Individual differences in creativity: measurement, structure, aetiology and prediction

Teemu Toivainen

Department of Psychology
Goldsmiths, University of London

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Declaration

I declare that work presented in this thesis is my own. Where I have consulted the work of others, this is always clearly stated.

1 September 2020

Personal contribution to the study

The work presented in this thesis is original and my own. I have conducted all the data analyses reported in the present thesis on my own.

Dr Nicholas Shakeshaft created the computerised data collection format for the research presented in Chapter 2. Dr Dr Ana-Maria Olteteanu provided her expertise with the study presented in Chapter 3. Dr Juan Jose Madrid Valero provided assistance with the twin modelling analyses, presented in Chapter 6.

I was responsible for collecting data, presented in Chapter 2, 3 and 4. Part of the data collection, presented in Chapters 2 and 4 was facilitated by Dr Maxim Likhanov and Vlada Repeykova. Data presented in Chapter 6 of this thesis were collected as part of the Twins Early Development Study (TEDS), a large-scale developmental twin study funded by the Medical Research Council. The data preparation for the research presented in Chapter 6 required a management of large group of research volunteer which I organised and managed.

A slightly modified version of Chapter 3 has been published in Frontiers in Psychology. Research presented in Chapter 6 is currently under review in British Journal of Educational Psychology. The initial stages of research, presented in Chapter 6, were published as peer-reviewed conference proceedings. Two of these proceeding outputs, for which I was the first author, are included as appendices in this thesis. The third proceeding output was based on an undergraduate third-year dissertation by Isabella Badini, who I co-supervised with my PhD supervisor, Professor Yulia Kovas. In preparation for all these publications, all co-authors read and provided feedback on the manuscripts before the submission.

Author’s Publications

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Abstract

Creativity is becoming an increasingly important research topic, with implications for education. However, many issues remain unresolved, including the underlying structure of creativity and factors influencing individual differences in childhood creativity. This thesis presents four empirical studies, based on different datasets, addressing questions in relation to the measurement, structure, aetiology and prediction of creativity. The first study, examining 13 creativity measures, found that the structure of creativity is non-unitary. This finding suggests that creativity is multidimensional; or, alternatively, that creativity is a collective term for largely unrelated processes, rather than a meaningful construct. The second study, using the cross-cultural design, explored the relationship between a verbal Remote Associates Test and its newly developed visual version. The associations between linguistic and visual versions of the test were moderate. This, together with the finding of non-unitary structure of creativity, demonstrates that there is no one measure that could be used as a proxy for creativity. The third study corroborated previous finding that Openness to Experience is the most robust personality predictor of creativity. The study found that Openness to Experience was related to self-rated creativity, creative self-efficacy and to the ability to think divergently, among adolescents selected for high achievements in Science and Art & Literature. The role of other personality traits and intelligence was small if not negligible in these samples. The fourth study used the Consensual Assessment Technique to evaluate creativity in children's writing; and explored longitudinal associations of this measure with educational achievement, beyond intelligence and motivation. Additionally, a genetically sensitive analysis showed that creative content is children's writing is moderately heritable, with some variance also explained by shared environmental effects. The findings of this thesis will guide measurement and planning of interventions in educational contexts.

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1 Introduction: Creativity of an individual

The importance of creativity is increasing in many areas of society. A recent report by the Organisation for Economic Co-operation and Development emphasised the relevance of creative thinking skills in future workforces (Berger & Frey, 2015). Also, creativity is now mentioned in educational strategies. For example, it is listed as an objective in the National Curriculum in the UK, which describes the government guidelines for assessment in compulsory education (Joubert, 2001). In both education and work contexts, creativity is conceptualised, discussed and measured as an individual's characteristic - as the creativity demonstrated by each student or employee. Creativity is considered as positive attribute, and there is much interest in understanding differences between individuals in their creative behaviours.

Due to the positive connotations and relevance to numerous areas of society, research in creativity has accelerated in recent years. However, the word creativity is not a scientific term (Batey & Furnham, 2006). This means that the construct is not based on a single, commonly accepted definition which allows for measurement. Herein lies the biggest challenge for creativity research.

