younger TD children discriminate contour-violated melodies better than interval-violated melodies because contour processing places fewer demands on STM resources than processing the relative intervals within a melody. Digit span improves over age in TD children (Gathercole & Baddeley, 1993) and it may be that this improvement in digit span is paralleled by an increased capacity to represent and remember the interval structure within melodies. The correlational analyses support this interpretation, showing that as digit span improves over age so does the ability to process the longest interval-violated melodies. It is possible that in typical musical development, melody processing is initially contour based, but becomes increasingly sensitive to interval structure as the short-term memory capacity needed to represent and retain the individual tones in the melodies increases.

Visual inspection of the length discrepancy scores across the three groups showed that for contour-violated melodies, sequence length did not impact largely upon discrimination accuracy in any group (as indexed by small length discrepancy scores). Whereas for the interval-violated melodies the sequence length had a large impact upon discrimination accuracy in the VMA-matched controls particularly (as indexed by the large length discrepancy score). Correlational analyses showed that discrimination accuracy was less influenced by the sequence length of interval-violated melodies in children with good auditory STM than children with poor auditory STM, at a level approaching statistical significance, whereas auditory STM capacity was not related to the effect of sequence length on discrimination accuracy for contour-violated melodies. Thus it may be that in typically developing children the capacity to process interval-structure within melodies is related to the development of auditory STM.

It has been consistently shown that SLI is characterised by impairments in auditory short-term memory (Gathercole and Baddeley, 1990a; Montgomery, 1995; Bishop, North & Donlan, 1996). The observation that digit span mediated performance on the melody discrimination task in typically developing children supports the notion that the phonological loop component of working memory is implicated in the processing of both verbal and musical information (Roden et al., 20130; Williamson, Baddeley & Hitch, 2010; Koelsch et al., 2009; Mandel et al., 2007; Anvari et al., 2002). Given the importance of auditory STM for melody discrimination, an impairment in auditory STM should be reflected in poor melody discrimination with markedly worse performance for longer melodies with high memory load (Gathercole & Baddeley, 1996). However in the children with SLI it was found that they performed at chance when discriminating interval-violated melodies but showed better than chance discrimination of contour-violated melodies irrespective of length.

In typical adults, the processing of contour and interval are separable processes (Trainor et al., 2002) and it is possible that global contour processing imposes fewer demands on auditory memory than the representation of the pitches comprise the contour. In the SLI group, the length discrepancy scores for interval-violated and contour-violated melodies did not differ, which seems to indicate that the children with SLI were not relying upon auditory STM to process the melodies in the same way as the typically developing children. Support for the notion that auditory short-term memory was important for the discrimination of interval-violated melodies in the typically developing controls comes from the observation that digit span scores were significantly negatively correlated with the length discrepancy scores for interval-violated melodies. This indicates that in typically developing children with good auditory short-term memory, discrimination accuracy for interval-violated melodies was less influenced by the length of the melodies than it was for children with poor auditory memory. Thus typical children with good auditory memory were able to represent and to process interval changes in 3-tone and 5-tone melodies equally well.

The observation that auditory short-term memory is important for musical processing in typical children, and that children with SLI show short-term memory deficits but perform better than chance on some musical tasks, suggests that they adopt a qualitatively atypical music processing strategy. Support for the notion that children with SLI may rely on a different strategy to TD individuals comes from the literature on speech processing. It has been suggested that when processing speech, adults and children rely on different cues to process the different speech sounds (Nittrouer & Lowenstein, 2007). Speech cues may be more or less distinctive and informative, and it has been suggested that TD children adopt a strategy in which the most distinctive and informative cues are selectively processed (Sussman, 2001). Musical tones have distinctive and informative qualities and the observation of above-chance levels of pitch-interval direction discrimination accuracy in experiment one indicates a degree of spared pitch processing in the SLI group. It is therefore possible that the SLI participants' pattern of performance on the melody discrimination task reflected a strategy that involved processing the most distinctive tones rather than representing both novel melodies in their entirety within short-term memory. Such a strategy would lead to better discrimination of contour-violated melodies in which the deviant tone that marks a change in contour in one of the melodies is especially distinctive alongside poorer discrimination of interval-violated melodies in which the deviant tone is much less distinctive.

Frequency discrimination has classically been investigated behaviourally, with psychoacoustic tasks in which children are asked to listen to three tones and to identify the odd one out (Mengler et al., 2005). For experiment one, the decision was taken to test pitch-interval direction discrimination because the motivation was to investigate musical cognition and not frequency discrimination with SLI and this method had been successfully used in children with neurodevelopmental disorders in past studies (Heaton et al., 2005). In the second experiment, when participants were required to listen to three pitches and to represent and discriminate between them at an individual interval-level, the SLI group were performing at chance. However, they showed much better discrimination of contour-violated melodies. Taken together these findings seem to indicate that the ability to discriminate discrete pitch intervals is impaired in children with SLI, and yet the capacity to discriminate contour change is relatively preserved. It is possible that the preserved pitch-interval direction discrimination observed in the SLI group in experiment one, may reflect the fact that the task involved representing the pitch-interval contour in order to determine the direction of the interval. Taken together the relatively preserved pitch-interval direction discrimination in experiment one and preserved discrimination of contour-violated melodies in experiment two may indicate that children with SLI show some sparing processing of musical contour. It has been observed that children with SLI show impaired short-term memory for auditory information and yet show intact, and sometimes even superior processing of visuospatial information (Archibald & Gathercole, 2006). Melodic contour can be represented in the visual as well as the auditory modality and it is plausible to suggest that relatively preserved musical contour processing in SLI results from an increased reliance on visuo-spatial short-term memory during music processing (Prince et al., 2009). The relationship between visuo-spatial short-term memory and musical processing in typically developing children and children with SLI warrants further investigation.

CONCLUSION

The second experiment described in this thesis investigated melody discrimination in children with SLI and TD controls. The findings indicate that children with SLI show atypical processing of melodies and one possible explanation is that their processing limitations in auditory STM lead them to adopt an alternative compensatory strategy when processing music. Investigation of the qualitative pattern of performance of the SLI group on the TROG-II measure of linguistic grammatical comprehension (detailed in chapter 3) demonstrated that poor performance on this measure could be attributed to processing imitations rather than a concrete absence of grammatical knowledge. Taken together the findings from chapter 3, 4 and 5 indicate that limitations in auditory short-term memory disrupt aspects of linguistic and musical processing in children with SLI. The next question to be addressed in this thesis is the extent to which imitations in processing and/or impaired procedural knowledge impacts upon the capacity to recognize and process hierarchical syntactic structures in motor and musical domains in children with SLI.

CHAPTER 6

SYNTACTIC PROCESSING OF VISUAL MOTOR-ACTION AND MUSICAL SEQUENCES

ABSTRACT

The studies reported in this chapter investigated the processing of syntactic structure in visual motor-action and musical sequences in children with SLI and typical controls. In experiments three and four, explicit response accuracy and implicit reaction times for the processing of targets following a sequence of related and unrelated musical chords and pictures, were measured. The findings from the two experiments revealed that children with SLI showed atypical processing of procedural information across action and musical domains relative to typically-developing matched controls. The findings from each of the experiments are discussed in the context of the procedural memory, auditory processing and auditory short-term memory deficit accounts of SLI.

INTRODUCTION

The ability to navigate a spatial environment in the real world and to skillfully act upon it is dependent upon the acquisition of skills necessary for the execution of complex motor-actions. For example to carry out a skilled action, such as reaching to pick up a glass, a series of single actions must be integrated to create a smooth action sequence and procedural knowledge allows for the execution of such complex motor actions. Anderson (1982) has suggested that whilst procedural knowledge is acquired automatically, working memory and attention are particularly important at the early stages of skill acquisition. Thus it is possible that deficits in either or both of these processes may impair the acquisition and processing of procedural knowledge and therefore the automaticity with which sequences of elements can be integrated into a coherent whole prior to executing a complex motor action.

It has been proposed that action has a hierarchical structure so that single actions are combined into more complex and meaningful sequences in accordance with implicitly acquired rules (Botvinik, 2008; Bates & Dick, 2002). Similarly in language, grammatically meaningful sentences are constructed through the combination of words that conform to an existing rule-system (Hulme & Snowling, 2009), and in music a similar process of integration of units according to a given rule-system enables the combination of tones and chords to create aesthetically pleasing and coherent music (Patel, 2008). In order to develop the skills needed to generate and comprehend sentences and musical sequences, knowledge of the culture-specific rules about how words and tones are organised must have been acquired (Saffran & McMullen, 2004). In music, implicit learning mechanisms enable the individual to acquire knowledge about musical structure, and that allows for recognition of rule-governed relations between musical events. Thus when tested experimentally with paradigms that do not ask for explicit, verbalized comments on musical structure, non-musicians demonstrate an ‘expert’ understanding of music (Tillman & Bigand, 2004). Grammatical constructs in language are also acquired without explicit instruction, and according to the Shared Syntactic Integration Resource Hypothesis (SSIRH) (Patel, 2008) similar cognitive and neural mechanisms sub-serve the processing of this implicit knowledge. Patel (2008) argues that although there may be domain specific long-term memory representations for music and language, there is a shared pool of resources within working memory that are implicated in the online processing of this stored knowledge.

Through exposure to different domains of knowledge, schematic representations are generated and these result in expectancies that confer a perceptual processing advantage known as a ‘priming effect’ (Bharucha & Stoeckig, 1986; 1987). The ‘priming paradigm’ is a method that is used to investigate implicit knowledge and to measure the effects of context and expectations on the efficiency of perception (i.e., accuracy and processing speed). One advantage of this method is that it taps implicit rather than explicit awareness (Tillman, 2012). In linguistics, priming for words has been investigated classically using a lexical decision task in which participants hear a prime sequence and judge whether a subsequently presented target word is a real or a non-word. In lexical decision tasks, typical adults and children show faster and more accurate responses when the target is semantically and/or syntactically related to the prime (Edwards & Lahey, 1996).

The SSIRH proposes that in adults there are domain specific long-term memory stores for music and language, however there are shared cognitive and neural mechanisms implicated in the online processing of this information (Patel, 2008). Thus the combination of discrete words into a coherent, grammatically correct sentence is reliant upon more general cognitive mechanisms that are also utilized in the combination of discrete tones according to specific musical structures. Neuroimaging studies have found that in typical adults a cortical language network, including Broca's area, is implicated in the processing of linguistic and musical syntax (Koelsch & Siebel, 2005; Koelsch, Gunter, Cramon, Zysset, Lohmann, & Friederici, 2002).

Typical adults show similar electrophysiological response to syntactic violations in music and language (Patel, Gibson, Ratner, Besson, & Holcomb, 1998). ERP studies have shown that syntactically incongruous words and out-of-key chords elicit an early negative component, stronger on the left in response to speech stimuli (ELAN: Hahne & Friederici, 1999) and on the right for musical stimuli (ERAN: Koelsch, Gunter, Friederici, & Schroger, 2000; Maess, Koelsch, Gunter, & Friederici, 2001). Importantly, this response has been demonstrated in non-musicians, indicating that musical training is not necessary for this level of implicit knowledge to develop. Furthermore this ERAN response does not only occur in response out-of-key chords but to those chords that are structurally unexpected within a given sequence (Koelsch et al.,

2007) and so this rules out the possibility that this particular response is due to the acoustic features of the out-of-key chord. A similar pattern of neurophysiological activation to harmonic violations has been observed in typical children. Typical 5-year olds and 9-year olds show electronic brain potentials (ERPs) in response to chord sequences that include a harmonically incongruent chord. Furthermore, these ERPs are modified according to the degree of the harmonic incongruity of the chords, indicating that at a neural level, children as young as 5-years are already processing syntactic regularities in music according to a cognitive representation of the major-minor system (Jentchke & Koelsch., 2009; Jentschke et al., 2008; Koelsch et al., 2003).

It has been suggested that 'action' may have a syntactic-like structure (Botvinik, 2008) and research has shown that cortical areas implicated in the representation of the abstract hierarchical structures involved in action, depend upon similar processing mechanisms as those implicated in processing hierarchical structure in language and music (Fadiga et al., 2009; Pulvermuller & Fadiga, 2010). Neuroimaging work indicates that Broca's area in the left hemisphere is involved in processing syntax-like information in language and action, and its right hemisphere homologue is implicated in the processing of musical structure (Fadiga et al., 2009). Furthermore, one study found that presenting adults with a sequence of pictures displaying a hand reaching for an object followed by a target picture of the hand incorrectly grasping the object elicited the same electrophysiological response as grammatical violations in language and harmonic violations in music (Sammler Harding, D'Ausilio, Fadiga & Koelsch, 2010). Thus it may be that there are overlapping mechanisms involved in processing hierarchical structures in music, language and action.

Implicit awareness of musical syntax has been investigated in musically untrained listeners with a priming paradigm in which the listener is played a sequence of tones from one key followed by a target tone that is either congruent (i.e. in the same key) or incongruent (i.e. not in the same key) with the prime. The listener is required to determine whether the target chord is related or unrelated to the preceding context, and the difference in response times across the two types of judgment is measured (Bharucha, & Stoeckig, 1986; 1987). It has been found that the context generated by the listener's knowledge of a particular musical structure facilitates the processing of target chords; hence target chords that are tonally-related to prime sequences are processed more quickly and with greater accuracy than target chords that are unrelated to prime sequences (Tillman & Bigand, 2004; Tillman, Bigand & Pineau, 1998). Bharucha (1987) suggests that the harmonic priming effect could be explained within a connectionist framework, in which the presentation of a tone activates representations of all other tones that are related to that tone within a specific key. According to this account the pattern of representation provides information about the key composition and enables the generation of expectancies of chords that ought to follow in any given sequence. Chords that fulfill such expectations place fewer demands on attentional resources than chords that violate these expectations and this explains the increased speed and accuracy within which they are processed (Poulin-Charronat et al., 2005). In one harmonic priming experiment, the harmonic relatedness of the target chord was systematically manipulated according to the circle of fifths, and it was found that the error rates and reaction times increased as the harmonic distance between the target and the prime increased (Bharucha & Stoeckig, 1986).

Developmental investigations of musical syntactic comprehension have demonstrated that typically developing children show an awareness of musical structure from around the age of 6-7 years (Schellenberg et al., 2005; Heaton et al., 2007). Schellenberg et al. (2005) investigated implicit knowledge of musical syntax in children using three harmonic priming experiments. They found that children were faster and more accurate at making a variety of judgments about the target chord (such as the timbre) when the target was harmonically related to the prime sequence. Similarly, Heaton et al. (2007) presented typically developing children and children with autism with harmonically conventional, hymn-like, 8 chord sequences. After presentation of each prime sequence participants heard a target chord and were required to indicate whether this final chord sounded right or wrong. Heaton et al. (2007) found that typical children as young as 7-years were able to explicitly recognise and accurately label chords that were harmonically related to the prime sequences. Taken together these findings provide strong evidence that typical children have implicitly acquired knowledge of culturally-specified musical structure by the age of 6-7 years, and that this knowledge confers a processing advantage for targets that are related to the prime sequence.

In one of the first experiments to investigate musical syntactic processing in children with SLI, Jentschke et al. (2008) presented chord sequences ending in a tonic or supertonic chord and simultaneously measured EEG activity. They found that typical children showed the same automatic early right anterior negativity (ERAN) in response to harmonic expectancy violations that is seen in typical adults (Maess et al., 2001; Koelsch et al., 2000) whereas the children with SLI did not. Interestingly, the children with SLI did not differ from controls in their processing of the acoustic features in the stimuli, and this indicated that the atypical ERP responses did not reflect a general impairment in auditory processing but were specific to the processing of musical grammar. Similarly, in one ERP investigation of syntactic processing in language, children with SLI failed to show the same early left anterior negativity (ELAN) to syntactically violated sentences that is observed in typically developing controls (Fonteneau & van der Lely, 2008). Taken together these findings demonstrate that whilst typical children show a similar ERP response to syntactic violations in music and language, children with SLI do not show the same ERP responses to violations in either music or language domains, and this may result from an impairment in the cognitive mechanisms implicated in processing hierarchical structure across domains.

There are various theoretical accounts that could explain the grammatical impairments in language processing in children with SLI. Some theories suggest that language impairments observed at a behavioural level may be due to limitations in underlying domain general cognitive abilities such as processing speed, working memory or procedural memory (e.g. Ullman & Pierpont, 2005; Leonard, Kail, 1994; Gathercole & Baddeley, 1990). In contrast, domain specific accounts of SLI have suggested that at least a sub-group of children with SLI (termed 'G-SLI') show a persistent and primary grammatical impairment due to a deficit in the computational mechanism necessary for processing rule-structures in language (Marshall & van der Lely, 2007).

The 'Computational Grammatical Complexity' (CGC) hypothesis is a development and extension of the Representational Deficit for Dependent Relations (RDDR) hypothesis (Marshall and van der Lely, 2007) and suggests that a subgroup of children with grammatical-SLI (G-SLI) exhibit a domain specific deficit in syntactical computation (van der Lely, 2005). It has been suggested that this deficit prevents children with G-SLI from building complex hierarchical structures in language. Support for the CGC hypothesis comes from both behavioural and electrophysiological investigations of linguistic syntactic processing in children with SLI (van der Lely, Jones & Marshall, 2011; Fonteneau & van der Lely, 2008). When asked to judge whether sentences were either grammatically correct or incorrect, children with G-SLI tended to show a 'correct' bias, indicating a lack of awareness of the grammatical rule-violations in the incorrect sentences (Marinis & van der Lely, 2007). This interpretation is further supported by findings from a neurophysiological study in which children with G-SLI failed to show the typical Early Left Anterior Negativity (ELAN) response to syntactical violations in language (Fonteneau & van der Lely, 2008).

In contrast, the 'procedural deficit hypothesis' (PDH) is a domain general theory of SLI and is rooted in a dual-system approach to understanding language processing. A dual-system approach posits that there are distinct neural networks implicated in the online computation of rules and the storage of lexical forms. According to this account, the formation and processing of rules associated with the procedural memory system are sub-served by fronto-parietal networks, and the retrieval of lexical forms associated with the declarative memory system are sub-served by temporal posterior regions (see Ullman & Gopnick 1999 for a review). Within this dual-system framework it is the procedural memory system that is responsible for the organisation and implicit learning of rule-systems and structural knowledge across domains, for example the sequential cognitive and motor skills needed to form grammatically meaningful sentences and to execute skilled motor actions (Ullman & Pierpont, 2005). The procedural memory network may therefore be particularly important for learning and performing skills that involve sequences (Ullman & Gopnick, 1999). Indeed, the procedural deficit hypothesis posits that in certain children with SLI the ability to learn and to use implicit grammatical rules is dysfunctional whereas lexical memory remains relatively intact.

Procedural learning has been investigated experimentally by measuring learning of novel rule sequences or 'artificial grammars'. The serial reaction time task (SRT) is a measure of implicit learning of sequential information. In one SRT study of procedural learning (Tomblin, Mainela-Arnold & Zhang, 2007), children with SLI were asked to press a button that corresponded to a visually presented box in which a creature appeared. The results showed that children with SLI who had poor linguistic grammatical abilities also showed poor sequence learning on this visual-spatial reaction time task. The findings from Tomblin et al. (2007) lend support to the notion that the procedural network is implicated in learning across domains and that the learning deficits observed in children with SLI are likely to be generic and not specific to language. Importantly for the procedural deficit hypothesis, Tomblin et al. (2007) found that poor sequential leaning was evident in those children with impaired linguistic grammatical skills but not those with poor lexical knowledge, therefore further supporting a dissociation between the role of procedural and declarative memory systems in language learning. Recently, Gabriel et al. (2011) measured procedural learning of visual sequences and found that children with SLI were able to learn an 8 element visual sequence as fast and as accurately as typical controls. Counter to Tomblin et al. (2007), the findings of Gabriel et al. (2011) may indicate that procedural learning in the visual modality is relatively spared in children with SLI.

Plante, Gomez and Gerken (2002) investigated the capacity of typical adults and adults with learning disabilities to determine whether novel sentences either obeyed or violated the rules of an artificial grammar. The results showed that the adults with learning disabilities performed significantly below the comparison controls on this task, suggesting that those with language impairment were less able to acquire the rules of a new grammatical system than those with typical development. However, the extent to which this study can inform understanding of an implicit learning deficit in SLI is limited, since the sample included a broad range of students with different types of learning disability. One further difficulty with this study is that the outcome measure was based upon an explicit judgment of the grammatical correctness of the sentence. Studies have shown that implicit measures are more sensitive than explicit measures and indicate that there may be a degree of independence between explicit and implicit measures of recognition (Kunst, Wilson & Zajonc, 1980). Evans and Saffran (2009) investigated implicit statistical-learning of speech stimuli and non-speech tone stimuli in children with SLI. They found that after controlling for variability due to age and non-verbal IQ, the children with SLI showed chance performance and were significantly poorer at tracking transitional probabilities in speech and tones than typical controls, indicating that implicit learning for speech and non-speech stimuli is impaired in children with SLI.

Investigations of short-term procedural learning under controlled conditions in children with SLI have yielded somewhat contradictory results. Whilst there is evidence for disrupted implicit learning of regularities in auditory sequences (Evans & Saffran, 2009; Plante et al., 2002), studies investigating sequential learning of visual pattern information (Gabriel et al., 2011; Tomblin et al., 2007) have yielded mixed findings. To date, there has been very little exploration into the ability of children with SLI to implicitly acquire structural knowledge outside of the language domain. It has been argued that both music and action have a syntactic structure that dictates how tones should be combined to create music and how motor movements should be combined to create action sequences (Botvinik et al., 2008; Fadiga et al., 2009). If SLI is characterised by impaired procedural knowledge this ought to be reflected in atypical performance on behavioural measures that probe implicit knowledge of structural information. Alternatively if the grammatical impairments in SLI are restricted to the language domain it would be expected that children with SLI would perform like typical control children on tasks that tap implicitly acquired knowledge of structural constructs outside of the language domain.

One prediction that follows from the PDH is that a domain general deficit in the procedural memory network disrupts the acquisition and/or online processing of structural knowledge outside of the language domain. As a domain general account other skills should also be disrupted by the procedural memory deficit, and motor skill/sequencing would be predicted to be one of these. Indeed, difficulties with motor development, including motor imitation have been observed in children with SLI (Marton, 2009; Hill, 1998; see Hill 2001 for a review) and it may be that an impairment in procedural learning disrupts the acquisition and online processing of structural knowledge in the motor domain. One of the difficulties associated with the behavioural investigations of motor-action is that experiments requiring action imitation involve both accurate comprehension and accurate reproduction, suggesting that difficulties with perception and production are dissociated. One way to disentangle perception and production is to measure these facets separately.

Considering the investigation of the processing of hierarchical structural constructs in music and language, behavioural studies have investigated participants' implicit knowledge and comprehension using perceptual priming paradigms (Schellenberg et al., 2005; Edwards & Lahey, 1996). These studies have revealed that in both music and language domains, typically developing children show faster and more accurate responses to targets that are syntactically correct in relation to a prime sequence. Although it has been demonstrated that children with SLI show atypical ERPs to violations of musical syntax (Jentschke et al., 2008) it is not yet clear how this may relate to behavioural performance when asked to determine the structural harmonic correctness of a musical target chord or the structural correctness of a visual motor-action hand-grasp target picture. .

Hierarchical structural processing of music and action were investigated in children with SLI and typically developing controls.. In experiment three, the processing of visual motor-action targets was investigated by presenting participants with a sequence of pictures displaying a hand reaching for an object followed by target picture displaying a hand either correctly or incorrectly grasping the object. In experiment four, the processing of a musical target was investigated by presenting participants with a hymn-like sequence of chords followed by a target chord that was either harmonically related or unrelated to this sequence.

Experiment three: Investigating the structural processing of visual motor-action sequences in typical children and those with SLI.

Experiment three investigated the structural processing of visual motor-action sequences in children with SLI and TD matched controls. The stimuli were adapted from a previous study that investigated ERP responses to structural rule-violations in musical and motor domains (Sammler et al., 2010).

One prediction that follows from the PDH is that a domain general deficit in the procedural memory network should disrupt the regulation of motor as well as language behaviour. As previously suggested, studies have reported motor coordination difficulties in children with SLI (Marton, 2009; Hill, 2001; Hill, 1998) and these may stem from an impairment in the procedural memory network. It was hypothesized that an impairment in the procedural memory network in SLI would delay the automatisation of procedural knowledge of action and that this would predispose a continued reliance upon attention and working memory whilst processing action sequences. Therefore it was predicted that children with SLI would show faster reaction times for processing targets that were congruent with the prime sequence and slower reaction times for those that were incongruent due to the attentional cost associated with processing a structurally unexpected target (Poulin-Charronat et al., 2005).

METHOD

Participants

All participants completed this experiment, resulting in data from a total of seventeen children with SLI and sixteen controls matched for chronological age and non-verbal IQ (CA) and seventeen controls matched for verbal mental age (VMA) (see chapter three for psychometric data).