Standard Definition of Creativity

This diversity of the term creativity is not easy to combine into a single definition. Still, various attempts have been made to define it in a way that can be used to guide research. The most commonly used definition of creativity in the literature is the

Standard Definition of Creativity (Runco & Jaeger, 2012). According to this definition, creativity is an ability that aims at an original and useful/appropriate outcome (Barron, 1955). Originality, quantified as a frequency of a particular response in comparison to the pool of all responses, is commonly considered an essential element of creativity. However, originality is a necessary but not sufficient criterion of creativity (Runco & Jaeger, 2012). As a random process could generate something that is original but nonsensical and therefore could not be considered creative. For example, a highly original text can be produced by randomly selecting words from a large pool of text. This original text would not be creative because it also needs to be useful or appropriate. This criterion of useful/appropriate is not easy to define but it is an essential element of the Standard Definition of Creativity.

The Standard Definition of Creativity has loosely guided the operationalisation of measures which are used to study individual differences in creativity. This area of research, which is interested in variation among people, largely relies on quantitative data and seeks to understand how and why variations occur in creativity within a population (Cooper, 1998). Questions can be asked about why certain individuals score higher than others on specific creativity measures and to what extent these differences are due to genetic and environmental influences. This research area, which in a reductive manner assigns creativity a numerical value, has faced some criticism. Such as, this individualistic tradition has been contested for promoting somewhat static, disjointed, and contextual approaches to creativity (Glăveanu, 2013). According to this criticism, individualistic tradition in creativity research does not account for the complex interactions with social environments, which are essential for creativity to take place. While some of the critiques are justified, others require further investigation. For example, longitudinal designs with repeated measures should be used to investigate intra-individual change and hence promote a more dynamic view of individualistic creativity.

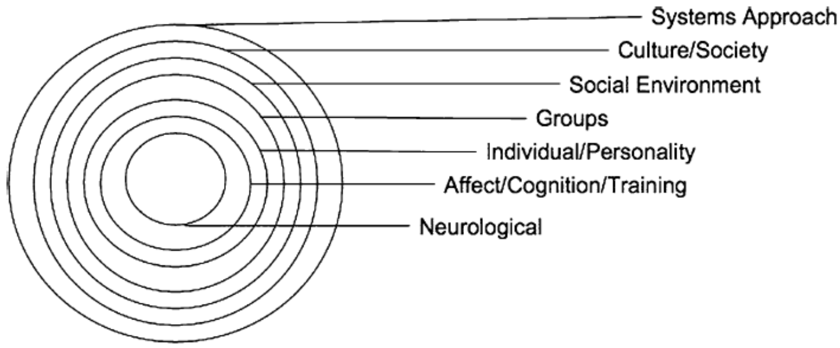
A key distinction in defining creativity is whether it is viewed as a normally distributed trait or as a rare behaviour only possessed by some individuals. Little-c creativity refers to creative cognition and behaviours which are normally distributed across a population. Normally distributed traits are categorised by a large proportion of the population scoring similarly, close to the population average and where there are much fewer individuals who have very low or high scores. In comparison to everyday creativity, eminent Big-C creativity, according to some, is a trait that is only present in a small number of individuals, such as Einstein and da Vinci, who will produce paradigm shifting creative work (Silvia et al., 2014).

The studies presented in this thesis utilise several everyday, or little-c creativity measures, rather than considering only eminent creative – Big-C – outputs.

Creativity at the level of an individual

Psychological research in this field has commonly concentrated on investigations at the level of the individual. At this level creativity refers to a wide range of abilities: it includes an individual's ability to imagine, synthesise, connect, invent and explore, particularly when tackling challenging and ill-structured problems (Sternberg & Lubart, 1995). The variation in behaviours will differentiate individuals in their creativity. However, these individual differences in creativity can be influenced and maintained by other factors at different levels. Individual differences can also be investigated through analysing underlying cognitive and neurological differences or by considering larger social systems that contribute to creativity. Creativity research can look at individual differences at these levels, as well as across levels.