Design and procedure

The design was mixed factorial, with group as the between-subject factor (SLI, CA and VMA) and congruency (congruent and incongruent) as the within-subject factor. There were two dependent variables: the first was the reaction time of the response to the target and the second was the number of correct responses.

The task was presented as a computer game in which the children were required to determine whether an observed hand position and shape was correct or incorrect in response to an object to be grasped. Before beginning the task, the experimenter familiarised the children with the concept of correct and incorrect hand grasps by reaching for a pencil on the table and asking them to say whether the experimenter's hand 'got it right' or 'got it wrong' when they made the grasping gesture. The children were asked to press a button with a tick on it, if they thought that the experimenter 'got it right' and were asked to press a button with a picture of a cross on it if they thought that the experimenter 'got it wrong'. Participants were given feedback on their responses during this pre-test training and the training was repeated until 100% accuracy was reached.

Following the pre-test training, participants were seated at a comfortable viewing distance from a laptop computer screen. They were then given the task instructions. Participants were told that they would watch a short sequence of pictures showing a hand trying to pick up an object and that sometimes the hand was very good and did the right thing to pick up the object but sometimes the hand was very silly and either forgot to open its fingers to pick up the object, or missed the object it was reaching for. They were told that, just like the experimenter, sometimes the hand would 'get it right' and sometimes the hand would 'get it wrong', and in this game it was their job to say as quickly as possible whether the hand 'got it right' or 'got it wrong' when it tried to pick up the object. Children were asked to use the button box and to press the 'tick' button if the hand got it right, and the 'cross' button if the hand got it wrong. Participants then completed a short practice block consisting of 4 trials (2 congruent hand targets and 2 incongruent hand targets). The practice block took around 2 minutes to complete, after which the children moved on to the experimental trials. Each experimental block took around 5 minutes to complete and children were offered stickers between the practice and experimental blocks to maintain their interest in the task.

Stimuli

E-prime was used for stimulus presentation. The experiment was comprised of a practice block and 24 test trials, divided into two blocks of 12 stimuli. Each trial consisted of a 4 picture sequence displaying an object grasp trajectory. The target picture either displayed a correct grasp and was congruent with the preceding sequence or displayed an incorrect grasp and was incongruent with the preceding sequence. In the incongruent hand target pictures the hand either failed to open the fingers to grasp the object, or it opened its fingers too wide and missed the object (see figure 6-1). Each picture was presented for 1000 milliseconds, with a 1000 millisecond silent interval before the presentation of the target picture (that was also 1000 milliseconds duration). Sequences were randomised across blocks and each trial appeared twice in the experiment.

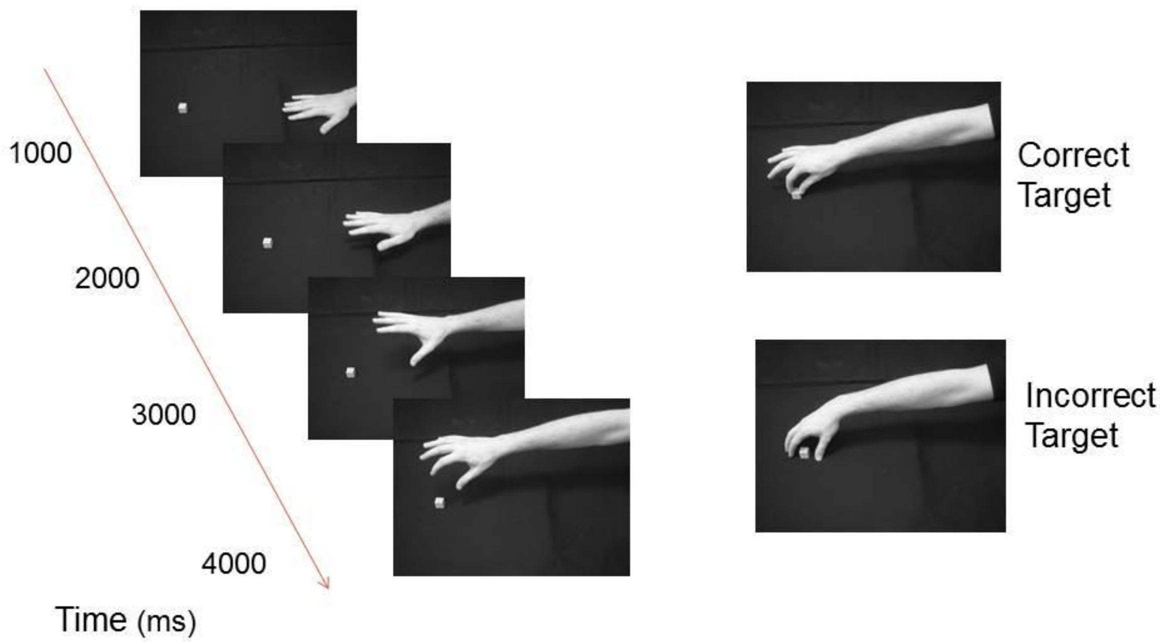


Figure 6-1. Examples of correct and incorrect trials in the visual motor-action task

RESULTS

The data were screened and Shapiro Wilk tests of normality revealed that in the CA-matched control group the RT data for congruent targets significantly deviated from normality ($p<.05$). Data screening revealed an outlier in the CA-matched control group who had an RT to a congruent target that was 3 SDs from the mean RT (Mean + 3SD = 2065). This dataset was removed from the analysis and the distribution of the data no longer significantly deviated from normality ($p>.05$).

Total accuracy scores, along with accuracy scores for correct and incorrect targets in experiment three are shown in table 6-1.

	Correct		Incorrect		Total	
	Mean	SD	Mean	SD	Mean	SD
SLI	10.94	1.39	11.00	1.37	21.94	2.05
CA	10.69	1.66	9.31	2.62	20.00	4.03
VMA	10.59	1.28	11.05	1.68	21.65	2.42

Table 6-1. Mean accuracy scores and standard deviations (SD) for congruent and incongruent targets for each group. The maximum score for each target type is 12.

This task required participants to make a judgment as to whether the target hand grasp picture was correct or incorrect. Responses to congruent and incongruent targets were combined to give one overall score for response accuracy on this task. These data were screened and found to be normally distributed. One-way t-tests comparing the total correct scores to a test value of 12 (constituting 50% accuracy) showed that all three groups were able to explicitly discriminate the correctness of the target grasp with above-chance accuracy (SLI: $t(16) = 19.746$, $p<.001$; CA: $t(15) = 7.934$, $p<.001$; VMA: $t(16) = 16.421$, $p<.001$).

A mixed ANOVA with one within-subject factor: hand position (congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. The main effect of hand position was not significant ($F(1,47)=1.270$, $p>.05$, $n_p^2=.026$) and the main effect of group was not significant ($F(2,47)=2.065$, $p>.05$, $n_p^2=.081$), however there was a significant interaction between hand position and group ($F(2,47) = 4.909$, $p<.05$, $n_p^2=.173$). Further Bonferonni-corrected paired-samples t-tests carried out on the interaction demonstrated that the CA-matched control group were significantly more accurate at determining the correctness of the target grasp when the hand target was congruent (M = 10.69; SD = 1.66) than when it was incongruent (M = 9.31; SD = 2.62) ($t(15)=3.149$, $p<.01$). The younger VMA-matched controls and the SLI group did not show a significant difference in their explicit recognition for congruent versus incongruent hand-grasp targets ($p>.05$).

D’ scores were calculated using the same procedure as described in Chapter 5, as an indicator of sensitivity to correct and incorrect hand targets. A Oneway ANOVA was carried out to compare d’ scores across the SLI, CA and VMA-matched controls. The analysis revealed that there was a difference across the three groups that was approaching significance $F(2,48)=2.985$, $p=.06$. Further Tukey PostHoc comparisons revealed that the only difference that was approaching significance was between the younger VMA-matched and the older CA-matched controls ($p=.066$). Overall this analysis indicates that the SLI group did not differ from controls in their sensitivity to correct and incorrect hand targets.

To investigate the impact of structurally unexpected targets on implicit response times, the reaction times to accurately identify whether or not the hand-grasp target was correct were compared across all three groups. A mean reaction time was calculated (correct responses only) separately for each child for both conditions. Responses that were longer than 3 standard deviations from each child’s mean reaction time were excluded (Schellenberg et al., 2005). Table 6-2 and figure 6-2 show the implicit reaction time data for the three groups across the two experimental conditions.

	Congruent		Incongruent	
	Mean	SD	Mean	SD
SLI	1700.16	528.78	1864.51	679.54
CA	1108.54	308.89	1263.56	358.02
VMA	2331.33	605.77	2376.67	472.43

Table 6-2. Mean reaction times (ms) and standard deviations to the hand-grasp target

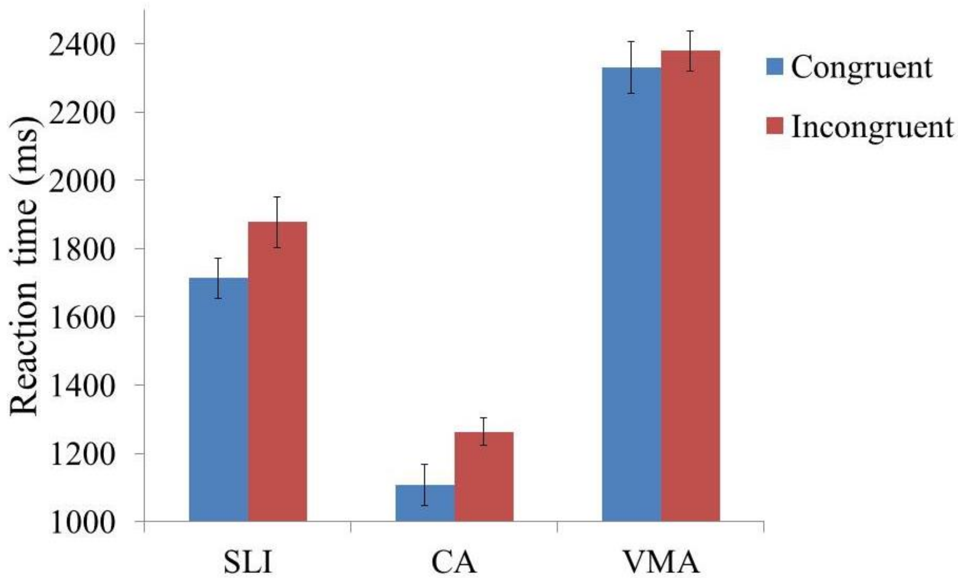


Figure 6-2. Mean reaction times and standard error (SEMs) for congruent and incongruent hand-grasp targets.

A mixed ANOVA with one within-subject factor: hand position (congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. This analysis revealed that the main effect of hand position was not significant ($F(1,46) = 3.012$, $p>.05$, $n_p^2=.061$), demonstrating that overall reaction times were not significantly different for judging congruent over incongruent targets. There was a significant main effect of group ($F(2,46) = 25.576$, $p<.001$, $n_p^2=.527$). Tukey HSD post-hoc comparisons revealed significantly slower reaction times for the SLI compared with the CA group ($p<.01$) and the VMA group ($p<.01$) and significantly slower reaction times for the VMA group compared with the CA group ($p<.001$). There was no significant interaction between hand position and group ($F(2,46)=.318, p>.05$, $n_p^2=.014$). However, as the hand position and group interaction was significant on the explicit measure, post-hoc tests were also carried out to further investigate RTs for processing structurally congruent and incongruent visual motor-action targets across the three groups. The decision was taken to carry out further post-hoc analyses on the implicit reaction time measures as this is the first clinical study of this kind and so this further analysis was considered to be valuable, although the findings must be interpreted cautiously and any conclusions recognized as indicative rather than concrete.

Bonferonni-corrected ($p=.025$) paired-samples t-tests revealed that the SLI group showed faster reaction times for the congruent ($M = 1700.16$; $SD = 528.78$) over incongruent ($M = 1864.51$; $SD = 679.54$) hand targets at a level approaching significance ($t(16) =-1.973=.06$). The CA and VMA-matched TD controls did not show a significant difference in implicit RTs for congruent versus incongruent targets (CA: $t(14) = -1.806$, $p>.05$; VMA: $t(16) = -.529$, $p>.05$).

To further investigate the relationships between reaction time and accuracy judgments for correct and incorrect visual motor-action targets and age and auditory memory, correlational analyses were carried out. A measure of the strength of the structural correctness of the visual motor-action target on RTs was derived by subtracting the RTs to congruent targets from the reaction times to incongruent targets to create a single RT discrepancy score for each participant. Explicit recognition was measured by summing the correct responses for congruent and incongruent targets to create one total accuracy score. Data from the CA-matched and VMA-matched controls were collapsed to create one typically developing (TD) control group and correlational analyses were carried out on the TD controls and the SLI group. The decision was taken to measure correlations with auditory STM in order to rule-out the possibility that general limitations in short-term memory may be related to the processing of structural regularities in visual motor-action sequences.

The RT discrepancy scores were not significantly correlated with the total accuracy scores in the TD controls ($p>.05$). However, in the SLI group these two capacities were significantly negatively correlated ($p<.05$). Neither age nor auditory short-term memory was significantly related to the strength of the implicit priming effect or the accuracy of explicit target judgments in either the TD or the SLI groups. The findings from the correlational analyses in the TD controls and the SLI group can be seen in tables 6-3a and table 6-3b.

	Age	Implicit	Explicit	DS
Age	1.00	.079	-.344*	.616**
Implicit		1.00	.039	-.097
Explicit			1.00	.026
DS				1.00

*p<0.10, **p<0.05, ***p<0.001

Table 6-3a. Correlation matrix for the typically developing (TD) children showing the relationships between age, implicit priming of visual motor-action targets, explicit recognition of visual motor-action targets and digit span (DS).

	Age	Implicit	Explicit	DS
Age	1.00	.167	-.238	.027
Implicit		1.00	-.434*	.101
Explicit			1.00	-.031
DS				1.00

*p<0.10; **p<0.05, ***p<0.001

Table 6-3b. Correlation matrix for the SLI children showing the relationships between age, implicit priming of visual motor-action targets, explicit recognition of visual motor-action targets and digit span (DS).

SUMMARY

All groups were able to make an explicit judgment about the correctness of the target hand-grasp picture with above-chance accuracy, with the SLI group and the VMA-matched controls performing close to ceiling on this measure. The CA-matched controls, but not the VMA-matched controls or the SLI group, showed significantly better response accuracy for congruent over incongruent targets. The CA-matched controls also showed faster overall RTs for both congruent and incongruent targets than the VMA-matched controls and SLI group. Taken together, these findings may indicate that because the CA-matched controls were responding so quickly to both congruent and incongruent targets this meant that they were more susceptible to the additional attentional cost associated with making an explicit response to an unexpected target (Poulin-Charronat et al., 2005; Escoffier & Tillman, 2008). This increased attentional cost may have been reflected in fewer explicit correct responses for incongruent targets, but may have had less of an impact upon the automatic and unconscious implicit reaction times to process the target (see Kaufman et al., 2010 for a review).

Analysis of the implicit reaction times (RTs) to congruent and incongruent targets demonstrated that the SLI group showed significantly faster reaction times to congruent hand-grasp targets than incongruent. The observation that the SLI group and not the TD controls showed this processing cost may indicate that in the SLI children the procedural knowledge needed to perform the task had not become fully automatized. In the controls it is possible that through repeated exposure and skill learning, the procedural knowledge needed to implicitly react to the target hand-grasp picture was fully automatized and so did not load upon working memory and/or attention (Kaufman et al., 2010). Conversely in the SLI children a delay in the automatisation of procedural knowledge may have resulted in an increased reliance upon attention and memory for processing the structural regularity of the sequence and corresponding target (Anderson, 1982). Support for the notion that the SLI group were relying on similar cognitive mechanisms for both implicit and explicit processing of the visual motor-action targets comes from the observation that the strength of the implicit RT processing cost was significantly correlated with the total number of explicit correct responses. In the SLI group those children who showed a larger discrepancy in reaction times for congruent and incongruent targets (e.g. faster RTs to congruent over incongruent targets) also made fewer correct explicit judgments about the correctness of the targets. This could indicate that mechanisms of attention and visual working memory were implicated in the online monitoring of motor-action sequences in the SLI group at both implicit and explicit levels so that those children who showed the greatest attentional cost for processing an unexpected, incongruent target also made more explicit response errors. The TD controls did not show this same correlation between implicit and explicit responses.

The children in the SLI group were found to have an impairment in auditory short-term memory (see chapter three) and it is not clear whether or not this reflects more domain general short-term memory and attentional difficulties in SLI. A general impairment in attention and memory could disrupt the processing of procedural knowledge across auditory and visual modalities. In order to address the question of whether or not limitations in auditory short-term memory were related to the processing of procedural knowledge of visual motor-action sequences, the scores from the digit span task were included in correlational analyses. It was found that digit span was not significantly correlated with performance on the visual motor-action task in either the SLI or the typically developing groups. This may indicate that there are separate mechanisms within short-term and working memory for processing auditory and visual information and that the limitations in auditory short-term memory do not impact upon the processing of visual stimuli in the children with SLI.

Relating the findings back to the theoretical accounts of SLI outlined in the introduction, it is possible that the presence of an RT processing cost in the SLI group but not the TD controls reflects a delay in procedural learning and the automatisation of procedural knowledge in the motor domain in children with SLI. This interpretation would be consistent with the procedural deficit hypothesis, which proposes that individuals with SLI show impaired procedural memory outside of the language domain (Ullman & Pierpont, 2005). The next question, addressed in experiment four, was whether or not this apparent delay in procedural learning observed would be reflected in the musical domain in children with SLI.

Experiment four: Investigating music-syntactic processing in typical children and those with SLI.

Experiment four investigated music-syntactic processing in children with SLI using a paradigm that has been used widely in music research with typical populations and has been successfully adapted for use with children with neurodevelopmental disorders (Heaton et al., 2007).

Previous research has shown that by the age of around 6-7 years typical children have acquired a cognitive representation or 'schema' of Western tonality and can readily demonstrate explicit recognition of whether or not a target chord is congruent or incongruent with the broader harmonic context (Corrigall & Trainor, 2010; Heaton et al., 2007). Furthermore, implicit priming studies have shown that this representation of tonality is reflected in greater accuracy and faster judgments for target chords that are congruent with prime sequence than those that are incongruent with them (Schellenberg et al., 2005). The first aim of experiment four was to investigate the processing of musical targets that were either structurally expected or unexpected following a preceding sequence. Based on previous research it was hypothesized that typical children would show faster and more accurate responses to congruent musical target chords than incongruent target chords.

It has been suggested that SLI may be associated with a domain general impairment in the procedural memory network that is responsible for the acquisition and online processing of rule-structures across domains (Ullman & Pierpont, 2005). One prediction that arises from this theoretical account of SLI is that children with this disorder will show impairments in processing structural regularities outside of the language domain. As with the capacity to understand the planning and execution of skilled actions, tested in experiment three, music is organised according to a rule-system and, in line with the interpretation of the SLI data on the implicit measure of the visual motor-action task, it was predicted that disruption in implicit learning should result in delayed acquisition of knowledge about musical structure. Research has demonstrated that 5-year old children with SLI do not show the same electrophysiological response to incongruent chords as typically developing children, and this has been interpreted as a failure to build a cognitive representation of musical structure (Jentschke et al., 2008). Whilst the results from experiment three revealed clear differences between children with SLI and TD controls, the observation of an RT processing cost in the children with SLI indicated that they possessed some ability to acquire implicit knowledge within this domain, although the automatisation of this knowledge was significantly delayed. The second aim of experiment four was therefore to determine the extent to which structural irregularities in the musical domain impacted upon the processing of a target in children with SLI. From the procedural memory deficit account and findings from previous studies of music perception in SLI, it was hypothesized that a delay in procedural learning of musical structural knowledge would be manifest in a failure to explicitly recognise the harmonic correctness of target chords and the absence of RT cost associated with processing a structurally unexpected musical target chord in the children with SLI.

Finally, whilst this chapter is concerned with testing the procedural deficit hypothesis account of SLI, the results from experiments one and two described in chapters four and five, revealed delays in pitch-interval direction discrimination and deficits in auditory short-term memory in children with SLI. As such difficulties are likely to impact upon the early acquisition and processing of information about hierarchical tonal relations in children with SLI, the relationship between perceptual and memory skills and musical syntax processing were also addressed. It was hypothesized that performance on measures of pitch-interval discrimination and auditory short-term memory would be related to the processing of musical targets in children with SLI.

PILOT STUDY

A task that involved the processing of musical structural regularities, with a similar methodological design to that adopted in prior studies of musical syntactic comprehension (Heaton et al., 2007; Schellenberg et al., 2005) was developed for experiment four. In order to ensure that the paradigm developed was suitable for use with children with SLI, a pilot study was conducted. A total of 12 participants were included in this study: 6 children diagnosed with SLI (6-10-yrs; Mean age 7:7) and 6 chronological age (CA) matched controls (6-10-yrs; Mean age 7:2).

24 chord sequences comprised of 4 chord sequences ending in a target chord were digitally recorded in piano voice, using Sibelius student version 6. Tempo was set at 120 quarter beats per min. In half of the trials the target chord was harmonically related to the preceding sequence (i.e. was the tonic chord of that key) and in half of the trials the target chord was chosen to be the least harmonically related chord. Participants were told that they would hear some music that would either end in the right way or the wrong way, and were asked to point to a picture of a tick if they thought that "the music finished in the right way", and to point to a picture of a cross if they through that "the music finished in the wrong way".

One of the difficulties encountered during the pilot testing was that the time needed to complete the task was too long for children at this stage of development. To address this problem the task was computerised to create a game with visual characters that marked the progression through each of the chord sequences (see figure 6-3 below for an example). The use of E-prime for stimulus presentation increased the speed with which participants were able to progress through the trials and the introduction of a button box and visual characters helped to alleviate boredom and to maintain the childrens' attention on the task.

A second question that arose during pilot testing concerned a potential dissociation between the participants' ability to explicitly state whether or not the target chord sounded right or wrong and their implicit awareness of musical structure. To address this potential confound an implicit reaction time measure was incorporated into the task.

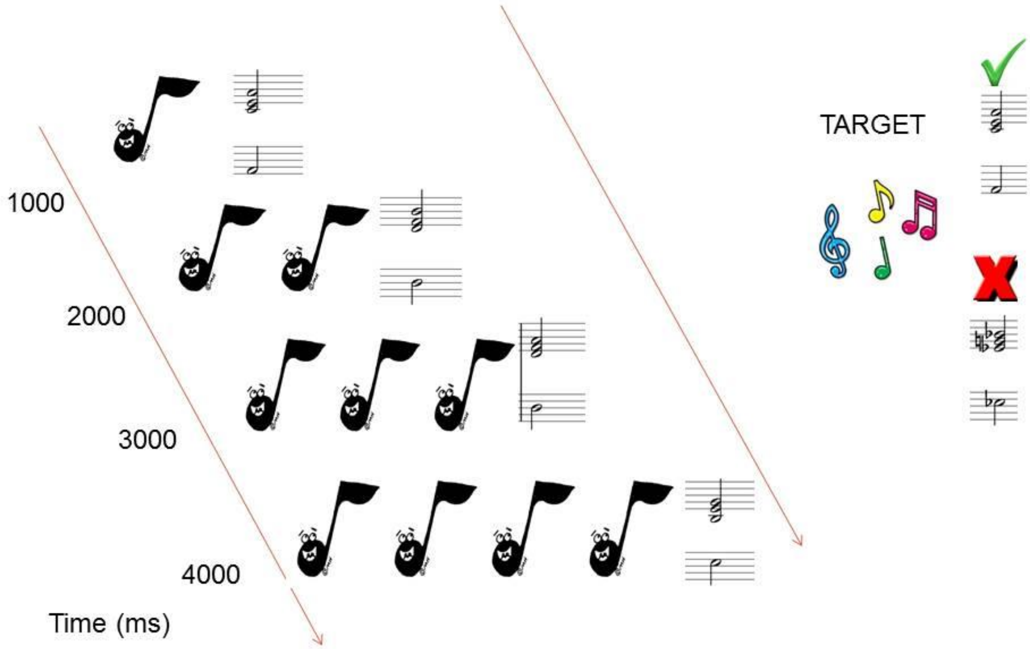


Figure 6-3. Examples of the pictures that accompanied each of the chords in the prime sequence and the picture that accompanied both 'correct' and 'incorrect' target chords.

METHOD

Participants

Two of the children with SLI and five of the typically developing controls (2 CA-matched and 3 VMA-matched) did not complete the task and so their data were not included in the analysis. In total, data from fifteen children with SLI, fourteen CA matched controls and fourteen VMA matched controls were included in the analysis. The CA-matched control group were matched to the SLI group for non-verbal IQ using the Ravens Matrices ($t(29) = -2.03$, $p>.05$) and the VMA-matched controls were matched for verbal-mental age using the BPVS ($t(27) = -1.147$, $p>.05$).

Design and procedure

The design was mixed factorial, with group as the between-subject factor (SLI, CA and VMA) and congruency (congruent and incongruent) as the within-subject factor. There were two dependent variables: the first was the reaction time of the response to the target and the second was the number of correct responses.

The task was presented as a computer game in which the children were asked to listen to the music and to try to decide if they thought that it sounded 'right' or 'wrong' at the end. Children were seated at a comfortable viewing distance from a lap top computer and were then given the task instructions. They were told that they would hear a short sequence of music, followed by short period of silence and then the end of the music would be played. Sometimes the music would finish in the right way and sometimes the music would finish in the wrong way. Children were asked to use the button box and to press the 'tick' button if the music finished in the right way and the 'cross' button if the music finished in the wrong way. They were asked to try to press the button as quickly as they could.

The children then put on headphones and the volume was set to a comfortable listening level, they completed a short practice block consisting of 4 trials (2 congruent 2 incongruent). The practice block took around 2 minutes to complete and each experimental block took around 5 minutes to complete. The children were offered stickers between the practice and experimental blocks to maintain their interest.

Stimuli

Chords were digitally recorded in piano voice, using 'MuseScore' (freely downloadable, www.musescore.com) and E-prime was used for stimulus presentation. The experiment comprised 24 trials, divided into two blocks of 12 and a separate practice block. Each trial consisted of a 4 chord sequence with a Bach progression (I, IIb, IV, V) and a target chord that was either congruent with the sequence and was harmonically related (the tonic: I), or incongruent with the sequence and was as harmonically unrelated as possible (Neapolitan chord; the furthest tonic on the circle of fifths). Each chord was presented for 1000 milliseconds, with a 1000 millisecond silent interval before the presentation of the target chord (that was also 1000 milliseconds duration). Chord sequences were randomised across major keys and each trial appeared twice in the experiment. Sound delivery was via an external sound card (Edirol UA-4FX) and Sennheiser HD265 headphones set at a comfortable listening level (see figure 6-4).

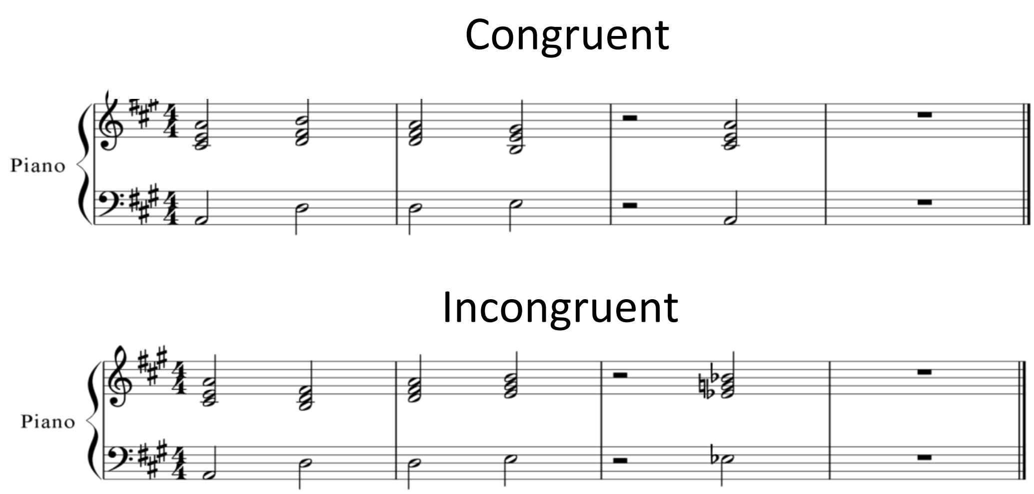


Figure 6-4. Congruent and incongruent trials for the music syntactic processing task

RESULTS

The data was screened to check for outliers and the normality of the distributions for each of the variables across the three groups. Shapiro Wilk tests of normality revealed that the RTs for incongruent targets in the CA-matched control group significantly deviated from a normal distribution. Data screening revealed an outlier in the dataset; one participant in the CA-matched control group had an RT to an incongruent target that was 3 SDs from the mean RT (Mean + 3SD = 2722). This dataset was removed from the analysis and the distribution of the data no longer significantly deviated from normality ($p>.05$). The means and standard deviations for explicit correct response scores for congruent and incongruent targets can be seen in table 6-4.

	Congruent		Incongruent		Total	
	Mean	SD	Mean	SD	Mean	SD
SLI	7.67	2.13	5.07	2.12	12.73	2.43
CA	8.43	2.5	7.5	2.79	15.93	4.32
VMA	7.43	2.59	6.14	2.66	13.57	3.2

Table 6-4. Mean accuracy scores (maximum score of 12) and standard deviations for congruent and incongruent targets.

This task required participants to make an explicit judgment about whether the target chord sounded correct or incorrect. The correct scores for both the congruent and incongruent targets were combined to give one score for response accuracy on this task. These data were screened and found to be normally distributed. One-way t-tests comparing the total correct scores to a test value of 12 (constituting 50% accuracy) showed that the group mean for the SLI group was not significantly better than chance on this explicit measure ($t(14) = 1.167$, $p=.253$). However, within the SLI group, 7 children (41% of the total SLI sample), determined the correctness of the final target chord at a level that was significantly better than chance ($t(6) = 3.422$, $p<.05$). The group mean score for the CA-matched control group was above chance overall ($t(13) = 3.400$, $p<.01$), with 9 children (60%) showing above-chance performance ($t(9) = 7.494$, $p<.001$); whilst group mean scores for the VMA matched control children were at chance level ($t(13) = 1.835$, p.05), with 8 children (62%) showing above-chance performance ($t(7) = 4.005$, $p<.01$).

A mixed ANOVA with one within-subject factor: chord (congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. This analysis revealed a significant main effect of chord ($F(1,40)=8.582$, $p<.001$, $n_p^2 = .176$), indicating that participants showed better explicit accuracy for judging the correctness of congruent over incongruent target chords (see table 5). There was also a main effect of group ($F(2,40)=3.423$, $p<.05$, $n_p^2=.146$), demonstrating that there were significant differences in the responses across the SLI and CA-matched and VMA-matched control groups. Tukey HSD post-hoc comparisons revealed significantly poorer correct recognition scores in the SLI group in comparison with the CA-matched controls ($p<.05$), but not the VMA-matched controls ($p>.05$). The CA and VMA-matched controls did not differ significantly from one another ($p>.05$). The interaction between chord and group was not significant ($F(2,40)=.876$, $p>.05$, $n_p^2=.042$).

D' scores were calculated using the same procedure as described in Chapter 5, as an indicator of sensitivity to congruent and incongruent targets. A One-way ANOVA was carried out to compare *d'* scores across the SLI, CA and VMA-matched controls. The analysis revealed that there was a significant difference across the three groups F(2,42)=4.035, p=.020. Further Tukey PostHoc comparisons revealed that the *d'* scores of the SLI group were significantly different than the CA-matched controls (p=.022), demonstrating that the SLI group showed poorer sensitivity to incongruent and congruent chord targets as compared with the CA-matched controls.

To investigate implicit RT responses to the musical targets, the reaction times for congruent and incongruent targets were compared in the SLI group, the CA-matched controls and the VMA-matched controls. A mean reaction time was calculated (correct responses only) separately for each child for both conditions and responses that were longer than 3 standard deviations (SDs) from each child's mean reaction time were excluded (see Schellenberg et al., 2005). Figure 6-5 and table 6-5 show reactions times for the three groups for congruent and incongruent targets.

	Congruent		Incongruent	
	Mean	SD	Mean	SD
SLI	2180	644.79	2023	961.93
CA	1327	640.25	1445	573.97
VMA	2333	737.4	2693	906.6

Table 6-5. Mean reaction times (ms) and standard deviations to the target chord

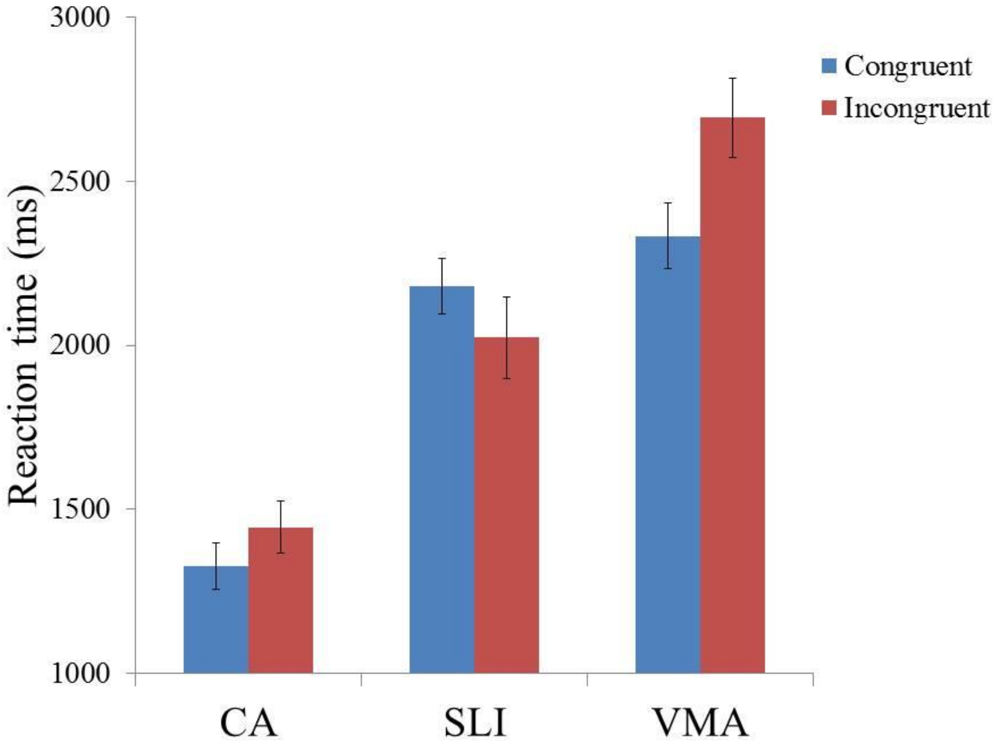


Figure 6-5. Mean reaction times (SEMs) to the target chord

A mixed ANOVA with one within-subject factor: chord (congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. This analysis revealed a significant main effect of chord ($F(1,38) = 4.773$, $p<.05$, $n_p^2=.112$), demonstrating that overall reaction times were faster for congruent over incongruent target chords. There was also a main effect of group ($F(2,38) = 10.278$, p=.<.001, $n_p^2= .351$). Tukey HSD post-hoc comparisons revealed that the CA-matched controls showed faster reaction times than the VMA-matched controls ($p<.01$) and the SLI group ($p<.05$), but the SLI group did not differ from the VMA-matched controls ($p>.05$). There was no significant interaction between chord and group ($F(2,38)=.926$, $p>.05$, $n_p^2= .046$), however visual inspection of the reaction times for congruent and incongruent targets revealed a different pattern of performance across the three groups and so post-hoc analyses were carried out to explore this further. Given the small sample sizes, the findings from the post-hoc analyses must be interpreted with caution.

Bonferonni-corrected paired-samples t-tests ($p=.008$) demonstrated that the typically developing VMA-matched controls showed faster reaction times for congruent (M= 2333; SD = 737.4) versus incongruent targets (M = 2693; SD =906.6) at a level approaching significance ($t(13)=-1.838$, $p=.07$). In contrast the CA-matched controls did not show a significant difference in RTs for congruent (M=1327; SD = 640) over incongruent (M=1445; SD=573) targets ($t(12)=-.977$, $p>.05$) and this result was also observed for the SLI group (congruent; M=2180; SD =644/ incongruent;=2023; SD=961) ($t(13)=-.800$, $p>.05$). Whilst a significant RT difference across congruent and incongruent trials was only observed for the VMA group, mean RT scores for the CA group were also lower on the incongruent than congruent trials and it may be that there was a lack of statistical power due to the small sample sizes for each of the groups. To increase the statistical power the data were collapsed to form one typically developing control group, and a paired-samples t-test was carried out. This analysis revealed that overall the TD control group showed significantly faster RTs for congruent over incongruent targets ($t(26)=-2.076$, $p<.05$).

Relationships between pitch-interval direction discrimination, musical syntactic processing and digit span.

To investigate the relationships between performance on the pitch-interval direction discrimination task and the digit span measure of auditory short-term memory alongside the RT processing cost for structurally incongruent targets and the number of correct explicit responses, correlational analyses were carried out. In order to correlate these measures, the explicit measure was calculated by totaling the correct responses to incongruent and congruent targets, the RT processing cost was measured by calculating RT discrepancy scores for responses to congruent and incongruent targets. The scores for the digit span, pitch-interval direction discrimination, implicit and explicit processing can be found in table 6-6.

	DS	Pitch-interval	Implicit RT	Explicit CR
SLI	10.83 (1.9)	22.07 (5.65)	99.79 (466)	12.73 (2.4)
CA	17.57 (1.3)	27.38 (4.5)	117.1 (432)	15.93 (4.3)
VMA	12.38 (2.8)	22.83 (6.01)	360.31 (733)	13.57 (3.2)

Table 6-6. Raw scores on the digit span (DS) and pitch-interval discrimination tasks and implicit reaction time discrepancy scores (RT) and explicit correct responses (CR) for the harmonic priming task.

These correlational analyses demonstrated that in the TD controls the strength of the implicit RT processing cost was significantly negatively correlated with the explicit recognition of the correctness of the target ($r(27)=-.418$, $p<.05$). Digit span was significantly positively correlated with explicit recognition ($p<.05$), however partial correlations revealed that this relationship was no longer significant once variability due to age was controlled ($p>.05$) (see tables 6-7a & 6-7b). Performance on the pitch-interval direction discrimination task was not significantly correlated with the strength of the implicit RT processing cost or explicit recognition of the harmonic correctness of the target chords in either the TD or the SLI groups ($P>.05$).

In the SLI group the strength of the implicit RT processing cost was not significantly correlated with explicit correct response scores, however there was a negative correlation with digit span ($p<.05$).

	Age	Implicit	Explicit	DS	Pitch-interval
Age	1.00	-.115	.484*	.615**	.425*
Implicit		1.00	-.418*	-.196	-.269
Explicit			1.00	.316*	.038
DS				1.00	.568**
Pitch-Interval					1.00

Note: *p<0.05, **p<0.01

Table 6-7a. Correlation matrix for the typically developing (TD) children showing the associations between age, implicit RT cost for processing musical chord targets, explicit recognition of the correctness of musical chords, digit span (DS) and pitch-interval discrimination.

	Age	Implicit	Explicit	DS	Pitch-interval
Age	1.00	.037	-.596**	.020	-.331
Implicit		1.00	-.057	-.575*	-.255
Explicit			1.00	-.118	.188
DS				1.00	.295
Pitch-interval					1.00

Note: *p<0.05, **p<0.01

Table 6-7b. Correlation matrix for the SLI children showing the relationships between age, implicit RT cost for processing musical chord targets, explicit recognition of the correctness of musical chords, digit span (DS) and pitch-interval discrimination.

<u>Relationships between performance on the visual motor-action and musical syntactic processing tasks in the SLI group and the typically developing controls</u>

One prediction that arises from a procedural deficit account of SLI is that impairments in the procedural memory network impact upon the acquisition and/or processing or procedural knowledge across domains (Ullman & Pierpont, 2005). If there are shared mechanisms in the procedural memory network implicated in the processing of structures across language, music and action domains then it would be expected that performance on each of these measures would be significantly correlated in typically developing children and in children with SLI. The aim of the third research question motivating this chapter was to investigate the relationship between the processing of sturcutral regularity in visual motor-action stimuli and musical stimuli in children with SLI and TD and then to measure the extent to which performance on the musical and visual motor-action is associated with grammatical processing in language in children with SLI.

The CA and VMA-matched controls showed a similar pattern of performance on this task and so their data were collapsed to form one TD group. In the initial analysis, exploring this relationship in TD children, explicit correct responses for visual motor-action and musical targets were not significantly correlated with one another (r(27)=.006, p>.05). Neither were implicit RT discrepancy scores for processing visual motor-action and musical targets significantly correlated (r(27)=.166, p>.05). Age was significantly positively correlated with explicit correct responses for the the musical task (r(27)=.391, p<.05) but not the visual motor-action task (r(28)=-.218, p>.05).

In the SLI group the TROG-II measure of linguistic grammatical comprehension was included in the analysis and these data can be seen in table 6-8.

Visual motor-action		Music		Language
Explicit CR	Implicit RT	Explicit CR	Implicit RT	Blocks passed
21.94 (2.07)	164.35 (343)	12.73 (2.4)	99.79 (4.6)	8.8 (3.38)

Table 6-8. Means and Standard Deviations (SDs) for implicit discrepancy scores in (ms) (Implicit RT) and total explicit correct response accuracy (maximum score of 24) (Explicit CR) to visual motor-action targets in experiment three, musical targets in experiment four and the total number of blocks passed on the TROG-II measure of linguistic grammatical comprehension (maximum score of 20) in the SLI group.

Correlational analyses revealed that the explicit correct responses for visual motor-action and musical targets were not significantly correlated with one another (r(14)=-.078, p>.05) and implicit RT discrepancy scores for processing visual motor action and musical targets were not significantly correlated with one another (r(14)=.-.016, p>.05). To investigate the relationship between grammatical comprehension in music and language in the SLI group, the total number of block passed on the TROG-II measure of linguistic syntactic comprehension were included in the analysis. Correlational analyses demonstrated that there was a significant negative correlation between the total number of blocks passed on the TROG-II and the total explicit correct recognition scores from the music task r(15)=-.640, p<.05).

DISCUSSION

The two experiments reported in this chapter investigated implicit and explicit processing of structural regularity in visual motor-action and musical sequences in a group of children with SLI and typically developing children matched for either chronological age (CA) or verbal-mental age (VMA).

Experiment three investigated the processing of structural regularity of visual motor-action sequences. The findings indicated that all children across the three groups showed better than chance accuracy when making an explicit judgment about the correctness of the visual motor-action target hand-grasp picture. At an explicit level, the CA-matched controls showed significantly higher response accuracy for correct hand-grasp targets than incorrect. This may reflect a de-automatisiation of procedural knowledge as participants were asked to focus on a specific feature of the acquired skill (e.g. the final hand-grasp following a well-learned reaching motion) and to make an explicit judgment about it (Ford, Hodges & Williamson, 2005). In requiring skilled participants to make an explicit judgment about the final hand-grasp target, it may be that the procedural knowledge of the action sequence was brought back into working memory and so there was a cost associated with processing a target that was incongruent with the preceding sequence, leading to better explicit accuracy for congruent over incongruent visual motor-action targets. Escoffier and Tillman (2008) showed that, for adults, the ability to make an explicit judgment about a musical target was facilitated when it followed a congruent preceding sequence. In the current study, increased global efficiency in processing stimuli may have resulted in adult-like performance in the CA-matched control group in the visual motor-action task. It may be that the younger VMA-matched controls and the children with SLI were more motivated to make a correct explicit judgment (rather than a fast response) and so may have responded more slowly to both congruent and incongruent targets in order to ensure that their explicit response was correct. If this is the case, any attentional cost associated with processing an unexpected target would not necessarily be evident at an explicit level in these children.

At an implicit level, the SLI group showed significantly faster RTs to congruent versus incongruent visual motor-action targets, demonstrating that the congruency of the target with the prime sequence did impact upon the implicit responses. The extent to which implicit and explicit processing of visual motor-action stimuli were related was investigated using correlational analyses. These analyses showed that implicit awareness did not significantly correlate with the ability to make an explicit judgment about the correctness of the hand-grasp target in the TD controls but were significantly negatively correlated in the SLI group. For children with SLI the ability to explicitly judge the correctness of the visual motor-action target was negatively related to the RT processing cost for structurally unexpected targets. Thus children who showed a larger RT cost for processing an incorrect visual motor-action target also showed fewer correct explicit responses overall. This finding may reflect reliance upon similar cognitive mechanisms of attention and working memory for processing visual motor-action stimuli at implicit and explicit levels in the children with SLI.

The aim of experiment four was to investigate implicit and explicit awareness of musical structure. Based on previous research demonstrating atypical ERPs to harmonic structural irregularities in children with SLI (Jentschke et al., 2008), it was hypothesised that impaired procedural knowledge of musical structure would be manifest in the absence of a RT cost for processing structurally unexpected targets or explicit knowledge of the correctness of musical targets in the children with SLI but not the TD controls. Group analyses demonstrated that the CA-matched controls, but not the VMA-matched or the SLI group, were able to explicitly determine the correctness of the target chord with above-chance accuracy. Further individual analyses showed that although at a group level the children with SLI were performing at chance, within this sample 41% of children showed better than chance accuracy in their ability to explicitly judge the correctness of correct and incorrect target chords. Similarly, in the VMA-matched controls, 62% of the sample showed better than chance explicit judgments. Overall the SLI group showed better explicit response accuracy for correct over incorrect target chords. This finding reflects the increased likelihood of the children in the SLI group to rate the final targets as sounding ‘right’, a similar effect was found in a study in which children with SLI were asked to make explicit judgments about the correctness of sentences that were either grammatically correct or incorrect (Marinis & van der Lely, 2007). Marinis and van der Lely (2007) interpreted this effect as indicating that the children in the SLI group were unable to recognize when a sentence was grammatically incorrect.

Investigation of implicit awareness of musical structure demonstrated that both the VMA-matched and CA-matched TD controls showed faster responses to congruent over incongruent targets, although this only approached significance in the VMA-matched controls. The SLI group did not show this same implicit processing advantage for congruent over incongruent musical targets. One possible interpretation of the results showing an explicit but not implicit congruence advantage for children with SLI and an implicit but not explicit congruence advantage for the TD controls is that for TD controls, but not children with SLI, implicitly acquired knowledge of musical structure conferred a processing advantage for targets that were congruent with the preceding sequence.

The findings from experiment three showed that SLI may be associated with a delay in the acquisition and automatisation of procedural knowledge of action. The findings from experiment four demonstrated that in comparison to TD controls, children with SLI showed an atypical pattern of implicit and explicit responses to musical targets which may indicate impaired procedural knowledge in the musical domain (Jentschke et al., 2008; Miranda & Ullman, 2007). The analysis showed that 59% of children in the SLI group were performing at chance when asked to explicitly determine the correctness of the final target chord however, 41% of the SLI group showed above-chance explicit recognition of the harmonic correctness of the final target chord. Thus it seems that within the SLI group there were some children who were able to explicitly recognize harmonic structural regularities in music.

To address the question of whether or not implicit and explicit processing of musical and visual motor-action information were related, correlational analyses were carried out on the data from experiments three and four. These analyses failed to reveal significant correlations across visual motor-action and musical tasks for either the TD controls or the children with SLI. Thus it seems that the processing of procedural knowledge in the visual motor-action paradigm is not related to the processing of procedural knowledge in the musical paradigm at either implicit or explicit levels in TD children and children with SLI. This could indicate that there are separable networks within a broader procedural memory network dedicated to visuo-spatial and auditory information (Janascek & Nemeth, 2013; Sammler, et al., 2010), equally it may reflect different involvement of visuo-spatial and auditory working memory processes in the online processing of procedural information across modalities (Kaufman et al., 2013; Archibald & Gathercole, 2006).

Correlational analyses revealed that in the TD children the ability to explicitly determine the correctness of the target chord was significantly positively correlated with age, indicating that there are age-related improvements in explicit recognition of musical structure in typical development. However in the SLI group explicit recognition was negatively correlated with age, indicating that the younger children in this sample showed better explicit recognition of musical structure. When investigating the relationship between implicit awareness and explicit recognition of musical structure it was found that these two capacities were negatively correlated in TD children. A similar negative correlation was found for children with SLI when processing visual-motor-action stimuli, and it may reflect the separable nature of implicit and explicit processing and the role of additional cognitive factors such as working memory when activating and maintaining existing procedural knowledge in order to make an explicit response (Janascek & Nemeth, 2013).

To investigate whether or not impaired grammatical comprehension in language was related to the capacity to process grammatical constructs outside of the language domain in children with SLI correlational analyses between the visual motor-action and musical priming tasks and the TROG-II measure of linguistic grammatical comprehension were carried out. This analysis demonstrated that performance on the TROG-II was significantly negatively correlated with explicit recognition of structural regularities in music but not visual motor-action sequences in children with SLI. Thus it seems that in the SLI group those children who showed better explicit recognition of musical structure also showed the poorest comprehension of linguistic grammar.