Figure 1.1 below represents proposed levels at which creativity forces operate (Hennessey & Amabile, 2010).



Note. Reproduced with a permission from “Creativity” by B. A. Hennessey and T. M. Amabile, 2015, Annual Reviews Psychology, p. 571. Copyright 2010 by Annual Reviews.

Figure 1.1. The increasingly large concentric circles in this simplified schematic represent the major levels at which creativity forces operate.

In addition to the levels in Figure 1.1, studies have considered the role of genetic (and environmental) influences on creativity, adding a further concentric circle towards the centre of this model.

A complimentary way, in addition to different levels of creativity, is to conceptualise creativity at the level of individual differences based on the 4P-model (Rhodes, 1961). The 4P-model differentiates creativity based on attributes relating to an individual:

(1) the Personal characteristics of the creator, e.g., personality and intelligence
(2) the cognitive Processes involved in the creation, e.g., thinking and reasoning styles (divergent thinking, remote semantic associations etc.)
(3) the environment (or Press, as in environmental pressures) which refers to the association between the individual and their environment, i.e., due to immediate social environments and wider cultural influences.
(4) the Product that results from creative activity, e.g., a piece of music or artwork, a new statistical procedure, an innovative technological product.

In relation to the first ‘P’ -personal characteristics, creativity can be investigated in relation to personality and intelligence. The 2nd ‘P’ - cognitive processes relate to underlying creative cognition. The 3rd 'P' refers to external influences that may either promote or decrease creativity. The 4th 'P' – product - relates to the creativity of a product.

As with the levels of creativity, presented in Figure 1.1., the components of the 4P-model are not separate but overlapping and function simultaneously. For example, creative cognitive processes (e.g., coming up with original ideas) is a trait associated with creative individuals. However, creative products are, at least to certain extent, a reflection of the creators' cognitive abilities, and have been created within certain environmental contexts that have been interacting in the process of creation.

Several theories have aimed to explain creativity based on different individualistic characteristics. The following section will shortly introduce a selection of theories embedded in cognitive processes, personality characteristics and environmental context. The section will also discuss confluence theories, which emphasise creativity being an outcome of many variables coming together in an ideal alignment.

Theoretical basis of creativity

In psychological research, creativity has been largely conducted from three theoretical viewpoints (cognitive, personality and sociocultural), with only limited attempts to combine across approaches. It should be noted that these approaches are not solid theories on creativity, but proposed explanations that also rely on different sources of data and methodologies.

Cognitive approaches explain creativity in the context of cognitive processes that are viewed as essential to creative thinking and behaviours. For example, Associative Theory of Creativity argues that creativity is based on the ability to connect distant concepts, make remote associations (Mednick, 1962; see Chapter 3 in this thesis).

Another cognitive theory has emphasised a more top-down, executive functions explanation of creativity (Beaty & Silvia, 2012; Benedek et al., 2014). According to this theory, executive processes play a central role, particularly processes involved in the strategic retrieval and manipulation of knowledge, in creative idea production. A further example of a cognitive theory of creativity is the dual-process theory of creativity (e.g. Sowden et al., 2015). This theory suggests that creative thinking relies on shifting between the process of generating ideas and those involved with their refinement, evaluation, and/or selection. Other cognitive approaches to creativity include Gestalt theories, which emphasise the role of restructuring on creative idea production, for example in relation to insight moments (Ward & Finke, 1995).

The cognitive approach is utilised in the operationalisation of creativity measures in the studies presented in this thesis. The Alternative Uses Task (Chapters 2 and 4) and Remote Associates Test (Chapters 2 and 3) are measures of creative cognition. The measures are discussed in in their respective chapters.