Interpretation of the error patterns on the TROG-II (detailed in chapter three) indicated that the poor performance of the SLI group on this measure may be attributed to cognitive limitations in auditory memory rather than a lack of grammatical knowledge (Montgomery & Evans, 2009; Bishop, 2003). The observation that performance on the TROG-II is positively correlated with digit span (at a level approaching significance) supports the notion that limitations in auditory short-term memory may disrupt performance on the TROG-II in the SLI group (see chapter three). It is possible that the negative relationship between performance on the TROG-II and explicit recognition of the correctness of musical targets in the SLI group reflects a different method for processing auditory information that may be beneficial for musical comprehension and yet detrimental to spoken sentence comprehension. For example attending to the pitch contour and representing the contour shape in memory could facilitate processing of a target chord in relation to the prime (e.g. the visuo-spatial representation may be one way to keep the memory trace of the prime sequence activated within working memory), however representing the pitch contour of the spoken sentences would not facilitate comprehension of the sentences presented in the TROG-II. In experiment two (chapter five) it was found that children with SLI showed relatively preserved musical contour processing and it was suggested that this may be due to the ability to represent contour in both auditory and visual forms (Prince et al., 2009). Thus it may be that in experiment four, the ability to represent a visuo-spatial contour of the prime sequence enabled better linking of the target to the prime and therefore better explicit recognition of the harmonic correctness of that target chord. However, a similar visuo-spatial representation of the contour of a spoken sentence could actually be detrimental for the processing of the syntactic content embedded within that sentence.

CONCLUSION

Experiments three and four investigated implicit and explicit processing of structural regularity in visual-motor action and musical sequences. The procedural memory network is implicated in the acquisition and online processing of procedural knowledge across domains and it has been suggested that impairments in this memory network disrupts procedural learning in children with SLI (Ullman & Pierpont, 2005). Thus, according to this account there are domain general resources that are implicated in the processing of structural information across domain. If this explanation is correct, it would be expected that under conditions in which a typically developing child must concurrently process visual-motor action and musical hierarchical information, the increased cognitive load could result in the processing of procedural information becoming less automatized, leading to an increased reliance upon attention and working memory to perform the task. However, the findings from experiments three and four indicate that there may be separable networks implicated in the online processing of auditory and visual-spatial information and so it is possible that under a condition in which visual motor-action and musical structural information must be concurrently processed there would not necessarily be an interaction in processing across these different modalities. To test these predications a cross modal priming paradigm was devised in which participants were asked to make a judgment about the correctness of a final hand-target grasp picture whilst simultaneously listening to music that either conformed to or violated harmonic expectations. This cross modal experiment will be described in chapter 7.

CHAPTER 7

CROSS MODAL PRIMING FOR VISUAL MOTOR-ACTION AND MUSICAL STIMULI

ABSTRACT

The experiment reported in this chapter investigated priming effects for visual-motor action stimuli within a cross modal paradigm in children with SLI and typical controls. Sequential visual motor-action and musical stimuli were presented concurrently. Reaction times and response accuracy to make a judgment about the correctness of a visual-motor action target were measured. The results demonstrated that all participants showed above-chance accuracy for explicit judgments of the correctness of the visual motor-action target and overall participants showed an implicit priming effect with faster judgments for congruent hand-grasp targets than incongruent. Analysis of RT discrepancy scores revealed that in the SLI group and the VMA-matched controls the strength of the implicit priming effect varied significantly under conditions in which the target was accompanied either by silence or by a congruent or incongruent target chord, however once digit span was entered as a covariate in the analysis these differences ceased to be significant. Overall the findings indicate that implicit priming for visual motor-

action targets is influenced by the congruency of a concurrently presented target chord in children with SLI and younger TD controls and that auditory short-term memory is an important factor mediating the influence of concurrent musical information on the processing of a visual motor-action target.

INTRODUCTION

It has been found that from the age of around 6-7 years, in typical children the capacity to unconsciously process structural regularities in music influences the speed and accuracy with which judgments about a target chord can be made. For example, Schellenberg et al (2005) found that typically developing children consistently showed faster and more accurate responses to judgments of a target chord when that chord was related to the prime. Similarly, Escoffier and Tillman (2008) demonstrated that this musical processing advantage extends beyond the auditory domain to the processing of concurrent stimuli in the visual domain.

In a series of experiments, Escoffier and Tillman (2008) found that when adult participants were asked to make a judgment about a visually presented word or geometric shape (whist concurrently listening to music) they regularly responded more quickly when the target was accompanied by a harmonically related, rather than unrelated target chord. One explanation for this apparent facilitative effect of harmonically correct music is that processing the structural regularities in music is an unconscious process in which expectations are generated; because the listener is expecting a harmonically correct target chord to follow a prime sequence then when that expectation is fulfilled there are more attentional resources available to process concurrently presented information (Poulin-Charronat et al., 2005). Escoffier and Tillman (2008) suggest that this audiovisual interaction between the processing of tonal functions and visual information is mediated by shared attentional resources that are made available for processing a concurrent target when that target is accompanied by a harmonically related target chord. One of the implications of Escoffier & Tillman's findings (2008) is that there are domain general attentional resources that are involved in the online processing of information across domains and modalities.

Both music and action sequences have syntactic structure and neuroimaging work has demonstrated that the processing of syntax across domains may be sub-served by the same fronto-parietal neural network (Farag, Troiani, Bonner, Powers, Avants, Gee & Grossman, 2010). To investigate the extent to which the processing of syntactic structures across music and language domains interacted in typical adults, Sammler, Harding, D'Ausilio, Fadiga & Koelsch, 2010) used a cross modal paradigm in which participants were concurrently presented with a series of pictures depicting a hand reaching for an object and a series of chords. Following this visual motor-action and musical prime, a target picture of either a correct or incorrect hand-grasp was presented and accompanied by a chord that was either harmonically related or unrelated. Irregular chords were found to elicit a typical early right anterior negativity (ERAN; 150-250 ms) and an N500 (450-750 ms) indicating the detection of harmonic violations, and the incorrect hand grasp also elicited an early negativity (150-250 ms) and a late positivity (300-600 ms). The same electrophysiological patterns of response have been observed when there are rule violations in language (Hahne & Frederici, 199) and music (Patel et al., 1998). Sammler et al (2010) found that although the patterns of electrophysiological response were similar for music and action stimuli, the brain signatures for these expectancy violations did not interact, the authors suggest that this lack of interaction may be due to the specific nature of the stimulus material used. Similarly, the analysis of data from experiments three and four (described in chapter 6) showed that implicit and explicit priming for visual motor-action stimuli and musical stimuli were not significantly correlated with one another in either the TD controls or the SLI group. Thus it may be that there are separable working memory resources implicated in the online monitoring of procedural information across auditory and visual modalities (Kaufman et al., 2013).

The findings of Sammler et al (2010) indicate that music, language and action share a similar syntactic-like structure and neuroimaging work has indicated that the frontal network (including Broca's area) is activated when processing scripts that have a hierarchical organisation (Farag et al, 2010). Escoffier & Tillman (2008) have argued that there may be domain general cognitive mechanisms implicated in monitoring online processing across domains and once such mechanism may be 'cognitive control' (Slevc & Norvick, 2013). Cognitive control is the term given to the mental operation needed to re-evaluate an unexpected outcome in order to resolve conflicting cognitive representations (Miller & Cohen, 2001). In one experiment, manipulations of musical structure were paired with a Stroop task and it was found that harmonic manipulations, but not timbral manipulations, interacted with Stroop interference effects in typical adults (Slevc et al., 2013). The authors argue that online processing and monitoring of hierarchical knowledge across music, language and action domains is likely to rely upon a pool of shared cognitive resources including mechanisms of attention and cognitive control.

From a developmental perspective it has been suggested that through experience, memory representations become more precise and this results in increased efficiency when processing familiar stimuli (Gomes, Molholm, Christodoulou, Ritter & Cowa, 2000). Considering the acquisition of procedural knowledge of actions, cognitive memory representations will be strengthened through regular experience and the processing of this information will become automatic. In a cross modal paradigm, such as that employed by Sammler et al (2010), where attention must be divided between concurrently presented visual and auditory information, increased cognitive load may reduce the automaticity with which the visual motor-action stimuli can be processed in typical children (Lavie, Hirst, de Fockert & Viding, 2004). Alternatively, it could be that the implicit processing of regularities in music and the generation of expectancies, makes more attentional resources available and aids the processing of a concurrent visual target when it is accompanied by a correct target chord (Poulin-Charrnoat, 2005). In experiment four (described in chapter 6), a significant proportion of children with SLI failed to show better than chance explicit recognition of musical structure and at the group level they differed from controls and did not show an implicit priming effect for musical target chords. One interpretation of these findings is that children with SLI have impaired syntactic comprehension in music and are not processing the harmonic regularities in music to the same extent as TD controls. Support for the notion that SLI is associated with impaired musical syntactic processing comes from Jentschke et al (2008) who found that children with SLI failed to show the typical ERP responses to harmonic violations of chord sequences. It is plausible to suggest that children with SLI are not generating expectancies for musical information in the same way as TD children and so the processing of visual-motor action targets will not be facilitated by the concurrent presentation of an expectation-fulfilling, harmonically correct target chord. The aim of the experiment described in this chapter was to investigate the influence of harmonic regularity on the processing of visual motor-action targets using a cross modal priming task in which visual-motor action sequences were presented with concurrent musical sequences. Given that previous research suggests that the concurrent presentation of music could have either a facilitative or detrimental impact upon the concurrent processing of a visual motor-action target a non-directional hypothesis was adopted. It was hypothesized that the concurrent presentation of music would influence the processing of a visual motor-action target in the cross modal task.

It has been suggested that procedural memory is implicated in processing rule-structures across domains (Ullman & Pierpont, 2005) and that there may be shared cognitive mechanisms for processing structural information in music and action (Slevc & Novick, 2013; Escoffier & Tillman, 2008). Experiments three and four demonstrated that explicit and implicit priming effects for processing visual motor-action and musical stimuli were not significantly correlated, however it is not yet known whether the concurrent presentation of these stimuli will place demands on shared domain general cognitive resources such as attention and cognitive control. If there are shared mechanisms implicated in monitoring online hierarchical processing across music and action domains then it may be that the increased cognitive load associated with concurrently processing visual and musical information may reduce the automaticity with which TD children are able to respond to the visual targets.

Priming paradigms have demonstrated that typical children show evidence of having acquired knowledge of musical regularities by the age of 6-7 years and that this knowledge confers a processing advantage when making judgments about targets that are harmonically correct (Schellenberg et al., 2005; Heaton et al., 2007). It may be that existing cognitive representations of musical structure result in an unconscious processing advantage for visual motor-action targets that are accompanied by an expected, harmonically related target chord (Escoffier & Tillman, 2008). One investigation of musical syntactic comprehension in children with SLI has demonstrated that this group, do not show the same responses to structural irregularities in music as typical children (Jentschke et al., 2008). Furthermore, the findings from experiment four seem to indicate that at a behavioural level the majority of children with SLI do not show explicit awareness of musical structural regularities and also fail to show an implicit harmonic priming effect. Taken together, these findings seem to indicate that children with SLI are not processing the structural regularities in music in the same way as TD children. It is possible that atypical musical syntactic comprehension in children with SLI will interfere with the extent to which an expected, harmonically correct target chord confers a processing advantage for visual motor-action targets in this group.

Throughout this thesis it has been demonstrated that auditory short-term memory is related to performance on a variety of music tasks and that at the group level, children with SLI have impaired auditory short-term memory relative to TD controls. It has been suggested that as typical children develop they are better able to control their auditory environment and to block out irrelevant auditory information (Gomes et al., 2000). It is possible that in a task that necessitates divided attention to concurrently process two competing stimuli, those children who have better scores on measures of auditory short-term and working memory also have better auditory attention and are therefore better at ignoring distracting auditory information in order to attend to the visual target. Therefore a second aim of this experiment was to investigate the extent to which auditory short-term memory mediates the impact of music on the concurrent processing of visual motor-action targets. It was hypothesised that auditory short-term memory would mediate the strength of the implicit RT priming effects for visual motor-action targets accompanied by congruent and incongruent musical chords.

Finally, in experiment one (chapter four) the children with SLI showed poorer pitch-interval direction discrimination than CA-matched controls. It is possible that limitations in pitch-discrimination may disrupt the processing of harmony in children with SLI, however, in experiment four (chapter six) there were some children in the SLI group showing better than chance explicit recognition of harmony, and so it may be that harmonic processing is not necessarily disrupted in children with SLI. A final aim of this experiment was to investigate the extent to which performance on a measure of pitch-interval direction discrimination was related to performance on the cross modal task.

Experiment five. Cross modal priming for visual motor-action and musical stimuli

METHOD

Participants

All participants completed this experiment, resulting in data from a total of seventeen children with SLI and thirty-three typically developing controls matched to the SLI group for either CA and non-verbal IQ (CA) or VMA. The children who completed this experiment also completed experiment three, and their data are shown in table 6-1 in chapter 6.

Design and procedure

The correctness of the final chord/picture was manipulated in a mixed 2x2 factorial design. The first within-groups independent variable was the visual motor-action target picture which had two levels: congruent and incongruent; the second within-groups independent variable was the target chord which had two levels: congruent and incongruent. This resulted in four experimental conditions (chord congruent target & hand congruent target; chord congruent target & hand incongruent target; chord incongruent target & hand congruent target; chord incongruent target & hand incongruent target). The between-subject variable was group (SLI, CA and VMA). There were two dependent variables; the first was the total number of correct responses and the second was the response reaction time.

The task was presented as a computer game in which the children had to watch pictures of a hand reaching for an object and decide if the hand 'got it right' or 'got it wrong' when it tried to grasp the object. At the beginning of the testing session, participants engaged in the same pre-test training as described in experiment three (visual motor-action priming task). They were then asked to watch some sequences of pictures and to press a button as quickly possible to indicate whether the hand grasp was appropriate for the target object. After this, participants were told that whilst they were watching the pictures of the hand trying to grasp the object there would be some music playing, but that they should ignore this music and continue to concentrate on what the hand was doing. Children were then asked to put on headphones and the volume was set to a comfortable listening level. A short practice block consisting of 4 trials (2 congruent hand targets and 2 incongruent hand targets) and lasting for around two minutes was completed, before presentation of the experimental blocks. Each experimental block took around 5 minutes to complete and children were offered stickers between the practice and experimental blocks to maintain their interest in the task.

Stimuli

Chords were digitally recorded in piano voice, using 'MuseScore' (freely downloadable www.musescore.com) and e-prime was used for stimulus presentation. The experiment comprised 48 trials, divided into two blocks of 24 and a separate practice block. Each trial consisted of a 4 chord prime sequence with a Bach progression (I, IIb, IV, V) and a target chord that was either congruent with the prime sequence and was harmonically related (the tonic: I) or incongruent with the prime sequence and was as harmonically unrelated as possible (Neapolitan chord; the furthest tonic on the circle of fifths). Each chord was presented for 1000 milliseconds, with a 1000 millisecond silent interval before the presentation of the target chord (that was also 1000 milliseconds duration). Chord sequences were randomised across major keys and each trial appeared twice in the experiment. Sound delivery was via an external sound card (Edirol UA-4FX) and Sennheiser HD265 headphones set at a comfortable listening level. Simultaneously to the auditory presentation of the chords, sequences of four black and white photographs portraying a hand trajectory were presented, at a rate of 1000 milliseconds per picture. After a 1000 millisecond silent interval, a target picture in which the hand attempted to grasp the object was shown. In half of the trials the target hand-grasp was correct and congruent with the prime sequence, in half of the trials the target hand-grasp was incorrect and incongruent with the prime sequence. In the incongruent hand target pictures the hand either failed to open the fingers to grasp the object or it opened its fingers too wide and missed the object (see figure 7-1).

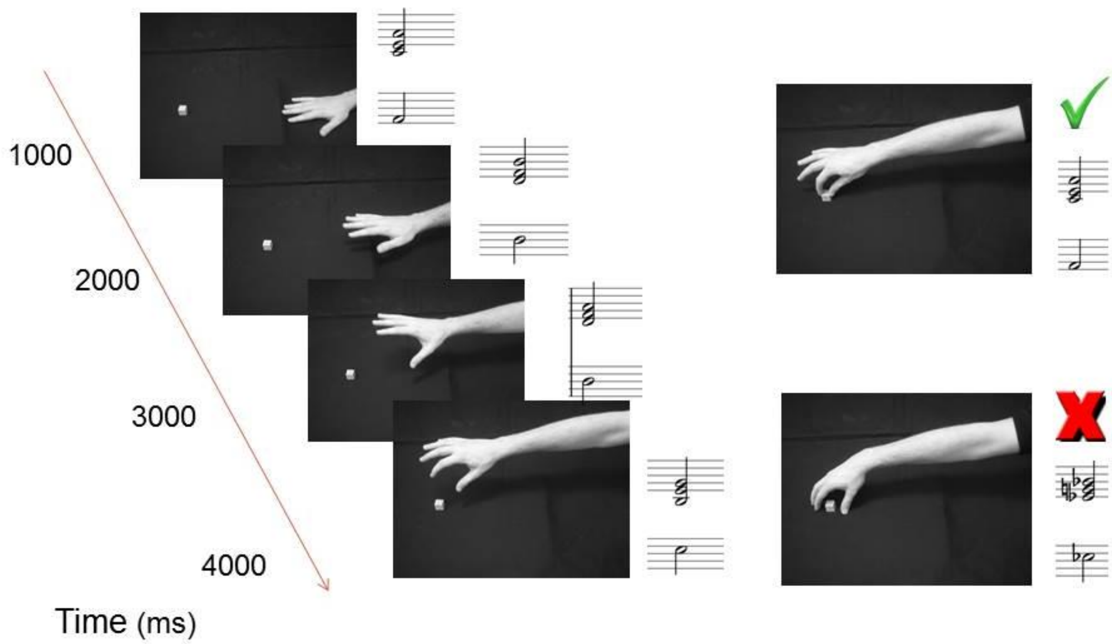


Figure 7-1. Examples of congruent and incongruent target trials in the cross modal priming paradigm.

RESULTS

This task required participants to make a judgment as to whether the target hand grasp picture was correct or incorrect. The total correct scores for both the congruent and incongruent targets were combined to give one overall score for response accuracy on this task. The means and standard deviations (SDs) for correct responses across conditions and groups are shown in table 7-1.

	Hand Congruent		Hand Incongruent	
	Chord Congruent	Chord Incongruent	Chord Congruent	Chord Incongruent
SLI	11.06 (1.25)	10.88 (1.4)	11.18 (1.01)	10.53 (1.28)
CA	10.25 (2.11)	10.5 (2.19)	9.5 (3.48)	10.69 (2.16)
VMA	11.12 (0.93)	11.18 (0.88)	10.94 (1.25)	11.47 (0.62)

Table 7-1. Mean accuracy scores and standard deviations for congruent and incongruent visual motor-action targets accompanied by congruent and incongruent musical chords.

. One-way t-tests comparing the total correct scores to a test value of 24 (constituting 50% accuracy) showed that all three groups were able to explicitly discriminate the correctness of the target grasp with above-chance accuracy (SLI: $t(16) = 24.159$, $p<.001$; CA: $t(15) = 8.811$, $p<.001$; VMA: $t(16) = 32.63$). The performance of all groups was close to ceiling across conditions.

To investigate differences in explicit response accuracy across conditions a mixed ANOVA with two within-subject factors: hand position (2 levels: congruent and incongruent) and chord (2 levels: congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. This analysis revealed that there were no significant main effects of hand, chord or group (hand: $F(1,47)=.252$, $p>.05$; chord: $F(1,47) = 1.246$, $p>.05$; group: $F(2,47) = 2.471$, $p>.05$) and there were no significant interactions. Bonferonni-corrected paired-samples t-tests comparing the total number of correct responses to targets accompanied by a congruent chord to those accompanied by an incongruent chord demonstrated that there were no significant differences in the number of correct explicit judgments for visual motor-action targets when they were accompanied by a congruent versus an incongruent target chord (CA; $t(15) = -1.766$, $p>.05$: VMA; $t(16)=-1.3$, $p>.05$; SLI; $t(16)=1.66$, $p<.05$). Similarly, the total number of correct explicit judgments of the correctness of the visual-motor action target picture did not vary for congruent versus incongruent visual targets in any group (CA; $t(15) = .670$, $p>.05$: VMA; $t(16)=-.139$, $p>.05$; SLI; $t(16)=.077$, $p<.05$).

D' scores were calculated using the same procedure as described in Chapter 5, as an indicator of sensitivity to correct and incorrect hand targets that were accompanied by either a congruent or incongruent musical chord. The *d'* scores for hand targets accompanied by a congruent musical chord were calculated and compared across groups with a one-way ANOVA. The analysis revealed that there was no significant difference across the SLI, CA-matched and VMA-matched groups $F(2,48)=0.819$, $p=.447$. A second one-way ANOVA was carried out to compare *d'* scores for hand targets accompanied by an incongruent musical chord and again this analysis demonstrated that there were no significant differences across the SLI, CA-matched and VMA-matched controls $F(2,48)=1.883$, $p=.183$.

To investigate implicit priming effects mean reaction times for correct responses across the four conditions (HCCC; HCCI; HICC; HICI) were calculated for each participant. For each participant the reaction times that were above three standard deviations from the mean reaction time were excluded.

The data was screened to check for outliers and the normality of the distributions. It was found that in the CA-matched controls the distributions for the HCCI and HICI significantly deviated from normality (Shapiro-Wilk: $p<.05$). In each dataset it was found that one participant had an outlying RT that was above three standard deviations from the group mean (HCCI: mean + 2 SDs = 2147.92; HICI: mean + 2 SDs = 2365). These datasets were removed from the analysis and it was found that the distributions no longer significantly deviated from normality (Shapiro-Wilk: $p>.05$). Mean RTs across conditions for the three groups can be seen in table 7-2 and figures 7-2 and 7-3.

	Hand Congruent		Hand Incongruent	
	Chord Congruent	Chord Incongruent	Chord Congruent	Chord Incongruent
SLI	1881.6 (393)	1866.84 (327)	2010.05 (315)	1870.33 (427)
CA	1142.89 (447)	1046.84 (278)	1241.1 (467)	1158.7 (225)
VMA	2003.32 (369)	2099.92 (244)	2186.45 (298)	2095.68 (259)

Table 7-2. Mean reaction times (standard deviations) to hand-grasp targets across the four conditions.

Visual inspection of the raw data from the implicit RTs suggested that the younger VMA and the older CA-matched TD children show a qualitatively different pattern of performance across conditions (figure 7-2).

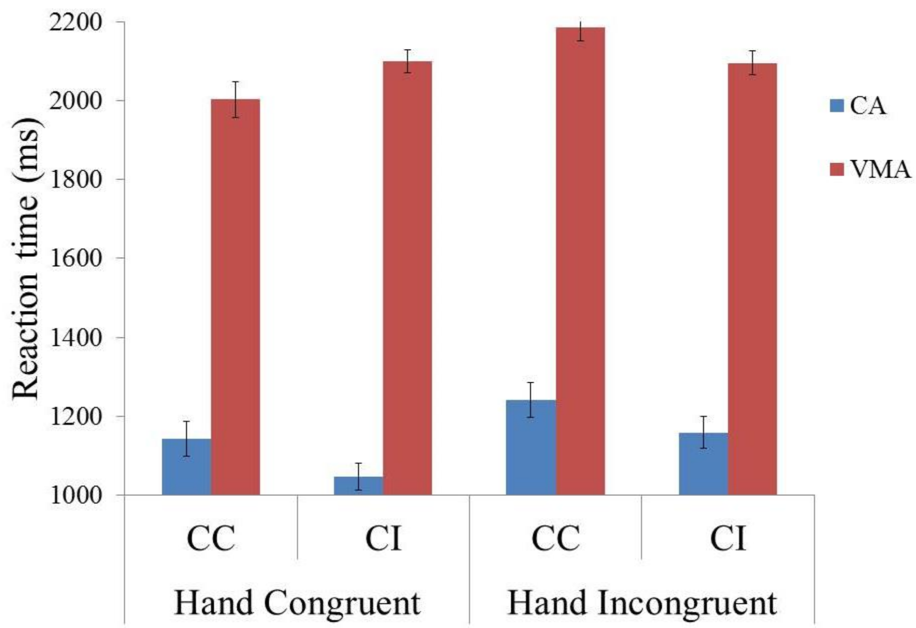


Figure 7-2. Implicit RTs for cross modal task in chronological age (CA) and verbal mental age-matched (VMA) typically developing controls.

In order to understand this potential developmental change in cross modal priming in the typical participants, an initial analysis was carried out on their data. A mixed ANOVA with two within-subject factors: hand (2 levels: congruent and incongruent) and chord (2 levels: congruent and incongruent) and a between-subjects factor of group (CA and VMA) was carried out. This analysis revealed a significant main effect of hand position ($F(1,30)=5.990$, $p<.05$, $n_p^2=.166$) and a significant main effect of group ($F(1,30)=128.924, p<.0001$, $n_p^2=.811$). The main effect of chord was not significant ($F(1,30)=.232$, $p>.05$, $n_p^2=.008$) and there were no significant interactions. Tukey HSD post-hoc comparisons demonstrated that the RTs were significantly faster in the CA-matched controls as compared with the VMA-matched controls ($p<.001$). The analysis of the typical control data indicates that the older children show significantly faster RTs overall, but the lack of a significant interaction across the groups demonstrates that the pattern of performance is not significantly different in the CA-matched and VMA-matched typically developing children.

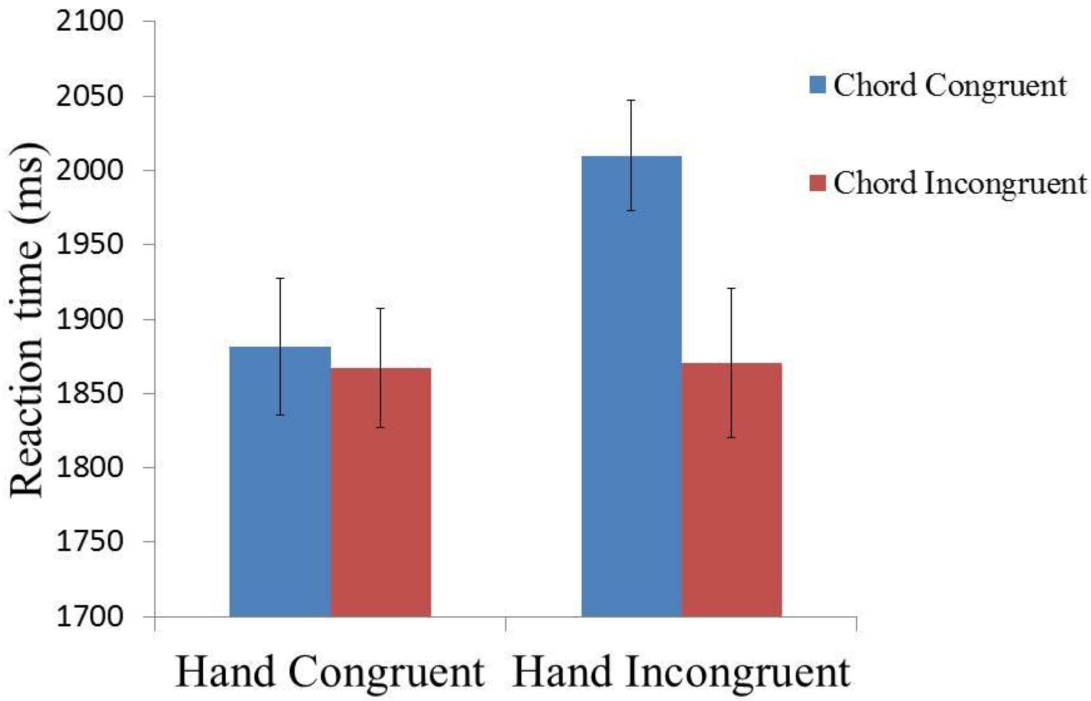


Figure 7-3. Implicit RTs for cross modal task in the SLI group.

To compare performance across the SLI, the CA-matched and VMA-matched groups a mixed ANOVA with two within-subject factors: hand position (2 levels: congruent and incongruent) and chord (2 levels: congruent and incongruent) and a between-subjects factor of group (SLI, CA and VMA) was carried out. This analysis revealed a significant main effect of hand position ($F(1,46) = 5.652$, $p>.05$, $n_p^2=.109$) demonstrating that overall reaction times were faster for congruent visual-motor targets versus incongruent. There was also a significant main effect of group ($F(2,46) = 61.518$, $p<.001$, $n_p^2=.728$), demonstrating that there were significant differences in the reaction times across the three groups. The main effect of chord was not significant ($F(1,46) = 1.827$, $p>.05$) and there were no significant interactions. Tukey HSD post-hoc comparisons revealed that the CA-matched controls showed faster RTs overall than the VMA-matched controls ($p<.0001$) and the SLI group ($p<.0001$). The RTs for the SLI and the VMA-matched controls did not differ significantly (p>05).

The strength of the implicit priming effect (e.g. faster RTs for congruent versus incongruent visual-motor action targets) in conditions in which the visual targets were accompanied by a congruent musical target versus an incongruent musical target were calculated. RTs for congruent visual-motor targets were subtracted from the RTs for incongruent visual motor-targets when they were either accompanied by a congruent or an incongruent target chord. This resulted in two separate measures of the cost of implicit RT when processing targets accompanied by either a congruent musical chord or an incongruent musical chord (see table 7-2).

A mixed ANOVA with one within-subject factor of RT discrepancy (2 levels: chord incongruent and chord congruent) and a between-subject factor of group was carried out. There was a main effect of RT discrepancy ($F(1,46)= 8.203$, $p<.01$, $n_p^2=.154$), the main effect of group was not significant ($F(2,46)=.023$, $p>.05$, $n_p^2=.001$) and the interaction between RT discrepancy and group was not significant ($F(2,46)=.446$, $p>.05$, $n_p^2=.017$).

The RT discrepancy analysis demonstrated that overall there was a significant difference in the reaction time responses discrepancy scores for visual motor action targets accompanied by a congruent and incongruent target chord. This finding indicates that the harmonic correctness of the accompanying musical target influenced the reaction time to respond to congruent and incongruent visual motor action targets. This was further explored in a comparison with data from experiment three in which the visual motor-action targets were processed without accompanying music and the data from experiment five in which the visual motor-action targets were either accompanied by a congruent or incongruent musical target chord. The differences in RT discrepancy scores across conditions in which the visual-motor action targets were accompanied by congruent chords, incongruent chords or were presented in silence were investigated (see table 7-3). A mixed ANOVA with a single within-subjects factor of RT discrepancy (3 levels: chord congruent, chord incongruent and silence) and a between-subjects factor of group (3 levels: SLI, CA and VMA) was carried out. There was a main effect of RT discrepancy ($F(2,45)=5.101$, $p<.01$, n_p^2 =.188), the main effect of group was not significant ($F(2,46)=.266$, $p>.05$, n_p^2 =.010). Bonferonni-corrected paired-samples t-tests ($p=.017$) demonstrated that in the CA-matched controls the differences in RT discrepancy scores across the different conditions were not significant ($p>.05$). In the VMA-matched controls the difference in RT discrepancy scores accompanied by a congruent and incongruent musical target were approaching significance ($t(16) = 2.069$, $p=.05$). In the SLI group the difference in RT discrepancy scores for targets accompanied by an incongruent chord and silence were also approaching significance (t(16)=-2.417, p=.028).

	RT discrepancy Congruent Chord	RT discrepancy Incongruent Chord	RT discrepancy Silence
SLI	128.45 (306)	-56.94 (246)	164.35 (343)
CA	97.42 (196)	-26.23 (194)	59.44 (278)
VMA	183.1 (419)	-90.76 (229)	48.33 (597)

Table 7-3. Mean RT discrepancy scores (standard deviations) for visual motor-action targets accompanied by a congruent target chord, incongruent target chord or silence

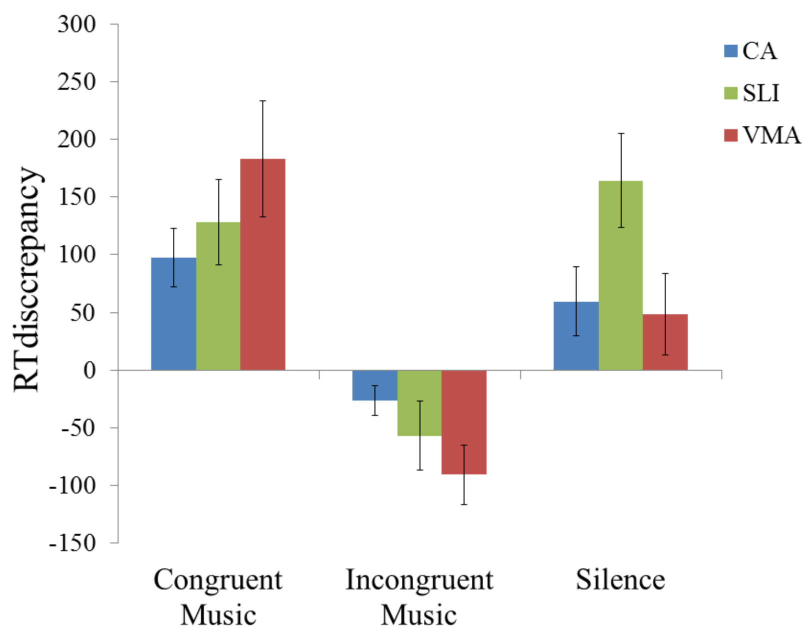


Figure 7-4. RT discrepancy scores for visual motor-action targets accompanied by a congruent musical target, incongruent musical target or silence.

Individual Analyses

Visual inspection of the means and standard deviations for the RT discrepancy scores indicated that there was a large degree of variability in the size of the RT discrepancy scores in each of the conditions across all participants. Further investigation of the individual differences in RT discrepancy scores for processing visual motor-action targets accompanied by a congruent musical chord revealed that there were five participants in the SLI group, six participants in the CA-matched controls and five participants in the VMA-matched control group that did not show a positive RT discrepancy score for processing visual motor-action targets accompanied by a harmonically congruent musical chord. Similarly in the incongruent chord condition there were eight participants in the SLI group; seven participants in the CA-matched controls and five participants in the VMA-matched control group that did not show a negative RT discrepancy score for processing visual motor-action targets accompanied by a harmonically incongruent musical chord.

In order to identify possible subgroups a two-step hierarchical cluster analysis with RT discrepancy scores for targets accompanied by harmonically congruent or incongruent musical chords was carried out. This analysis revealed that there were two main clusters and that the most important predictor was the harmonic congruency of the target chord. Cluster one had 18 participants (37.5%) with a mean RT discrepancy score for congruent musical targets of 450.93 ms and RT discrepancy score for incongruent musical targets of -243.05ms. Cluster two included 30 participants (62.5%) with a mean RT discrepancy score for congruent musical targets of -42.1ms and RT discrepancy score for incongruent musical targets of 50.91 ms.

Taken together these findings indicate that there is individual variability across both the SLI group and typically developing children in the extent to which the processing of visual targets may be influenced by the concurrent presentation of a musical target that is either structurally expected (congruent) or unexpected (incongruent).

Correlational analyses

In order to further investigate the possible mechanisms that contributed to the differences in RT discrepancy scores for visual-motor action targets accompanied by congruent chords, incongruent chords or silence, correlational analyses with age, auditory memory and pitch-interval discrimination were carried out on the data. It was found that the RT discrepancy scores for visual motor-action targets accompanied by an incongruent target chord were significantly positively correlated with digit span scores in the SLI group only ($r(15)=.528, p<.05$).

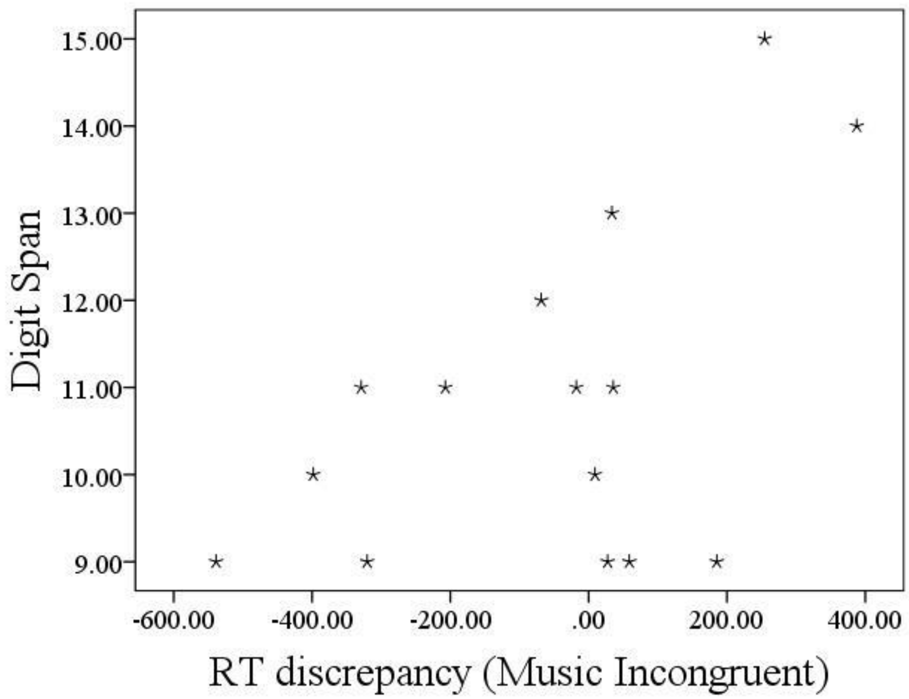


Figure 7-5. The relationship between RT discrepancy scores for visual motor-action targets accompanied by incongruent target chords and scores from the digit span in children with SLI.

To control for the contribution of variability in auditory short-term memory to the differences in RT discrepancy scores across conditions in the three groups a mixed ANOVA with digit span scores as covariates in the analysis was carried out. The ANOVA had one within-subject factor of RT discrepancy (3 levels: chord incongruent, chord congruent and silence) and a between-subject factor of group (3 levels: SLI, CA and VMA) and scores from the digit span entered as covariates in the analysis. In this analysis the main effect of RT discrepancy was not significant ($F(2,41)=,78$, $p>.05$, $n_p^2=.012$), and there was no significant main effect of group

($F(2,42)=.012$, $p>.05$, $n_p^2 =.001$) and no significant interactions. This suggested that once digit span was controlled the effect of RT discrepancy was no longer significant.

DISCUSSION

The aim of this experiment was to investigate cross modal priming in typically developing children and children with SLI. It was hypothesised that in typically developing children the concurrently presented music would impact upon the visual target in one of two ways. Firstly, the increased cognitive load in the cross modal task would reduce the automaticity with which participants could respond to visual motor-action targets and they would show faster RTs to congruent visual motor-action targets than to incongruent visual motor-action targets (Lavie, 2004). Secondly, the concurrent processing of a musical target would facilitate the processing of a concurrent visual motor-action target when the musical prime was harmonically congruent. This effect would be due to an increase in attentional resources available for processing the visual motor-action target (Poulin-Charronnat, 2005). Based on the findings of Jentschke et al. (2008) it was hypothesised that atypical processing of hierarchical structure in music would result in a reduced processing advantage for concurrently presented congruent musical targets in the children with SLI. Finally it was hypothesized that auditory short-term memory would mediate the extent to which the concurrently presented musical chord sequences impacted upon the processing of visual motor-action targets.

Analysis of the explicit correct responses to visual motor-action targets demonstrated that all three groups showed above-chance accuracy for the identification of the correctness of the visual motor-action targets with performance at ceiling for a number of the conditions. There were no significant differences in the explicit accuracy across conditions or groups, indicating that all groups were able to explicitly recognise the correctness of the visual motor-action target and that this explicit judgment was not influenced by the congruency of the accompanying target chord.

Analysis of the implicit RTs demonstrated that overall the CA-matched controls showed significantly faster RTs across all conditions than the VMA and SLI groups. The RTs of the SLI group were not significantly different to the VMA-matched controls. The analyses revealed a main effect of hand position, indicating that overall participants were faster to respond to congruent over incongruent visual motor-action targets. Therefore the data support the first hypothesis and indicate that the automaticity with which the visual targets were processed was reduced in the TD controls when they were processing a competing musical stimulus. This is shown by the observation that in experiment three when the visual motor-action targets were presented in isolation the typical controls responded equally quickly to congruent and incongruent targets, however in the cross modal task, responses were significantly faster for congruent over incongruent visual motor-action targets. Although the CA and VMA-matched controls appeared to show a qualitatively different pattern of mean RTs across conditions, no statistically significant interactions emerged in the analysis of the data from the two TD control groups. Similarly, the analysis that included the SLI group also failed to reveal any significant interactions in performance across the SLI group and the TD controls.

To compare the strength of the implicit priming effect for visual motor-action targets across different conditions, RT discrepancy scores were calculated. These scores were calculated by subtracting the RT for congruent visual motor-action targets from the RT for incongruent visual motor-action targets. The data from experiment three, in which incongruent and congruent hand stimuli were presented without concurrent auditory stimuli, was included in the analysis so that the strength of the implicit priming effect for responses to a visual motor-action target presented in isolation or accompanied by correct or incorrect musical target chords could be compared.

Visual inspection of the mean RT discrepancy scores revealed that participants in all three groups showed faster RTs when judging the correctness of a congruent visual motor-action target when that target was accompanied by a congruent musical target chord (as indicated by a positive RT discrepancy score). Conversely, participants were faster to make a judgment about the correctness of an incongruent visual motor-action target when that target was accompanied by an incongruent target chord (as indicated by the negative RT discrepancy score). The second hypothesis stated that processing of visual targets would be facilitated by the concurrent presentation of a congruent musical target. However, the results from the experiment revealed a degree of interaction between the music and visual motor-action sequences. In all three groups participants showed faster RTs for processing congruent visual motor-action targets when they were accompanied by congruent musical chords, and faster RTs for incongruent visual motor-action targets when they were accompanied by incongruent musical chords. This pattern of performance may reflect a degree of audio-visual integration in the processing of hierarchical structure across domains. Further individual analyses revealed that across all groups of participants there were differences in the extent to which the concurrent presentation of a structurally expected (harmonically congruent) musical chord influenced the speed with which participants responded to the visual motor-action target. Therefore it may be the case that across both typically developing and SLI groups there may be some children who are better able to exert control and block out irrelevant auditory interference than others.

Statistical comparisons of the RT discrepancy scores demonstrated that there was a significant difference in the RT discrepancy scores for targets accompanied by a congruent target chord, an incongruent chord and silence in the SLI group and the VMA-matched controls. However, when scores from the Digit Span measure of auditory short-term memory were included as covariates in the analysis this difference in RT discrepancy scores across conditions ceased to be significant. This finding supported the third hypothesis which stated that auditory short-term memory would mediate the strength of the implicit RT priming effects for visual motor-action targets accompanied by congruent and incongruent musical chords. The results indicated that differences in RT discrepancy scores across the different conditions observed in the younger VMA controls and the SLI group were mediated by variability in auditory short-term memory. Further support for the notion that auditory short-term memory was an important factor in the relative influence of silence, congruence and incongruence of musical targets on the strength of the implicit priming effect for visual motor-action targets, comes from the observation that for children with SLI, the RT discrepancy score for targets accompanied by incongruent musical chords were significantly positively correlated with scores from the digit span task. In the SLI group those children with better auditory short-term memory showed faster RTs to congruent visual motor-action targets than incongruent targets (indexed by a higher RT discrepancy score) even when the target was accompanied by an incongruent target chord. In other words, the RT discrepancy scores to visual motor-action targets were more influenced by the concurrent presentation of an incongruent musical target in those children with poor auditory STM. One possible explanation for this relationship between the strength of implicit priming for visual motor-action targets and auditory short-term memory is that children with relatively preserved auditory short-term memory are more able to exert control over competing auditory information in the environment than those with poor short-term memory, and are therefore less likely to show disrupted processing of visual motor-action sequences as a result of the concurrent presentation of incongruent musical information (Gomes, 2000).

It has been suggested that shared cognitive mechanisms are implicated in online processing across domains and modalities (Escoffier & Tillman, 2008; Poulin-Charronat et al., 2005). When a listener hears (or sees) a target that is congruent with a prime sequence, the target fulfils expectations and there is no need to resolve a competing cognitive representation. In this situation, no re-evaluation is necessary and fewer demands are made on attentional resources (Slevc & Novick, 2013). In the cross modal priming task, the concurrent presentation of sequential visual motor-action and musical stimuli would necessitate involvement of these cognitive control mechanisms to monitor and process this information across domains and modalities. Under conditions in which both music and visual motor-action targets must be concurrently processed, all participants showed faster responses to congruent versus incongruent visual motor-action targets which supports the notion that there is an attentional cost associated with processing an unexpected visual target (possibly due to a need to re-evaluate an unexpected outcome). Further investigation of RT discrepancy scores revealed that the strength of this implicit priming effect for visual motor-action stimuli varied depending on whether the target was accompanied by a congruent musical chord, an incongruent musical chord or silence. Younger children and children with SLI showed a significantly smaller reaction time advantage for processing a congruent visual motor-action target when that target was accompanied by an incongruent musical target chord. One interpretation is that there is a degree of audiovisual integration in the online monitoring of hierarchical structure so that deviancy in one modality facilitates the processing of a deviant, unexpected outcome, in the other modality.

Although all listeners showed a similar performance profile, the differences in RT discrepancy scores were only significant in younger VMA-matched controls and children with SLI and when auditory memory was controlled these differences were no longer significant. As noted, it may be that older typically developing children, at a later developmental stage, had developed the auditory memory and attention needed to selectively attend to visual information and so were less distracted by the concurrent presentation of auditory information (Doyle, 1973).

Thus it may be that the differences in RT discrepancy scores in the younger TD controls and the children with SLI reflect a degree of immaturity in auditory processing.

What is particularly striking about the findings from this cross modal experiment is that when musical harmonic processing was tested in isolation in experiment four, the majority of children with SLI did not demonstrate explicit recognition of harmonic structure and overall the SLI group did not show an implicit harmonic priming effect. However, when tested on a task that involved making a judgment about the presentation of a visual motor-action target, the harmonic regularity of the accompanying target chords influenced the implicit responses of children in the SLI group. The RT discrepancy scores were significantly different across conditions in which the visual motor-action target was accompanied by a congruent and an incongruent target chord in the SLI group. Thus it seems that at some level children with SLI are processing structural regularities in music, and the cognitive representations of hierarchical musical structure impact upon the processing of procedural information in other modalities and domains. The findings from this experiment may therefore indicate a degree of implicit awareness of musical regularities in children with SLI that interacts with the concurrent processing of hierarchical visual motor-action stimuli. This is contrary to what was expected given the findings of Jentschke et al. (2008) demonstrating that children with SLI do not show the same electrophysiological response to harmonic irregularities in music as typical controls do.

CONCLUSION

The experiments described in this thesis so far have demonstrated that SLI may be associated with a delay in pitch-interval direction discrimination, impaired auditory short-term memory and delayed automatisation of procedural knowledge across motor and music domains. However, the experiments have also indicated a degree of spared musical processing abilities in children with SLI. Experiments one and two indicated that although children with SLI do show poorer pitch-interval and melody discrimination than CA-matched controls, they are able to discriminate and to process pitch contours with above chance accuracy. Similarly in experiment four it was found that a number of children within the SLI group demonstrated explicit awareness of harmonic structure in music and experiment five indicated that the harmonic congruency of accompanying musical target chords had a similar influence upon responses to visual motor-action targets in the SLI children as observed in the typically developing controls. Taken together the findings from each of the experiments indicate that although SLI is associated with cognitive deficits in auditory short-term memory, and impaired language processing, there are aspects of musical cognition that appear to be relatively preserved and these preserved capacities may provide a route to compensation for musical processing in this group. Aiello (1994) has suggested that music is most meaningful at the level of emotional communication. To test the extent to which children with SLI are able to recognise the communicative intent of a group of classical composers, the final experiment tested emotional recognition of musical excerpts in children with SLI.

CHAPTER 8

EXPERIMENT SIX: RECOGNISING MUSICAL EMOTIONS

ABSTRACT

The experiments described in the previous chapters of this thesis have revealed that children with SLI, with a deficit in auditory short-term memory, and delayed pitch-direction discrimination, retain a capacity to process musical contour. The findings from experiments three, four and five demonstrated that although SLI may also be associated with atypical processing of hierarchical structural information in music and action, children with SLI nevertheless demonstrate implicit awareness of hierarchical musical structure. Experiment six investigated whether or not this pattern of deficit, delay and relative sparing of different components of musical information processing, as well as the cognitive deficits detailed in theoretical accounts of SLI, impact upon the children's ability to recognize musical emotions. In experiment six, children were required to listen to a series of musical extracts and indicate which, of a group of pictures best reflected the mood of the music they had heard. The paradigm tested emotion recognition using ecologically valid excerpts of classical music that are rich in rhythmic, pitch and timbral cues. As the stimuli and methods have already been tested in a study

of 240 four to ten year old typically developing children and groups of individuals with Autism and Down Syndrome (Heaton et al., 2008), a pilot study was not conducted.

INTRODUCTION

Music has been viewed by some as a language in which musical events represent specific emotions and musical emotions are embodied through structures that are analogous to human feeling (Kratus, 1993). Pitch and tempo are important in musical expression and as such strongly influence the listeners' recognition of emotional intent; major mode melodies are generally considered to be 'happy' and 'light', whereas minor mode melodies are considered 'sad' 'dreamy' and 'pathetic' (Huron, 2006, pg 145; Hevner, 1937). One of the first experimental investigations of the influence of mode on emotional responses to music was carried out by Heinlein (1928). In this study, participants were asked to use a list of emotionally loaded adjectives to rate 48 major and minor chords that were played on a piano. Both musically trained and untrained listeners associated the major mode with ‘happy’ and the minor mode with ‘sad’. This effect may be explained in terms of the acoustic spectral differences in the major and minor triads (Helmholtz, 1877) or alternatively may be a product of enculturation (Davies, 1994; Kivy, 1980). Whilst, this second suggestion may imply that the listener’s understanding of the emotional component of music from other cultures would be difficult to interpret, evidence suggests that through attention to the basic characteristics of rhythm and mode adults and children are able to judge the emotional meaning of music from familiar and unfamiliar cultures

(Balkwill & Thompson, 1999; Cunningham & Sterling, 1988; Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Kratus, 1993; Terwogt & Van Grinsven, 1991; Terwogt & Van Grinsven, 1991).

It has been found that typically developing children are able to recognise and determine emotional meaning in music by the age of around 4-years (Dolgin & Adelson, Kasner & Crowder, 1990; Schellenberg et al, 2005). In one investigation of musical emotion recognition, typical children were asked to listen to 30 excerpts of music (selected randomly from the Goldberg variations) and to circle the face (happy or sad/ excited or calm) that matched the feelings in the music (Kratus, 1993). Kratus (1993) found that formal musical education had little effect on children's interpretation of emotion in music, so that the 12 year olds with 6 years of formal musical training interpreted emotion in the same way as the 6-year olds. Investigations of musical processing in children and adults with neurodevelopmental disorders affecting language development (Autism and Down Syndrome) have consistently failed to observe marked deficits in the recognition of musical emotions that are independent of intellectual impairment (Heaton, Hermelin & Pring, 1999; Heaton et al, 2008; Allen et al, 2008). For example, Heaton et al (2008) observed that in children with Autism and Down Syndrome, the ability to recognize emotion in music is predicted by their level of receptive vocabulary development. This result led the authors to suggest that language may be a common mechanism, underlying understanding of emotional information across different domains, including music.

There has been a great deal of discussion around the origins of the typical listener's emotional response to music. Mayer (1956) and Huron (2006) have highlighted the way that composers manipulate the listener's expectancies via changes in the syntactic structure of the music. Cognition and emotion are closely linked in musical listening and appreciation of structurally irregular musical events, such as chords that violate musical syntax, can elicit emotional (or affective) responses such as surprise or fear (Huron, 2006). Thus, composers are able to exploit musical events as they unfold over time and to manipulate these expectations to elicit an emotional response in the listener (Huron, 2006; Koelsch & Siebel, 2005). The "meanings" that listeners attribute to these events and musical manipulations relate most strongly to the emotional responses they generate (McMullen & Saffran, 2004). According to expectancy theories of musical emotions, the listener's experience of emotions in music will rely on his/her ability to process its syntactic structure (Krumhansl, 2002).

Although the processing of syntactic structure is strongly implicated in emotional responses to music, a recent theoretical account of musical emotion perception has detailed a number of additional mechanisms that elicit similar effects (Juslin & Vastjfall, 2008). For example, it is possible that through a process of classical conditioning, a listener comes to associate a particular musical style or genre with a positive life event and so continues to show a positive emotional reaction to that same piece of music across different contexts (Davies, 1978). Similarly, in terms of emotional recognition it is quite possible that over time and musical exposure a listener comes to associate a particular musical style with a particular mental or emotional state. For example through exposure to a film scene in which a certain piece of music accompanies specific scenes (e.g. Superman making a death-defying rescue), the musical characteristics (rhythm, timbre, tonality) of the piece may become associated with a specific emotion (e.g. triumphant). In this case, musical emotion recognition results from learned associations rather than from personal experience.

Another candidate mechanism through which a listener may experience emotional responses to music is through emotional contagion. Here a neural mechanism responds quickly and automatically to the voice-like and emotion-specific acoustic properties of the music, resulting in an internal mimicking of the perceived emotion (Juslin, 2001). Boucher et al. (2000) observed that children with autism and SLI were impaired in their ability to recognise the emotional cues in the human voice and to map these cues onto facial expressions of emotion. Dissanayake (2000) has proposed that emotion recognition in speech, music and the arts have a common origin and one implication of this, is that difficulties in recognizing the emotional connotation of the acoustic properties of speech may generalize to the musical domain.

Considering the process through which typically developing children acquire knowledge of emotional cues in music, it is possible that there is some interaction between the listener's own subjective emotional responses to the music and their learned associations between particular musical characteristics and specific emotions. For example, a child may arrive at an association of 'happy' with the major mode through their own emotional reaction which may relate to mechanisms such as 'expectancy' and 'emotional contagion' (Juslin & Vastjfall, 2008;

Huron, 2006; Meyer, 1965). Electrophysiological and neuroimaging studies of typical adults have revealed different patterns of activation during processing of syntactic structure and semantic meaning in music (Miranda & Ullman, 2007; Koelsch et al., 2005). A similar dissociation between syntactic and semantic processing for language has been observed in children with SLI. For example, Fonteneau & van der Lely (2008) found that children with SLI showed late ERP responses associated with semantic priming of sentences and atypical ERP responses to grammatical violations. Given the separable patterns of activations that have been observed for syntactic and semantic processing it is possible that a listener could have impaired syntactic processing of music and yet retain the capacity to process semantics. Therefore children with SLI may show atypical processing of hierarchical structure in music (Jentschke et al., 2008) and yet retain the capacity to process its semantic and emotional meaning.

The first aim of experiment 6 was to investigate whether or not children with SLI map music and emotions to the same extent as typically developing children. EEG studies have demonstrated different areas of activation when processing grammatical constructs and semantic meanings in sentences and in music (van der Lely & Fonteneau, 2008; Miranda & Ullman, 2007) and the Multiple Mechanisms theory (Juslin & Vastjfall, 2008) has shifted the emphasis away from syntactic processing as a single explanation for musical emotions. Empirical evidence has shown that deficits in understanding emotions in speech do not generalize to music in children and adults with autism (Heaton et al., 2008) and a similar dissociation may be observed in SLI.

The findings from experiment one (described in chapter four) demonstrated that children with SLI do show poorer pitch-interval discrimination than chronological age-matched controls and a degraded auditory representation of pitch-intervals may lead to difficulties discriminating between major and minor thirds and thus impact upon the perception of musical mode. According to Huron (2009), musical emotions arise through anticipation, which in turn depends upon intact perception of musical syntax. In experiment five children with SLI showed marked deficits in musical priming indicating that deficits in processing linguistic syntax may generalise to music. However, the findings from the cross modal experiment indicated children with SLI do show an implicit awareness of musical structure and that the extent to which this implicit awareness affected the processing of visual motor-action targets was related to auditory short-term memory. If, as this suggests, children with SLI are processing syntactic structures in music at an implicit level they will show the same emotional responses to structural violations as typically developing children. Even if SLI is associated with impaired syntactic processing in music, alternative theoretical accounts (Juslin & Vastfjall, 2008) propose that multiple mechanisms influence listeners' perception of musical emotions. Therefore children with SLI may be able to compensate for limitations in syntactic processing by relying upon musical contour to recognize emotional content. Furthermore, empirical studies have highlighted the importance of rhythm and articulation (Hevner, 1937; Kratus, 1993) and children with poor pitch discrimination may compensate by increasing attention to these types of cues. It was hypothesised that multiple mechanisms would enable children with SLI to recognize the emotional connotations of classical musical excerpts as reliably as typically developing children.

The second aim of this experiment was to investigate the extent to which musical emotion recognition is related to cognitive abilities in the children with SLI. Heaton et al. (2008) observed that in children with Autism and Downs Syndrome the ability to recognise emotional cues in music was related to their verbal mental age, assessed through vocabulary knowledge. Many children with SLI have poorer vocabulary than age-matched typically developing controls (see chapter three) and this may result in music emotion recognition skills that are developmentally delayed. SLI is also associated with impaired auditory short-term memory and poor grammatical comprehension in language, and little is known about the extent to which limitations in these cognitive abilities relate to musical emotion recognition.

The third aim of the study was to investigate whether the ability to recognize emotion in music was related to pitch-interval direction discrimination, musical contour processing, implicit and explicit processing of musical syntax in the children with SLI. Considered in the context of a Multiple Mechanisms account, it is possible that some sparing in the ability to process pitch intervals and contours will be associated with a capacity to recognize emotion in music (Juslin & Vastjfall, 2008).

METHOD

Participants

Three of the children with SLI did not complete the emotion recognition task and so their data was not included in the analysis. In total, data from fourteen children with SLI was included. The mean chronological age of the SLI group was 9:4 (SD = 1.1) and their verbal mental age, derived from their vocabulary scores on the British Picture Vocabulary Scales (BPVS-11) was 5:8 (SD=0.9).

BPVS-II		**TROG-II**		**digit span**		**Age**	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
84.71	16.78	8.4	3.5	10.92	2.02	9.4	1.1

Table 8-1. Means (SDs) for the SLI group performance on receptive vocabulary (BPVS-II), linguistic grammatical comprehension (TROG-II) and auditory short-term memory (digit span).

The data from the children with SLI was compared with a pre- existing large sample of typical data collected from children in mainstream primary school by Heaton et al. (2008).

Stimuli

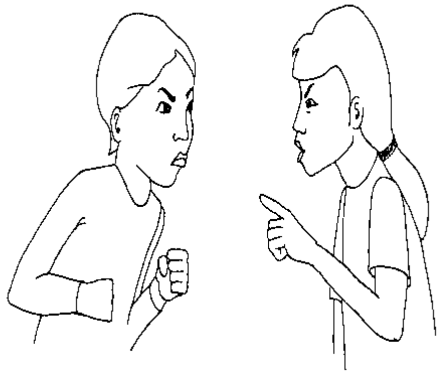
The investigation of facial emotion perception in typical children has shown that simple emotions, for example happy and sad, are considerably easier to identify and label than complex emotions like embarrassment and triumph (Williams & Happe, 2010). Similarly, research has indicated that basic emotions, such as happiness, anger, fear, and sadness, can be recognised in and induced by musical stimuli in adults and in young children (e.g. Heaton, Hermelin & Pring., 1999; Kratus, 1993; Dolgin & Adelson, Kasner & Crowder, 1990). To date, there has been relatively little work exploring the how recognisable more complex emotions such as triumph and contemplation are in music. It may be that emotional responses to music go beyond basic emotions such as anger and fear and that emotional recognition in music reflects these more complex emotional responses (see Bigand et al., 2005).

A further consideration is that many children with neurodevelopmental disability have particular difficulties understanding facial expressions of emotions and for them visual images of emotion evoking scenarios may be suitable cues for musical emotion identification. In the study of very young typically developing children, and children with autism and Downs syndrome, carried out by Heaton et al., (2008) children were asked to match musical excerpts with visual images of emotion evoking scenarios and no effect of diagnosis was observed in the results. Therefore these stimuli were selected for use in this experiment to test musical emotion recognition in children with SLI.

Members of the Royal Philharmonic and Philharmonia Orchestras in the United Kingdom. were given a list of emotion categories (anger, fear, love, triumph and contemplation) and asked to propose extracts of classical music that would correspond to them. This resulted in a large corpus of musical extracts, which were then piloted on a group of typical 10 year old children. The musical extracts were recorded onto a CD and then saved as .wav files. Each classical excerpt was played through speakers connected to a laptop computer and the volume was set at a comfortable listening level.

Visual representations of the musical stimuli were generated and are shown in Figure 8-1.

Contemplation



Anger

Fear

Triumph

Love

Figure 8-1. Visual representations for the corresponding emotion categories in the musical excerpts.

Procedure

All children were tested individually in a quiet room in their school setting. Five pictures (representing each of the emotional categories) were placed on a table in front of the participants. Children were asked to describe the pictures and to indicate the emotional feeling of each of the people in the pictures. For example children would be shown the picture of the man holding the trophy and asked to describe what is happening in the picture, how the man is feeling and why they think he may be feeling this way. This pre-test enabled the experimenter to confirm that all participants understood the emotion that was represented in each of the pictures. Once all children had completed this pre-test they moved on to the experimental task. Participants were told that they would hear some pieces of music, each of which related to one of the pictures on the table in front of them, they were asked to point to the picture that they felt best represented the music they were listening to.

In total there were 10 different excerpts with two related musical excerpts for each emotional category. The classical excerpts were presented to each participant in a single randomized cycle. Scores were recorded by the experimenter on a score sheet

RESULTS

The SLI group had a mean chronological age of 9.4 years (range: 7:3- 10;11) and a VMA of 5.11 (data for the SLI group can be found in table 1), therefore their data were compared with data from a group (N = 14) of typically developing children aged 7.1 – 11years (CA matched group) and a second group (N = 14) of typically developing children aged 5.1 – 7 years (VMA matched group).

The correct responses for each musical emotional category were summed to give a total of correct responses and this total score was used in the analysis. Shapiro-Wilk tests of normality were run and indicated that none of the variables significantly departed from normality.

The mean number of correct emotion identifications for the SLI group and the CA-matched and VMA-matched controls are shown in table 8- 2.

Emotion recognition score		
Group	Mean	*SD*
SLI	4.64	2.09
CA controls	5.86	1.79
VMA controls	4.14	1.46

Table 8-2. Means and (SDs) of total correct recognition scores in the SLI group and the CA-matched and VMA-matched controls (maximum score of 10).

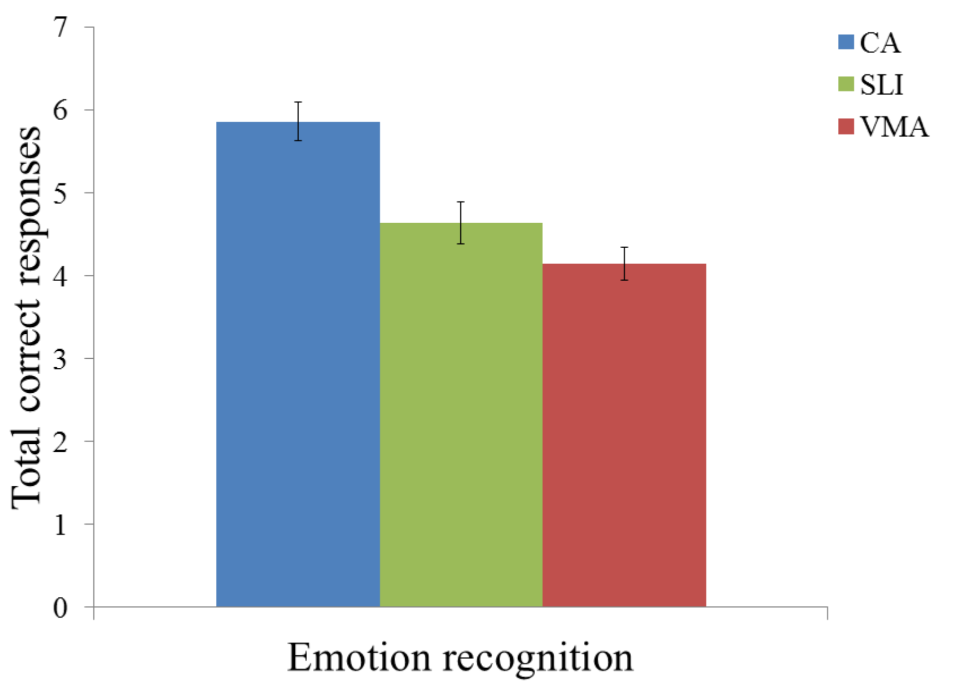


Figure 8-2. Mean and standard error (*SEMs)* for correct recognition of emotions in music in the SLI group, the CA-matched and the VMA-matched typical controls.

A Univariate ANOVA with the total correct scores as the dependent variable and group (SLI, CA and VMA) as fixed factors was carried out. There was a significant main effect of group ($F(1,39)=3.351$, $p<.05$, $n_p^2=.147$). Tukey HSD post-hoc comparisons demonstrated that the SLI group did not differ significantly from the CA-matched group ($p>.05$) or the VMA-matched group ($p>.05$), but the CA-matched group had significantly higher correct emotion recognition scores than the VMA-matched group ($p<.05$). These results suggest that musical emotion recognition is not significantly different in children with SLI as compared with typically developing children of the same chronological age and younger verbal-mental age.

Table 8-3 presents average accuracy rates for each emotion category in diagonal cells in bold, alongside the distribution of inaccurate categorizations in rows for the SLI group. Overall emotion recognition accuracy was quite low (46%), ranging from 32% (for contemplation) to 64% (for triumph). For all emotions, one-sample t tests confirmed that accuracy rates were higher than what would be expected by chance alone (20 %): anger, $t(13)=-4.182$, $p=.001$; fear, $t(13)=-10.817$, $p<.001$; triumph, $t(13)=-3.238$, $p=.006$; loving, $t(13)=-4.759$, $p<.001$; contemplation, $t(13)=-6.624$, $p<.001$ (all significant after Bonferroni correction, $p < .01$). This is evidence that in this set of classical musical excerpts was effective at communicating the intended emotions and that these emotions were reliably recognised in the SLI group.

Concerning the pattern of errors, the most common ones included contemplation excerpts categorized as expressing loving emotions and anger excerpts were often classified as expressing fear. It is possible that such confusions arose because these pairs of musical excepts are similar in that loving and contemplation may both be considered positive emotions, whereas fear and anger may be considered negative. Furthermore, there are acoustic similarities between these musical emotion categories that may have contributed to the confusions: Fear and anger expressions in music have both been characterised by staccato articulation with sharp duration contrasts between the notes (see Juslin & Laukka, 2003 for a review).

	ANGER	**FEAR**	**CONTEMPLATION**	**TRIUMPH**	**LOVING**
ANGER	**46%**	32%	7%	11%	0
FEAR	25%	**38%**	7%	11%	21%
CONTEMPLATION	0	11%	**32%**	0	57%
TRIUMPH	7%	4%	11%	**64%**	14%
LOVING	0	14%	18%	18%	**50%**

Table 8-3. % correct recognition accuracy for classical musical excerpts in the SLI group. Diagonal cells in bold indicate accurate categorizations.

Individual analyses

Previous research has identified deficits in recognizing emotions in voices in SLI (Boucher et al., 2000) and Dissanayaki (2000) has suggested parallels in emotion processing across language and music domains. As the results from experiment six suggested that SLI children recognize musical emotions as well as CA matched TD children at the group level, further individual analyses were carried on the data. To compare the performance of each child with SLI to that of a group of typically developing controls of the same chronological age a series of individual analyses were run. First, it was determined whether each participant's total correct emotion recognition scores fell more than 1.5 interquartile ranges (1.5 times the distance between the 25th and 75th percentiles) below the 25th percentile score of the sample of typically developing children in the same age-group. This point, the "lower fence" is commonly used as a cut-off, beyond which points are designated as outliers (Tukey, 1977). This same approach was used to determine whether each participant's total correct recognition score was an outlier above the "upper fence" (e.g. 1.5 interquartile ranges above the 75th percentile). The identification of outliers using this approach does not assume a normal distribution and therefore is quite robust (Ullman & Gopnick, 1999).

In the typical 8 year olds the 25th percentile score was 5 and the 75th percentile was 7. 1.5 interquartile ranges below the 25th percentile score for the 8 year olds was a score of 2 and 1.5 interquartile ranges above the 75th percentile was a scores of 10. In the SLI group there was one

8-year old with a score of '2', all other participants in the SLI group had scores that did not fall below 1.5 interquartile ranges below the 25th or above the 75th percentile.

In the typical 10 year olds the 25th percentile score was 4 and the 75th percentile score was 8. In the SLI group there were three participants with scores that fell below the 25th percentile. There was one participant in the SLI group with a score of 3 and one participant with a score of 1 and it should be noted that although these scores were below the 25th percentile they did not fall below 1.5 interquartile ranges outside of the scores achieved by the typically developing 10-year olds.

A modified t-test was used to compare individual scores of the children with SLI to the typical group data for children of the same age-group (e.g. 8-year olds and 10-year olds) (Crawford & Howell, 1998). For each SLI participant a t-value was calculated and compared to a critical value to determine if the score was significantly different (at an alpha of .05) to the scores obtained in the typical sample (see table 8-3 for the calculated t-values for each child in the SLI group).

SLI participant	Age group	DF	Calculated	Critical	Alpha = .05
1	8	49	-0.0478	2.009	p>.05
2	8	49	-0.0478	2.009	p>.05
3	8	49	1.7467	2.009	p>.05
4	8	49	-2.147	2.009	p>.05
5	8	49	1.034	2.009	p>.05
6	10	29	-0.487	2.045	p>.05
7	10	29	-0.487	2.045	p>.05
8	10	29	-0.9899	2.045	p>.05
9	10	29	1.02	2.045	p>.05
10	10	29	-1.49	2.045	p>.05
11	10	29	-0.9899	2.045	p>.05
12	10	29	0.015	2.045	p>.05
13	10	29	-0.9899	2.045	p>.05
14	10	29	0.517	2.045	p>.05

Table 8-4. Calculated modified t-values comparison of individual SLI scores to typically developing children in the same chronological age-matched group.

The total emotion recognition scores in the typically developing controls and the SLI group were converted to Z scores (with a mean of 0 and a standard deviation of 1). In the 8-year old age group, the individual Z Scores of the children in the SLI group were compared to Z scores for the TD controls. The minimum score was -2.63 and the maximum score was 1.87. In the SLI group, there was one child with a Z score of 2 (higher than the maximum score obtained by the 8-year old TD controls) all other scores were within the boundaries of the minimum and maximum scores obtained by the 8-year olds. In the 10-year old group the minimum Z score was -1.52 and the maximum was 2.06. There was one child in the SLI group with a Z score of -1.9 (below the lowest score obtained by the 10-year old typical controls). All other scores were within the boundaries of the minimum and maximum scores of the 10-year old TD controls.

Cognitive correlates of musical emotion recognition

To investigate that extent to which musical emotion recognition was related to cognitive abilities in children with SLI, correlational analyses were carried on the experimental data and scores from the digit span, TROG-II and the BPVS-II (shown in table 8-1). Musical emotion recognition was not significantly correlated with performance on the measures of vocabulary (r= -.143), linguistic syntactic comprehension (r=.389) or auditory short-term memory (r=.070) (p>.05).

Musical correlates of emotion recognition

To address the question of whether or not performance on measures of pitch-interval direction discrimination, contour processing and musical syntactic comprehension were related to performance on the emotion recognition task in the children with SLI correlational analyses were carried out. Table 8-5 contains means and standard deviations of total correct scores for each of the musical measures for the participants in the SLI group who also completed this emotion recognition experiment. Musical emotion recognition was not significantly correlated with performance on the pitch interval task (r=.359) or explicit response accuracy for the harmonic priming task (r=.-.090) (p>.05). The implicit RT discrepancy scores for the harmonic priming task were significantly negatively correlated with emotion recognition scores (r=-.548).

Pitch-interval scores		**Chord priming RT discrepancy scores**		**Chord priming response accuracy**		**Emotion recognition scores**	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
21.93	5.63	109.97	554	12.69	2.6	4.64	2.09

Table 8-5. Means (SDs) of scores on the pitch-interval discrimination task, reaction time discrepancy implicit harmonic processing, response accuracy for explicit harmonic processing and emotion recognition in the children with SLI.

DISCUSSION

The first aim of this experiment was to compare musical emotional recognition in children with SLI with that of typically developing children matched for chronological age and verbal-mental age. The group analyses demonstrated developmental gains in musical emotion recognition in the typically developing controls; the older CA matched group obtained significantly higher scores than the younger VMA matched group. However, the emotion recognition scores for the SLI group were not significantly different to either the VMA-matched or the CA-matched controls. The data were further explored in a series of individual analyses and confirmed that the large majority of the children in the SLI group performed at a level that was not significantly different to that of the typically developing chronological age matched controls. In the SLI group there was one 8-year old with a score that was below 1.5 interquartile ranges below the 25^{th} percentile, which may indicate that this one participant with SLI had impaired music emotional recognition. In the 10-year old age group none of the children with SLI had scores that could be considered 'outliers' although there was one participant with a score of '1' and this was below the 25^{th} percentile of the scores achieved by the typically developing 10-year olds. However, in the study by Heaton et al., (2008), which utilized the same musical and pictorial stimuli, similarly low scores were observed in a number of typically developing children, and this suggested that the ability to recognise musical emotions is more variable than is often assumed. Taken together the findings from this experiment seem to indicate that children with SLI are able to recognize and appreciate higher-order properties of music as accurately as typically developing children.

Theoretical accounts of SLI propose that language deficit results from abnormalities in auditory short-term memory (Gathercole & Baddeley, 1990) and it has been suggested that music and language depend on shared neural and cognitive mechanisms (Patel, 2008). Moreover, Heaton, et al., (2008) found a strong association between emotional recognition in music and language ability in children with autism and Down syndrome. However, the analysis of the SLI data failed to reveal significant correlations between total emotional recognition scores and measures of auditory short-term memory or language ability (receptive vocabulary and linguistic syntactic comprehension). Analysis of the data from the cross modal priming task (detailed in chapter seven) revealed that auditory short-term memory mediated the extent to which the simultaneous presentation of music impacted upon the processing of a visual target in the SLI group thus indicating that auditory short-term memory may be implicated in the ability to control the auditory environment. However, analysis of the pitch-interval discrimination and melody discrimination tasks (detailed in chapters four and five) revealed that auditory short-term memory was not related to performance on either of these musical measures in children with SLI. Thus it seems that whilst auditory short-term memory may be important for controlling the auditory environment, the processing of music does not rest exclusively upon this cognitive ability in children with SLI. It may be that the multi modal nature of music means that children with impaired auditory short-term memory can utilize visuo-spatial memory processes to represent and retain music and this may be an important strategy for the processing of emotional content in music also.

Experiments reported in chapters four and five revealed some sparing in aspects of musical processing, and it was hypothesized that pitch and contour discrimination ability might facilitate recognition of musical emotions. However, when the data from the emotion recognition study were correlated with scores from experiments testing pitch-interval discrimination and musical priming no relationship was observed. Thus it may be that the recognition of musical emotion is dependent upon a range of different mechanisms including learned associations of certain musical cues (such as tempo and timbre) with particular emotions (Juslin & Vastjfall, 2008).

The absence of any correlation between musical emotion recognition and language skills suggests differences across these neurodevelopmental disorders in the extent to which language ability is implicated in emotion recognition in music. The results from experiment six provided no evidence for an association between impaired vocabulary and syntax and a capacity to recognize and categorise musical emotions in SLI.

It has been reported that children with SLI are impaired in their capacity to name emotion expressed in speech and to match emotional speech gestures to facial expressions (Boucher et al., 2000). This poor vocal-facial affect matching has been interpreted as reflecting an impairment in cross modal processing in children with SLI (Boucher et al., 2000). In experiment six the children with SLI were able to recognize the emotional content of the music and to match that to a visual representation of the emotion. Thus it seems that cross modal limitations in matching emotion in speech to facial expressions of emotion do not generalise to difficulties matching classical musical excerpts to visual depictions of emotional states. However, there are a number of possible explanations for why SLI may be associated with impaired vocal-facial affect matching in speech and yet preserved emotional recognition in music. Firstly, it may be that SLI is associated with a deficit in processing emotions in faces and the pictures used in the experiment represented emotional scenarios rather than emotional faces. Secondly it may be that music provides more cues to emotional content than speech. For example in the classical excerpts used in the present study variations in rhythm, timbre, tempo and mode were all exploited by their composers to communicate particular emotional intentions to the listener. Thus in music there are multiple cues for conveying emotion that may not be present to the same degree in speech.

The findings from experiments one and two revealed some spared ability to process pitch intervals and chords in the SLI group. Whilst the correlational analysis failed to reveal any current association between these abilities and music emotion recognition, they may have functioned to increase the salience of music at earlier developmental periods. Music is ubiquitous in the environment and so the majority of musical listening and subsequent learning comes from mere exposure. At a very early age, infants are able to process and respond to melodic contour (Trehub, 2003) and it may be that contour is especially salient to listeners early in development and as such may facilitate early musical learning. For children with SLI, preserved contour processing may enable this music learning to take place at this early stage in development.

The findings from experiments three and four indicate that some children with SLI may be unable to explicitly recognise harmonic violations in music and this may reflect a degree of disruption to the procedural memory network (Ullman & Pierpont, 2005). However, the findings from the cross modal experiment (chapter seven) indicated that whilst children with SLI show impaired explicit recognition of musical structure, they do process structural regularities in music at an implicit level. Thus it could be that auditory processing limitations impact upon their ability to explicitly recognize whether or not a target chord is related to the prime sequence. Miranda & Ullman (2007) observed that typical adults showed a different ERP response pattern to variations in familiar melodies as compared with harmonic violations in unfamiliar melodies and argued for different and independent neural mechanisms in rule-governed and memory-based melody processing. Thus it is possible that even if disruption to the procedural memory network negatively impacts upon the ability to explicitly recognize structural violations in music, the capacity to recognise emotional content in music is retained, either because this information has been learned and stored within a declarative memory network or because the structure is processed at an implicit level. Support for the notion that semantic and syntactic processing may be separable in children with SLI comes from an ERP study of language processing. Fonteneau and van der Lely (2008) found that children with SLI showed intact semantic processing but atypical ERP responses to grammatical violations in sentences.

CONCLUSION

The findings from experiment six demonstrate that children with SLI are able to accurately match the emotional connotation of a classical musical excerpt to a visual representation of an emotional state. Despite delay in pitch-interval discrimination (experiment one), auditory short-term and working memory (experiment two) and disruptions in syntactic processing (experiments three, four and five), the findings from the experiment described in this chapter indicate that children with SLI do show some ability to recognise emotional cues in music. This may be an islet of preserved ability and may reflect a compensatory reliance upon alternative strategies for musical processing in children with SLI.

The final discussion chapter will review the findings from each of the experimental chapters and relate them back to the theoretical accounts of SLI outlined in chapter one.

CHAPTER 9

GENERAL DISCUSSION

ABSTRACT

This thesis addressed the question of how the study of musical cognition in children with Specific Language Impairment (SLI) can further understanding of this neurodevelopmental disorder. The six experiments described, explored different aspects of musical cognition, from simple pitch-interval discrimination though to more complex higher order processing of syntactic structure and emotional connotations in music. Performance on each measure of musical cognition has been considered and interpreted within the context of three broad theoretical frameworks of SLI: cognitive, linguistic and auditory. The findings indicate that SLI is associated with impairments in language and auditory short-term memory and yet there are aspects of musical cognition that appear to be relatively spared. The theoretical and clinical relevance of these findings will be discussed.

Why investigate musical cognition in children with SLI?

A diagnosis of SLI is associated with a range of negative consequences such as persistent difficulties with language and communication throughout childhood, and poorer academic and social outcomes in later life (Conti-Ramsden and Botting, 2008; Catts, 1993; Catts, Fey, Tomblin & Zhand, 2002). The investigation of musical cognition in children with SLI has both theoretical and clinical relevance. Firstly from a theoretical perspective, the study of musical cognition in children with impaired language can yield further insight into the extent to which music and language are subserved by shared cognitive mechanisms (Patel, 2008). Furthermore, the investigation of musical cognition in children with SLI can also inform current discussions about whether SLI is a domain specific or domain general information processing disorder.

From a clinical perspective the investigation of competencies outside of the language domain could lead to greater insight into the broader cognitive and auditory processing mechanisms potentially underlying the language impairments observed at a behavioural level in children with SLI. Therefore this investigation could inform the development of more refined diagnostic criteria and targeted interventions for those children most at risk of developing language problems (Clark et al., 2007). Interventions for children with language disorders are typically focused upon the remediation of the apparent language difficulties through explicit language instruction (e.g. teaching phonology and vocabulary). Whilst one investigation into the efficacy of the 'FastForWord' training programme, designed to remediate auditory perceptual deficits, failed to observe significantly greater improvements in language performance than those achieved through participation in existing speech and language therapy (Cohen et al., 2005), little is known about the potential benefits of musical training for children with SLI. One recent musical intervention study reported that typical 7-8 year old children, who participated in a musical training programme for a period of 18 months showed significantly greater gains in verbal memory over those observed in a control group who participated in a science training programme (Roden, Kreutz & Bongard, 2012). Whilst these findings suggest that participation in musical training is associated with improvements in auditory short-term memory in typical children, the results must be interpreted with caution since the allocation of participants into music, science and control groups was not randomized in the study. There is a great deal of interest in the extent to which participation in musical training can lead to improvements in cognitive abilities that are important for a range of different functions (Roden et al., 2012), and this work has important implications for future intervention programmes for children with SLI.

The investigation of processing outside of the language domain could offer insight into the broader cognitive limitations that may be present in children with SLI. If SLI is associated with impairments in cognitive mechanisms that process information from different domains, engagement in musical training could be of benefit. For example, if SLI is associated with impaired auditory short-term memory that disrupts the processing of verbal and melodic information, musical training targeting melodic memory may strengthen auditory short-term memory resulting in knock-on improvements in language processing. Musical training, especially individual music lessons, has been shown to convey a number of positive motivations and rewards (Patel, 2011) and may be particularly beneficial for children with SLI. The investigation of musical cognition in children with SLI can provide profiles of musical strengths and weaknesses that can inform the development of musical intervention programmes. Such programmes would primarily aim to strengthen impaired cognitive mechanisms but also provide opportunities for building self-esteem, improving self-efficacy and fostering social relationships (Welch et al., 2011).

Revisiting linguistic, auditory and cognitive accounts of SLI

In typical language acquisition, children first begin to communicate using single words and then combine these words to create sentences, with the use of grammatical sentences emerging at around age 2-3 years (Bates & Dick, 2002; Leonard, 1998). Children with SLI show a delay in language onset, with later first word production than typically developing children and particular difficulty learning verbs (McCune & Vihman, 2001; Leonard, 1998). Whilst it has been demonstrated that there is a genetic component to SLI, genetics alone cannot fully explain the etiology of this disorder and it has been suggested that genetic constraints in auditory short-term memory interact with environmentally mediated limitations in auditory processing to give rise to language difficulties severe enough to warrant a diagnosis of SLI (Bishop, 2001). Thus it seems that whilst genetic factors may contribute to the onset of SLI, this disorder is complex and is most likely diagnosed in children following an interaction of a number of different risk factors (Newbury et al., 2005; Skuse & Siegal, 2007; Clark et al., 2007).

Although SLI is associated with delayed language acquisition, there are particular aspects of language functioning that have been identified as atypical (e.g. grammatical aspects of language such as tense marking). Linguistic accounts of SLI have proposed that at least a sub-group of children with SLI have a primary grammar-specific language deficit that affects hierarchical structural processing of syntax, morphology and phonology (van der Lely, 1994). Support for the notion that SLI may be associated with a deficit in syntactic processing comes from one EEG study reporting that children with SLI show atypical ERP responses to structural violations in sentences (Fonteneau & Van der Lely, 2008). One problem with this account is that although it affords an explanation for the language difficulties observed in many children with SLI, it cannot explain the broader range of cognitive and auditory processing limitations that are often reported. An alternative account from within a cognitive theoretical framework, suggests that the grammatical impairments of language observed in SLI, stem from an impairment in the domain general procedural memory network, responsible for the implicit learning and online processing of rule structures across domains and modalities (Ulman & Pierpont, 2005). Support for the procedural memory deficit account of SLI comes from research reporting that children with SLI show impaired implicit learning of rule structures across domains and modalities (Evans et al., 2009; Tomblin et al., 2007).

The auditory processing deficit account of SLI suggests that low-level difficulties with auditory perception negatively impact upon the individual's ability to process speech (Tallal & Piercy, 1973). However, investigations of auditory processing in children with SLI have yielded somewhat mixed findings and intervention studies using computer-based training programmes designed to remediate auditory processing difficulties in children with SLI have reported mixed success (Cohen, Hodson, O'Hare, Boyle, Durrani, McCartney, Mattey, Naftalin & Watson, 2005; Temple, Deutsch, Poldrack, Miller, Tallal, Merzenich & Gabrieli, 2003). This may suggest that auditory processing difficulties are limited to a sub-group of children with SLI and may not be sufficient to explain the range of impairments often observed in this disorder (McArthur & Bishop 2004b; Mengler, et al., 2005; Rosen, 2003; Bishop, 1999; 2001).

There are a range of theoretical accounts that attempt to move beyond the observable language impairments to consider the specific higher cognitive deficits that result in language impairments observed at a behavioural level. From within a neo-constructivist framework it is possible that atypical cognitive development during infancy and childhood has repercussions on a range of different functions in children with SLI (Karmiloff-Smith, 2009; Thomas, 2006). Auditory short-term memory is one cognitive function that is important for efficient language processing (Gathercole & Baddeley, 1993), and an impairment at this level is likely to negatively impact auditory sequential information processing involved in language and music. One clinical marker of SLI, that has a distinct genetic component, is poor non-word repetition and it has been argued that poor performance on this measure reflects a deficit in the phonological loop component of working memory (Norbury et al., 2009; Clark et al., 2007; Bishop 2001; Gathercole & Baddeley, 1990; Gathercole & Baddeley, 1990a; Montgomery, 1995).

Characterising the language and cognitive profiles of children with SLI

The aim of this thesis was to carry out a comprehensive and systematic investigation of musical cognition and relate the findings to the linguistic, auditory and cognitive theoretical accounts of SLI. A range of language and cognitive abilities were investigated in a group of children with SLI and typically developing controls matched for chronological age and verbal mental age. The decision was taken to include two typically developing control groups so that it was possible to determine whether or not the performance of the children with SLI was similar to that of younger typically developing children and therefore indicative of developmental delay, or was atypical, signaling a deficit. The inclusion of a second younger VMA-matched control group also allowed typical developmental changes in aspects of music cognition to be investigated.

Investigation of the language profiles of children with SLI (detailed in chapter three) revealed very poor performance on the BPVS-II measure of receptive vocabulary and the TROG-II measure of linguistic grammatical comprehension. This was indicated by standardised scores that were more than 1.5 standard deviations below the typical population mean. In contrast, scores on the Ravens Matrices measure of non-verbal intelligence were within the low-average range for this group. This analysis of the verbal and non-verbal abilities confirmed that all of the children with SLI showed a discrepancy between their performance on the measure of non-verbal intelligence and the language measures and so met the diagnostic criteria outlined in the DSM-IV.

Although performance on the TROG-II was very poor in the SLI group, further investigation revealed that the majority of children showed a 'sporadic' pattern of performance. Through examination of the error rates produced on the most difficult final five blocks of the TROG-II, it was found that all but one of the children with SLI did not consistently show below-chance performance, indicating that they had some grammatical knowledge. Thus it seems that the poor grammatical comprehension observed in the children with SLI was attributable to processing limitations rather than a lack of knowledge of the grammatical constructs being tested (Bishop, 2003). Support for the notion that limitations in processing were underpinning the poor performance on the TROG-II comes from the correlational analyses showing that digit span scores were positively correlated with the total number of TROG-II blocks passed (at a level approaching significance). Therefore, for the majority of children with SLI, poor performance on the TROG-II could be explained by poor processing associated with an impairment in auditory short-term memory. These results call into question the extent to which the children included in this SLI group would meet criteria for Grammatical SLI (G-SLI) (van der Lely, 1994).

The findings from the cognitive analyses demonstrated that children with SLI showed impaired performance on the CNRep measure of phonological short-term memory and the digit span measure of auditory short-term memory. Investigation of discrepancy scores for forwards and backwards digit span revealed that the typically developing children showed significantly higher forwards than backwards digit span scores. This result is consistent with previous work demonstrating the additional involvement of attention and working memory resources on the backwards digit span measure (StClair Thompson, 2010). The children with SLI showed equivalent forwards and backwards digit span scores indicating that SLI is associated with a deficit in auditory short-term memory that results in poor retention and manipulation of auditory information within short-term memory. These findings support the cognitive phonological short-term memory deficit account of SLI and indicate that SLI may be associated with more general cognitive impairments outside of the language domain (Gathercole & Baddeley, 1990).

It has been suggested that the language difficulties in children with SLI may be in part attributable to a generalised slowing of information processing speed (Kail, 1994). To rule out the possibility that performance on measures of music or language cognition were attributable to a generalised slowing of processing speed, the 'coding' sub-test from the WISC-IV was administered. The findings demonstrated that the children with SLI did not differ from the CA-matched controls on this measure, thus the observed language difficulties could not be explained by generalised delays in processing speed. Furthermore, a comparison of performance across the digit span and coding sub-tests revealed that the younger VMA-matched typically developing children and the children with SLI showed better performance on the coding task than the digit span task, which may indicate that processing speed drives improvements in auditory short-term memory in typically developing children but not in children with SLI.

It has been suggested that low level auditory perceptual difficulties negatively impact upon the capacity to discriminate between sounds in speech (Ziegler et al., 2005). Therefore the TAAS measure of auditory processing was administered to children with SLI and typically-developing matched controls. The results revealed significantly poorer performance in the SLI than the CA or the VMA-matched groups, and this suggested that SLI may be associated with a deficit in processing speech sounds. This lends some support to the notion that SLI is associated with auditory processing difficulties that impact upon language abilities.

Analysis of the language and cognitive measures in chapter three revealed that, in line with a cognitive deficit account, the children in the SLI group showed impaired auditory short-term memory alongside intact non-verbal intelligence and processing speed.

<u>Findings from the musical experiments interpreted in the context of theoretical accounts of SLI.</u>

The broad aim of this thesis was to investigate musical cognition and to further understand the nature of language impairments observed in children with SLI. The experimental chapters described in this thesis investigated pitch-interval discrimination, novel melody discrimination, implicit and explicit priming of visual motor-action sequences and music, and musical emotion recognition.

As has been previously suggested, there is a somewhat mixed picture concerning the nature and prevalence of auditory processing difficulties in children with SLI (e.g. McArthur et al., 2009; Jentschke et al., 2008; Bishop et al., 2005) and some researchers have suggested that auditory perceptual difficulties may only be characteristic of a sub-group of children with SLI. Whilst some researchers have suggested that impairments in auditory short-term memory can be explained by low-level auditory perceptual deficits in children with SLI (see Vance, 2008 for a review), others have argued that these are distinct deficits with different origins (Bishop, 1999; 2001). Bishop (2001) suggests that deficits in auditory short-term memory and degraded auditory perception are separable impairments with different origins that may interact to contribute to the severity of the language profiles observed in children with SLI (Bishop, 1999; 2001). For example, degraded auditory processing could exacerbate an already existing impairment in phonological short-term memory so that a child with deficits in both of these areas is less able to compensate and therefore is more likely to present clinically with severe language impairments, leading to a diagnosis of SLI.

An important question, that not been previously studied in SLI, concerns the extent to which deficits in short-term memory and degraded auditory perception impact on musical perception and cognition. The aim of the first experiment, reported in chapter four was to investigate pitch-interval direction discrimination in children with SLI and typically developing controls. It was hypothesised that if SLI is associated with impairments in low-level auditory processing this ought to be reflected in poorer discrimination of both small and medium pitch intervals as compared with CA-matched controls. The second aim of this first experiment was to investigate the extent to which pitch-interval direction discrimination was related to auditory short-term memory in typically developing children and children with SLI.

In experiment one, all groups showed above-chance discrimination accuracy for small pitch-intervals. This finding shows that the children with SLI did not have an absolute deficit in pitch-interval direction discrimination. Between-group comparisons demonstrated similar levels of discrimination accuracy in the SLI and VMA-matched groups, with both groups performing at a lower level than the CA-matched controls. It seems then, that whilst children with SLI do not show an absolute deficit in their ability to discriminate between changes in pitch, they do show a delay, which may reflect a degree of immaturity in auditory processing (McArthur & Bishop, 2004b). Further analyses of the data showed that whilst pitch-interval direction discrimination was significantly correlated with auditory short-term memory in the typically developing children this was not the case for the children in the SLI group. Thus it seems that in children with SLI the ability to discriminate the direction of pitch-intervals is not related to auditory short-term memory. It has been suggested that auditory processing may be environmentally mediated in children with SLI (Bishop, 2001) and data on musical experience and training were available for analysis. However, it was found that the musical background of either the parents or the children did not predict performance on the pitch-interval discrimination task in this sample of children with SLI.

The results from the correlational analyses indicated that for typically developing children, the perception of pitch-direction is positively associated with auditory short-term memory. Although the children with SLI showed a deficit in auditory short-term memory they discriminated the pitch intervals at a level that was significantly above chance and as good as that of VMA-matched controls. Thus it seems that children with SLI show a degree of spared musical processing. Prior investigations of frequency discrimination in SLI (Mengler et al., 2005), typically present the child with a sequence of three tones and require him/her to determine which of the three tones is the odd-one-out. In a pitch-interval direction discrimination paradigm, as used in experiment one, contour is represented, and attention is focused on the direction of the pitch change within the contour. Bertz (1995) has suggested that contour representation places fewer demands on auditory short-term memory than groups of discrete pitches, and this may explain the relatively spared performance of the children with SLI on this first experiment. Pitch information is a crucial musical building block, and results showing some retention of pitch processing in SLI, has implications for the design of future musical training programmes. Building on these results, the second experiment, reported in chapter five investigated interval and contour processing in melodies over a longer duration.

Research has shown that musical and verbal information are rehearsed in auditory short-term memory (Roden et al., 2012; Williamson, Baddeley & Hitch, 2010; Mandell et al., 2007) and the results from experiment one, showing that pitch-interval direction discrimination is related to auditory short-term memory in typical development, supports this work. At a perceptual level it has also been suggested that there may be shared auditory networks implicated in processing sounds in music and in speech (Patel, 2011). For example, prosody and melody both depend upon the tracking of pitch contour within auditory sequences. The analysis of the cognitive and auditory data from the SLI group (described in chapter three) revealed deficits in auditory short-term memory and speech processing, and yet experiment one identified relatively preserved processing of pitch-interval contours. Experiment two investigated the extent to which the cognitive impairment in auditory short-term memory impacted upon the ability to represent and to process contour and interval changes in melodies over longer durations.

When asked to discriminate between two novel interval- or contour-violated melodies of three or five tones duration, the SLI group showed significantly poorer discrimination accuracy than the CA-matched and VMA-matched controls. Consistent with previous research (Heaton, 2005; Deruelle et al., 2005) all participants showed better discrimination of contour-violated than interval-violated melodies. At the group level, the children with SLI showed chance performance when asked to discriminate between interval-violated melodies and above-chance discrimination of contour-violated melodies. Their level of discrimination accuracy for either interval-violated or contour-violated melodies did not vary as a function of length and was not related to digit span. In contrast, the typically developing children showed better discrimination accuracy for shorter 3-tone melodies than longer 5-tone melodies, and their discrimination accuracy scores on the interval-violated melody condition were significantly positively correlated with digit span.

The findings from experiment two were consistent with the results from experiment one in several ways. Firstly, in contrast to typical controls, performance on neither the pitch-interval direction discrimination task nor the melody discrimination task, were significantly correlated with auditory short-term memory ability in children with SLI. One possible interpretation of this result is that deficits in auditory short-term memory predispose the development of a compensatory music processing strategy in this group. For example, they may not attempt to represent entire melodies within auditory short-term memory, but may instead attend to the most distinctive and informative cue in the music they hear (Sussman, 2001).

Research has shown that the contour shape of a melody is represented in both visual and auditory modalities during music listening (Prince, Schmuckler & Thompson, 2009). This raises the possibility that the children with SLI showed relatively spared processing of contour across experiments one and two because they compensated for their limitations in auditory short-term memory by relying on spared visuo-spatial memory to represent and successfully discriminate melodic contours. The cross modal representation of pitch contour could also go some way towards explaining why younger typically developing children show much better discrimination of contour-violated melodies and show age-related improvement in interval discrimination in parallel with the development of auditory short-term memory.

Music, like language and action is comprised of sequential elements that must be combined in accordance with rules embedded in a particular hierarchical structure (Fadiga et al., 2009). To construct or to comprehend a piece of music, or a sentence, a series of tones, or words, must be combined in accordance with a particular rule-sequence (Saffran & McMullen, 2004). Similarly, to perform a complex action, a series of small motor movements must be combined in a hierarchically governed action sequence (Botvinik, 2008). The processing of hierarchical information in music, language and action has been found to activate a fronto-cortical network including Broca's area and it has been suggested that the procedural memory network may sub-serve the processing of this type of structural information across domains (Ullman & Pierpont, 2005).

SLI is associated with impaired use and comprehension of linguistic syntax and it has been argued that this impairment is the consequence of a domain specific impairment in the language system (Leonard, Bortolini & Caselli, 1996; Marshall & van der Lely, 2007). An alternative account argues that the grammatical language impairments in SLI are the result of a deficit in a domain general procedural memory network (Ullman & Pierpont, 2005). From within each of these theoretical accounts specific predictions about the nature of hierarchical processing of information outside of the language domain arise. From within a domain general procedural deficit account, it would be predicted that children with SLI would show disrupted processing of procedural knowledge in motor and musical domains, whereas a linguistic grammar-specific deficit account of SLI would predict that procedural processing outside of the language domain should be relatively intact in children with SLI.

The analysis of the data from the TROG-II, confirmed a deficit in linguistic grammatical processing in the SLI group, and the aim of experiments three and four was to investigate the processing of implicitly learned procedural knowledge about music and action. Perceptual priming tasks were used to probe implicit knowledge of structural information in visual motor-action and musical sequences in children with SLI and typically-matched controls. Based on previous research showing impaired and delayed implicit procedural learning in SLI, the hypothesis for experiment three stated that an impairment in the procedural memory network would disrupt the learning and automatisation of procedural knowledge of visual motor-action sequences in children with SLI (Evans et al., 2009; Tomblin et al., 2007). It was also hypothesised that age, auditory memory and the ability to explicitly recognise the correctness of the visual-motor action and musical targets would be related to implicit responses to the target in the children with SLI.

Analysis of the implicit reaction times (RTs) for processing visual motor-action targets showed that the children in the SLI group were faster to make a judgment about the correctness of congruent hand-grasp targets than incongruent targets, whereas the TD controls processed both congruent and incongruent visual motor-action targets equally efficiently. One interpretation of these findings is that through extensive exposure and experience, procedural knowledge of motor-action sequences has become learned and fully automatized in typically developing children, leading to equally efficient processing of congruent and incongruent visual motor-action targets. However, children with SLI may process unexpected incongruent visual motor-action targets less efficiently than expected visual motor-action targets, because the automatisation of procedural skill learning is delayed and they continue to rely upon attention and working memory to process the procedural information (Ford et al., 2005; Beilock et al., 2002). Thus the continued reliance upon mechanisms of attention and cognitive control to process the visual motor-action stimuli result in a reaction time cost when a visual target is unexpected and there is a need to resolve a conflict between the unexpected representation and a cognitive representation of the predicted outcome.

Experiment four investigated explicit knowledge of musical hierarchical structure and implicit RTs for processing structural regularities in music. It was hypothesised that typically developing children, with implicitly acquired knowledge of Western tonality, would show faster and more accurate responses to congruent expected musical target chords than incongruent unexpected target chords. The results from the study showed that the older CA-matched controls were able to explicitly determine the correctness of the target chord with above-chance accuracy, whereas the younger VMA-matched controls were performing at chance. At the group level, the children with SLI were no better than chance at explicitly determining the harmonic correctness of the target chord. However, individual analyses revealed that within this group there were seven children (constituting 41% of the SLI sample) who were able to make correct explicit judgments at levels that were better than chance.

Analysis of the implicit RT responses indicated that the CA and VMA-matched typically developing children made significantly faster RT responses to congruent than incongruent musical targets, whereas the children with SLI did not. The implicit processing advantage for congruent musical targets observed in the typically developing children in experiment four replicates findings by Schellenberg et al. (2005), and supports the notion that by around the age of 6-7 years, typically developing children have acquired knowledge of Western harmonic structure (Corrigall & Trainer, 2010; Heaton et al., 2007), and this knowledge confers a processing advantage for expected targets. Similarly, the apparent absence of an implicit RT effect alongside poor explicit recognition of the harmonic correctness of the target chords are in line with results obtained by Jentschke et al. (2008), indicating that children with SLI do not process harmonic regularities in music in the same way as typically developing children. Thus it could be concluded from these findings that impairments in grammatical processing extend to musical information in children with SLI, supporting the notion that shared mechanisms within a procedural memory network are impaired (Ullman & Pierpont, 2005). However, a significant proportion of the SLI group showed explicit awareness of harmonic congruency/incongruency and a correlational analysis revealed a significant negative correlation between the explicit recognition of harmonic congruency of target chords and performance on the TROG-II measure of linguistic grammatical comprehension. Thus children in the SLI group with poor sentence comprehension actually showed better explicit recognition of musical structure than children with SLI whose sentence comprehension was less impaired.

In an attempt to better understand this negative relationship between explicit comprehension of musical structure and performance on the TROG-II, further analyses were carried out on the background data. The analysis of the cognitive and linguistic measures (detailed in chapter 3) revealed that digit span was positively correlated with performance on the TROG-II, demonstrating that in children with SLI, better auditory short-term memory is associated with better grammatical comprehension of spoken sentences. Experiments one and two showed that the ability to discriminate the direction of pitch-intervals or to process novel melodies was not related to auditory short-term memory in SLI. Thus it seems that in children with SLI, the online grammatical comprehension of spoken sentences is related to auditory short-term memory, whereas the online processing of aspects of music is not. It was earlier suggested that the relative sparing of contour processing in SLI reflects an increased reliance on the visual representation of melodic contour as a compensation for deficits in auditory short-term memory. In the experiment adopted in experiment four, it is possible that a reliance upon a visuo-spatial representation of contour facilitated musical syntactic comprehension by providing a more robust memory representation of the prime sequence that could then be compared with the target. A strategy of relying upon a visual representation of contour in the online processing of auditory information would be highly detrimental to the processing of syntactic cues in spoken sentences and this may explain the negative correlation between syntax processing across music and language domains in the SLI group.

One of the difficulties in interpreting the findings from experiments three and four is that they simultaneously measured explicit recognition and implicit responses. Participants were asked to determine whether the final target was ‘right’ or ‘wrong’, and the time taken to make their responses was measured. Thus the implicit reaction time measure is confounded by the need to make an explicit judgment about the structural correctness of the target. It is possible that the instruction to focus on a particular feature of the learned skill resulted in de-automatisation of procedural knowledge and a re-introduction of working memory and attention for the online monitoring of the already learned procedural knowledge (Ford et al., 2005). Thus in the children with SLI it is difficult to know if the absence of a RT advantage for processing structurally correct target chords is due to a failure to acquire and construct a schematic representation of musical structure, or difficulty with the online processing of acquired procedural knowledge needed to make an explicit judgment about the correctness of the musical target. To counter this problem, a cross modal priming task was devised, to measure the impact of music on the ability to make an explicit judgment about the correctness of a concurrently presented visual motor-action target.

Music, language and complex action all have a syntactic-like structure (Botvinik, 2008) and neuroimaging has shown that the same fronto-parietal neural network is implicated in processing hierarchical structure across domains (Farag et al., 2010). It has been suggested that the same pool of cognitive mechanisms (e.g. attention and cognitive control) are important for the online monitoring of syntactic processing across domains and modalities (Slevc et al., 2013; Escoffier & Tillman, 2008). The aim of the cross modal experiment was to investigate the extent to which the processing of visual motor-action sequences was influenced by the concurrent processing of musical syntactic information in typically developing children and those with SLI. It was hypothesised that in the typically developing children, increased cognitive load would reduce the automaticity with which responses to a visual motor-action target could be made in the cross modal task. The findings demonstrated that all children showed faster responses to congruent than incongruent visual motor-action targets, indicating that the automaticity with which the visual targets were processed was reduced in the TD controls when they were required to concurrently process a competing musical stimulus. This appeared to support the notion that a shared pool of cognitive resources may be implicated in monitoring the processing of procedural information across domains.

Escoffier and Tillman (2008) found that in typical adults, the concurrent processing of a musical target facilitated the processing of a visual motor-action target when the musical target was harmonically congruent with the musical prime. In the cross modal task, (experiment five) analysis of the RT discrepancy scores for visual motor-action targets demonstrated that across all three groups there was a degree of interaction between the musical and visual motor-action sequences. All participants showed faster RTs for congruent visual motor-action targets when they were accompanied by congruent musical chords (positive RT discrepancy scores), alongside faster RTs for incongruent visual motor-action targets when they were accompanied by incongruent musical chords (negative RT discrepancy scores). Correlational analyses demonstrated that RT discrepancy scores for visual motor-action targets accompanied by an incongruent musical target chord were significantly positively correlated with digit span scores in the children with SLI. Furthermore, when digit span scores were entered as covariates in the analysis the difference in RT discrepancy scores was no longer significant. This finding indicates that variability in auditory short-term memory was mediating the extent to which the concurrent presentation of a congruent or incongruent musical target influenced responses to the visual motor-action target.

One of the most interesting findings from the cross modal experiment was the extent to which the concurrent presentation of music influenced the processing of visual motor-action targets in the children with SLI. Contrary to earlier work indicating impaired musical syntactic processing in children with SLI (Jentschke et al., 2008), the findings from the cross modal task demonstrated that the processing of visual motor-action targets was strongly influenced by the concurrent presentation of music for children with SLI as well as typically developing controls. Across all three groups the concurrent presentation of a congruent or incongruent musical target influenced responses to the visual motor-action target. Boucher et al. (2000) observed that children with SLI were impaired in their capacity to match vocal affect in speech gestures to facial expressions of emotion and suggest that this may be due to a deficit in cross modal processing. However the findings from the cross modal priming task seem to indicate that children with SLI are showing cross modal integration in syntactic processing across visual-motor and auditory musical domains that is similar to that observed in typically developing children.

The findings from experiment five appear to indicate that children with SLI have acquired a schematic representation of Western tonality and that this structural knowledge influences the speed with which judgments about a concurrently presented visual motor-action target can be made. The final experiment in this thesis investigated emotion recognition of classical musical excerpts in children with SLI. The ability to recognise emotion in music is arguably the most complex and higher-order aspect of musical cognition, as it rests upon an ability to interpret the communicative intent of the composer. It has been suggested that the capacity to recognise emotion in music rests upon the listener's own subjective emotional response, whereas others have suggested that there are multiple routes to emotion recognition and personal emotional experience is only one of them (Juslin & Vastjfall, 2008; Huron, 2006; Krumhansl, 1977; Meyer, 1965). The aim of this final experiment was to determine whether or not children with SLI were able to recognise emotion in ecologically valid classical musical excerpts.

Previous research showing that SLI is associated with low-level auditory processing deficits (McArthur & Bishop, 2004) and impaired representation of musical syntactic structure (Jentschke et al., 2008), might lead to the prediction that children with SLI would show impaired appreciation of the emotional components in music. However the results from experiments one and two revealed a degree of spared musical perception and the findings from experiment five provided evidence for some understanding of harmonic relations in children with SLI. These aspects of spared musical processing may facilitate musical emotional recognition in this group.

In experiment six, participants were asked to listen to classical musical excerpts and to pair them with one of a group of pictures depicting particular emotional states. The results from this experiment showed that the children in the SLI group performed at a significantly higher level than VMA children as well as the CA-matched children on this task. Thus it seems that musical emotion recognition is intact in children with SLI. Furthermore, musical emotion recognition was not related to cognitive ability, demonstrating that impairments in language comprehension and auditory short-term memory do not disrupt musical emotion recognition in children with SLI.

Experiments one and two indicated that the capacity to discriminate the direction of pitch-intervals and to discriminate between two novel melodies was related to auditory short-term memory in typically developing children. The children with SLI showed impaired auditory short-term memory and yet retained a capacity to process pitch-intervals and contour-violated melodies with above-chance accuracy. One suggestion is that children with SLI show relatively spared processing of melodic contour. Experiment three demonstrated that SLI may be associated with a slight delay in the automatisation of procedural knowledge of visual motor-action sequences relative to typically developing children, and experiment four showed that explicit recognition of harmonic structure was poorer in children with SLI than typical CA-matched controls. However, in experiment five, in which a cross modal priming paradigm was adopted, the responses of the children with SLI were strongly influenced by the musical stimuli, and they showed a similar effect to typical controls. Thus it seems that acquired schematic knowledge of western tonality influenced the processing of a target in another domain in children with SLI. It does not therefore appear that SLI is characterized by a failure to acquire a representation of tonality.

It seems then that SLI is associated with relatively spared processing of musical contour and musical syntax and that this may contribute to the preserved capacity to recognise and to process the emotional components in music. Juslin and Vastjfall (2008) suggest that there are multiple mechanisms implicated in musical emotion recognition and the findings from the final experiment in this thesis indicate that children with SLI are able to utlise whatever mechanisms are needed to understand the communicative intent of the composer. At this, the highest and most complex level of music, children with SLI appear to be unimpaired.

The analyses of the error patterns on the TROG-II, and performance on the explicit measure of the harmonic priming task, both indicate that children with SLI do not have a concrete absence of musical and linguistic structural knowledge, but that cognitive deficits limit their ability to process already learned procedural knowledge. Experiment three demonstrated that SLI is associated with a delay in procedural learning and a continued reliance upon cognitive mechanisms of working memory and attention to process procedural information in the visual motor-action domain. Thus whilst the findings from this thesis do not support the notion that SLI is associated with an absolute deficit in the acquisition of procedural knowledge, it may be that a deficit in the procedural memory network results in delayed automatisation of procedural knowledge and a greater reliance upon working memory and attention for online processing in children with SLI. Furthermore it is possible that for children with SLI, cognitive limitations disrupt the online processing of procedural information in music and language domains. Whilst the findings from this thesis cannot disprove a grammar-specific linguistic deficit account of SLI (van der Lely, 1994), they do indicate that broader cognitive processing limitations contribute to the grammatical impairments observed in SLI.

Considering an auditory processing deficit account of SLI, impairments on the TAAS measures of auditory speech processing, together with lower scores on the pitch-interval direction discrimination and melody discrimination tasks than those of typical CA-matched controls, may indicate poorer auditory processing skills in children with SLI. The observation that performance on the pitch-interval direction discrimination task was significantly positively correlated with performance on the TAAS in the children with SLI may indicate that there are shared auditory processing mechanisms implicated in processing the pitch-intervals and speech sounds across these two measures. It may be that SLI is associated with additional limitations in auditory processing that contribute to performance on measures of music and language cognition and such underlying auditory processing difficulties may be an additional risk factor for the onset of SLI (Bishop, 2001).

The children in the SLI group showed a clear deficit in auditory short-term memory and throughout the thesis associations between this cognitive deficit and difficulties with aspects of language (e.g. processing grammatical constructs in spoken sentences) and music (e.g. the ability to represent and process embedded relative pitch-intervals in melody) have been demonstrated. Therefore the findings support a cognitive short-term memory deficit account of SLI. The observation of aspects of spared musical processing in the SLI group may reflect the cross modal characteristics of music. In relying on visual-spatial as well as auditory representations, music may allow for a route to compensation for those with very poor auditory short-term memory. Reliance upon course representations of contour would enable a child with SLI to reliably and efficiently extract important information from incoming auditory streams (e.g. following the intonation patterns in speech could provide an important cue as to whether an utterance is a question or a statement) and it could also help to retain musical material within short-term memory. Phoneme identification tasks in which the target sound is embedded in a phonetic context pose a particular problem for some children with SLI (Leonard et al., 1992; Sussman, 2001; Coady et al., 2005). For example, the SLI children performed more poorly than typically developing VMA-matched controls on the TAAS measure of speech processing in which they were asked to delete a phoneme from a word and to repeat it back. Whilst it has been suggested that difficulties with phonemic awareness are indicative of auditory processing limitations, they could also reflect limitations in auditory short-term memory and the use of compensatory strategies adopted to process incoming auditory information. In experiment two, the children with SLI were asked to discriminate interval-violated melodies and their performance was not better than chance and it is plausible to suggest that difficulties discriminating phoneme contrasts in speech and embedded pitch-intervals may stem from an underlying cognitive deficit in auditory short-term memory. Representing individual phonemes and tones within a short-term memory store is more costly than representing course-grained global properties such as contour. Therefore for children with very poor auditory short-term memory, reliance upon global cues may be the most efficient way to extract and to process relevant auditory information.

Implications of shared mechanisms within auditory short-term memory for processing music and language.

It has been reported that participation in musical training is associated with improvements in a range of cognitive functions in typical children (Roden et al., 2013; Moreno et al., 2009; Schellenberg, 2004). The observation that pitch-interval direction discrimination and melody discrimination are both correlated with auditory short-term memory in typically developing children supports the notion that there may be shared mechanisms within auditory short-term memory for processing verbal and musical information. Patel (2011) has suggested that musical training may be a particularly beneficial way to train generalised auditory processing networks as it is inherently rewarding and more taxing on the nervous system than processing speech. The same reasoning may apply to the training of cognitive mechanisms, such as auditory short-term memory which is important for a range of language functions. Participating in musical training brings the inherent reward of learning a new skill and as such has the potential to improve self-esteem and self-efficacy. This may be especially important for children who consistently struggle academically and for whom predicted long-term outcomes are not good. Furthermore, participation in group musical training provides a safe environment in which to socialise with other children, which again may be particularly beneficial for a child with communication difficulties who may ordinarily find social encounters particularly daunting (Farmer, 2000). Finally, and perhaps most importantly, learning a musical instrument provides an outlet for emotional expression and affect regulation, which again may be of particular importance to children with constrained language skills, who show a preserved capacity for musical emotion processing.

The evidence for cognitive benefits following musical training is not yet clear, and those studies that have been conducted are still in need of validation and replication. However, if the initial observations that musical training can lead to improvements in cognitive functions can be replicated, then participation in musical training could be one way to effectively target the cognitive difficulties underlying language impairments in children with SLI. The added benefits of musical training as compared with other forms of cognitive training (e.g. working memory training, see Holmes et al., 2010), may mean that this approach is particularly useful for children with SLI. The findings from this thesis demonstrate that children with SLI are able to process musical contour, show implicit awareness of musical syntactic structure and are able to recognise emotion in music. Thus it seems that for children with SLI, foundational aspects of musical cognition are preserved and participation in musical training may be rewarding and enjoyable. Engagement in musical activities may well lead to increased motivation and an increased likelihood of positive cognitive transfer effects in children with SLI.

Limitations

The findings presented in this thesis must be interpreted in light of certain limitations and unexpected difficulties encountered during testing. Firstly, it has been suggested that the auditory processing difficulties, present in some children with SLI, may be environmentally mediated (Bishop, 1999; 2001). Musical training serves to enhance low-level auditory processing and it was reasoned that children with SLI with an enriched musical background would show a different pattern of performance, across a number of tests, to those from less enriched musical backgrounds. In order to test this suggestion, a musical background questionnaire was administered to all participants directly and to the parents of all participants. The musical background data showed that although none of the children included in this study had received more than one year of formal musical training, there were a greater number of children in the typically-matched control groups with parents who played a musical instrument. Therefore it is possible that some children within the typical control groups came from slightly more enriched musical environments than the children with SLI. Whilst the musical task performance of the typically developing children was broadly consistent with results from previous studies into music perception, it is difficult to determine whether or not a higher level of musical enrichment in the SLI group would have served to close the gap between them and their age matched controls. As it was, the questionnaire data revealed a marked absence of any formal or structured musical enrichment in the SLI group. Indeed, it appeared that in some cases speech therapy sessions replaced class music, so they were even unable to access the limited musical opportunities on offer. One of the biggest problems in trying to capture something like 'musical background' is that music is ubiquitous and it may be that children differ in their preferences and responsiveness to music that they encounter on a daily basis in the surrounding environment. Thus it is possible for two children to come from identical environments, and yet have very different 'musical backgrounds' due to individual differences in their interest and motivation to attune to music. This random individual variability is likely to have a large impact upon the musical cognitive abilities of children, and yet it is not something that can easily be measured or controlled.

A second limitation with this work is that due to time constraints imposed by the schools in which the testing was conducted it was not possible to gather full background language data for the typically developing control children. However, all of the typically developing control children were recruited from mainstream schools and parental questionnaires indicated that none of the children had been diagnosed with a developmental disorder or had a history of neurological or audiological problems. Furthermore, all of the control children were screened for any potential undiagnosed language difficulties through administration of the 'Children's Test of Nonword Repetition'. However, the absence of comprehensive language data in the typically developing children meant that it was not possible to thoroughly investigate the nature of the relationship between music and language cognition in typical development. Whilst a detailed investigation of this type was beyond the scope of this PhD it will be an interesting topic for future work.

Future work

The first proposed future study is motivated by findings from experiments one and two, showing that SLI is associated with relatively spared processing of pitch contour. Archibald and Gathercole (2006) administered a range of measures to investigate short-term and working memory for auditory and visuo-spatial information, and found that children with SLI showed consistently poor auditory short-term and working memory but preserved visuo-spatial memory. Research has demonstrated that typically developing individuals represent melody in visuo-spatial as well as auditory formats (Prince et al., 2009), and this led to the suggestion that children with SLI show an increased reliance on visuo-spatial processing in music as a way of circumventing their auditory memory difficulties. This first study would test the notion that children with SLI are able to circumvent deficits in auditory short-term memory by relying upon a visuo-spatial representation of contour when processing music. In the first part of the study participants would be asked to complete visuo-spatial and auditory short-term and working memory measures and to carry out a melody discrimination task. Correlational analyses would be carried out to test whether or not performance on the melody discrimination task was related to either visuo-spatial and/or auditory short-term memory in the children with SLI and the TD controls. The second part of the study would test the notion that musical contour serves as a cognitive anchor for children with impaired auditory short-term memory. Short stories (adapted from the Children's Memory Scales) would either be read aloud or sung to participants. Following presentation of the stories, participants would then be asked to recall as much information as possible and to answer specific questions about the stories they have just heard. The amount of information recalled would be scored and compared across spoken and sung conditions.

Given the observation that auditory short-term memory and musical cognition are related in typically developing children (Roden et al., 2012), it would be of interest to investigate whether or not musical training could enhance auditory short-term memory function in children with SLI. Research has shown that when very young typical infants listen to melodies they represent its musical contour (Trehub et al., 1997; Trehub, 2003). For adults, melodies are also initially represented in contour form, although repeated exposure results in more detailed interval representations of the melodies. This suggests that in music perception, contour provides an anchor that allows for subsequent elaboration of the represented material. Studies described in this thesis show some preservation of contour processing in SLI, and it may be the case that musical training that capitalises on this ability could be of particular benefit to these children. Therefore the aim of this future study would be to investigate whether or not engaging in a targeted musical training programme, affords any benefits above those achieved through participation in regular speech and language therapy. It would also be of interest to compare the efficacy of such a musical training programme to other computer-based training programmes designed to improve working memory function in children (Homes et al., 2010), to see if musical training that focuses on the use of contour as a cognitive anchor, does confer any additional benefits to working memory training for children with SLI.

Finally, in experiments four and five it appeared that children with SLI demonstrated implicit awareness of musical hierarchical structure and yet were unable to use this information to make an explicit online judgment about the harmonic correctness of a musical target chord. The observation that children with SLI do show evidence of implicit awareness of structural regularities in music is counter to the observation of Jentschke et al. (2008), who found that children with SLI did not show the same EEG response to harmonic violations as typically developing controls. One possible explanation for this discrepancy is that the participants in the Jentschke et al. (2008) study were only 5-years old. It may be that SLI is associated with a delay in procedural learning and so children with SLI may take longer to construct a cognitive representation of Western tonality than typical children. Thus it is possible that older SLI children would show a similar implicit EEG response to harmonic violations as typically developing children and this warrants further investigation. Therefore a third area for further work would be to investigate implicit EEG responses and explicit recognition of harmonic violations in music in older children with SLI. Furthermore, Fonteneau and van der Lely (2008) found that children with SLI showed atypical EEG responses to grammatical violations in language and so it would be of interest to compare grammatical processing across music and language domains using a within-subjects design.

CONCLUSION

The aim of this thesis was to investigate musical cognition in children with SLI, from a relatively simple capacity to discriminate the direction of two-tone pitch intervals through to the more complex ability to understand the emotional connotations of music. The investigation of competencies outside of the language domain allowed for the broad auditory, cognitive and linguistic theoretical frameworks of SLI to be tested. The findings demonstrated that whilst SLI is associated with a cognitive deficit in auditory short-term memory there are many aspects of musical cognition that are relatively preserved. It seems that the multimodal nature of music allows for different processing strategies that children with SLI can adopt in order to compensate for cognitive limitations. The investigation of musical cognition in children with SLI has demonstrated that within this complex neurodevelopmental disorder, characterised by deficits in cognitive mechanisms and linguistic processes, music may be one area of relative preservation and this has important implications for potential interventions.

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APPENDIX ONE: Musical background questionnaire for participants

Environmental Intrinsic questions: child questioned within session

1a. Does your mummy play a musical instrument? Yes

No

b. If so, what kind?

…………………………………………………………………………………

2a. Does your daddy play a musical instrument? Yes

No

b. If so, what kind?

…………………………………………………………………………………

3a. Do you play a musical instrument? Yes

No

b. If so, what kind?

……………………………………………………………………………………..

c. If so, do you have music lessons on your own or in a group?

……………………………………………………………………………………

d. Where do these music lessons take place?

………………………………………………………………………………………..

e. How long are your music lessons?

………………………………………………………………………………………..

f. How often are these music lessons?

………………………………………………………………………………………

4a. Have you taken any music exams? (e.g. piano grades) Yes

No

b. If so, please explain

……………………………………………………………………………………..

5a. Do you sing in a choir or play in the orchestra (e.g. at school)? Yes

No

b. If so, please explain

……………………………………………………………………………………..

6a. Do you take dance lessons? Yes

No

b. If so, how often

……………………………………………………………………………………….

7a. Do you enjoy listening to loud music at home? Yes

No

b. If yes, how often do you listen to music at home?

Every day A few times a week

c. If expressed differently, write answer below

APPENDIX TWO: Musical background questionnaire for parents/carers

<u>Environmental Intrinsic questions: Sent to parents</u>

Please answer the following questions and return to the school

1a) Have you had any formal musical training?

(for example individual music lessons) Yes

(please tick) No

b) If yes, for how long?

(Please circle)

0-1 yr 2-4 yrs 5-10 yrs

2a) Has your partner had any formal musical training?

(for example individual music lessons) Yes

(please tick) No

b) If yes, for how long?

(Please circle)

0-1 yr 2-4 yrs 5-10 yrs

3a) Has your child had any formal musical training?

(for example individual music lessons) Yes

(please tick) No

b) If yes, for how long?

(Please circle)

Less than 1 year	1-2 yrs	2-3 yrs	3-4 yrs	4+ yrs

4) How many hours per week does your child engage in musical activities? (e.g. music lessons/ dance practice/ choir/ orchestra)

Less than 3 hours	3-5 hrs	6-8 hrs	8+ hrs

5) How often does your child choose to listen to music at home?

(Please circle)

Rarely	Moderately	Frequently
(once per week)	(2-4 times per week)	(every day)

6) How would you rate your child's reaction to music?

Dislike	Indifference	Mild liking	Moderately Enthusiastic	Very Enthusiastic

Please complete a couple of questions concerning your child's hearing and educational background.

Does your child have normal hearing?

Has your child had hearing abnormalities in the past (e.g. glue ear)?

Is your child diagnosed with dyslexia or any other learning disability?

Does your child receive any additional academic support in school?

<u>Thank you very much for your time</u>