Personality approach on creativity has emphasised it being a trait similar to personality traits (Barron, 1969; Eysenck, 1993). For example, Eysenck (1993) assumed that creative people possess the personality characteristics of Psychoticism (predisposition to psychosis) at a higher level than a typical individual in the population. According to this theory, personality characteristics associated with individuals who score high in Psychoticism trait, such as impulsiveness, or non-conformist behaviour, also make them predisposed to creativity. However, this theory has not been supported empirically. For example, a study reported negligible correlations between creativity and scores on a Psychoticism scale (Martindale & Dailey, 1996). Evaluations of one's own creativity in different domains (scientific, visual, verbal, social and sports) were incorporated in the studies reported in Chapters 2 and 4. The study reported in Chapter 4 also investigated the associations between these creativity measures and five personality traits of Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism.

Sociocultural approach of creativity emphasises that, instead of creativity only being accounted for individuals' abilities and traits, also sociocultural influences play an essential role in the trait. For example, Teresa Amabile (1982) has argued that creativity is defined by social environments: creativity is, by definition, what is consensually agreed upon within various social contexts (see Chapter 6 for more information). The sociocultural approach is related to the creativity measures and topics introduced in Chapters 2, 3 and 6. Chapter 2 includes behavioural inventory measures, which are based on socially recognised creative behaviours. Chapter 3 includes discussion on the role of sociocultural differences in creative cognition, and how language-based creativity measures may propose difficulties for cross-cultural investigations. Also, in Chapter 6, the measurement of creative content in children's writing is based on subjective evaluations of creativity, which are dependent on the social context.

The diversity of these theories indicates that the concept of creativity is complex and potentially multidimensional (Kaufman & Sternberg, 2019). This diversity is captured by another group of theories, confluence theories, according to which creativity is a combination of many factors. These theories suggest that creativity emerges when other resources come together in an ideal combination. One confluence theory argues that creativity relies on six resources: intelligence, knowledge, intellectual style, personality, motivation and environmental content (Sternberg & Lubart, 1995). Each of these resources are needed for creativity to take place. Confluence theories also imply that creativity may not be a latent construct, similar to general cognitive ability (*g*), driving associations between its subcomponents, but a composite, or perhaps a synergistic outcome, of several uncorrelated factors.

Research questions and chapter description

This thesis takes an explorative approach to address some of the long-standing questions about the structure, measurement, prediction and aetiology of creativity at the level of the individual. The relationship of creativity with other constructs, such as personality, intelligence and educational achievement, are also investigated. Furthermore, the research also addresses another unresolved issue – whether creativity is the same in different areas of expertise, for example in art compared to science; and whether the relationships between different creativity measures change for sample-specific reasons, such as between different cultures and age groups. Finally, the research considers the power of creativity to predict any real-life outcomes.

This research utilises different indicators of creativity, which are commonly used in current psychological research to enable the investigations of inter-relationships between the creativity indicators.

The thesis is organised in the following 7 chapters addressing 5 research questions:

Chapter 1 (this chapter) provides an introduction to the research questions, as well as theoretical approaches to the concept of creativity that informed the empirical studies presented in the remainder of the thesis.

Chapter 2 presents a study investigating the structure of creativity. Previous research has reported poor construct validity among various creativity measures. Potentially, indicating that creativity is not a unitary construct. However, more research is needed to investigate inter-relationships of diverse creativity measures. This study explores the latent component structure of thirteen commonly used creativity measures. The study was based on a sample of English-speaking adults. The main research question is:

1. Is the structure of creativity unitary or multidimensional?

Chapter 3 presents a study investigating the measurement of creativity in cross-modal and cross-cultural context. Much research into abilities linked to creative cognition, for example associative ability, have relied only on verbal measures. However, some aspects of creativity, such as creative idea generation, have been investigated using both verbal and figural versions of tasks. Detailed investigations on the different forms of the same test will improve the validity and applicability of the test. The present study investigates the relationship between two versions of the Remote Association Test: the established linguistic version, and a newly developed visual alternative. To consider environmental, linguistic and context differences, this research reports results from native speakers of in both Russian and Finnish. The main research question for this chapter is:

2. What is the role of stimuli modality (e.g., verbal vs. visual) in the measurement of creative cognition?

Chapter 4 presents a study investigating the amount of variance explained by the Big-5 personality traits and intelligence on eight measures of creativity. Previous research is inconsistent, potentially due to differences in creativity measures and sample-specific factors. Not many studies have utilised several creativity indicators in a single study; and most studies have been limited explored adult samples. Further research is needed exploring the relationships between creativity, personality and intelligence in younger samples, in order to understand the development of such relationships over the lifespan. The main focus of the study is to investigate the associations between personality, intelligence and creativity. Additionally, this chapter considers if these relationships differ between two adolescent samples. One with high achievements in the Sciences, the other with high achievements in Arts. The main research question of the chapter is:

3. What is the relationship between creativity, personality and intelligence?

Chapter 5 presents a systematic review of twin studies that have investigated the aetiology of different creativity measures to date. The chapter also describes the basic principles of classic twin modelling which can be used to separate the variance of individual differences in creativity based on genetic, shared environmental and nonshared environmental influences. This review guided the genetically informative study described in Chapter 6.

Chapter 6 presents a study investigating the association of creative content in childhood writing with intelligence, motivation and educational achievement (employing a longitudinal design). The study utilises genetically informative methods to estimate genetic and environmental influences on the creative content in childhood writing. This chapter also includes multivariate genetic analyses to estimate the proportions of genetic and environmental influences on the shared variance between creativity and three other measures: intelligence, motivation and educational achievement. The research questions that this chapter aimed to investigate is:

4. Can creativity predict other educationally relevant constructs, such as achievement, intelligence and motivation? To date, very few studies have explored this longitudinally.

5. What is the genetic and environmental aetiology of individual differences in creativity and its links with other outcomes? Only a few quantitative genetic studies have explored the aetiology of individual differences in creativity, as well as the aetiologies of the associations between creativity, intelligence and motivation.

Chapter 7 summarises the main findings of the thesis. Alongside which, the relevance of the findings is discussed in relation to educational and occupational areas is discussed. Finally, this chapter also presents the limitations of the research outlined in the thesis and how this can inform the future work in the field.

2 Structure of creativity: An investigation on a latent structure of thirteen measures of creativity

Chapter summary

Individual differences in creativity can be measured with cognitive tests; estimates of one's own individual characteristics (self-reported creativity); and inventories of previous creative behaviours. Such measures can estimate creativity in general or in specifically defined domains (e.g., in science and art). However, previous research has indicated poor construct validity which indicates that inter-relationships between different measures are inconclusive. The present study investigated latent component structure among thirteen creativity measures (three cognitive tasks, two behavioural inventories and eight self-reported questionnaires) in a sample of 188 English speaking adults. The results suggested a multidimensional structure of creativity, comprising six components explaining 74% of the variance of individual differences in this construct. Measures of previous creative behaviours (creative activity and creative achievement measures) were not strongly associated with any general creativity measures (self-reported or cognitive tests); but were associated with self-reported domain-specific visual and verbal creativity. Furthermore, out of five self-reported creativity domains (scientific, social, visual, verbal and sports), only social creativity was associated with any general creativity measures; it was associated with two cognitive creativity measures. General creativity measures (cognitive tests and self-reports), as well as behavioural inventories, loaded on three separate components. The results support a view of creativity as a multidimensional construct.

Introduction

Creativity assessment, based on psychometric measures, can broadly be sorted into three categories of creative cognition, creative traits, and creative activity and achievements (Kaufman et al., 2008). The measures include cognitive tests, self-reports and behavioural inventories. Most measures can also be used to estimate creativity in a broad sense or in a more targeted manner, at specific areas of creativity. For example, 'How creative are you?' in comparison to 'How creative are you in music?'.

Previous research on inter-relationships among different creativity measures has reported poor underlying construct validity. For example, one study reported a differential relationship of creative cognition with creative activity and achievement in science: a cognitive creativity task (a divergent thinking task) had a positive correlation with scientific creative activities (r = .22) but a negative correlation with scientific creative achievements (r = -.21; Agnoli et al., 2016). Creative activities refer to more common, everyday behaviours, such as thinking over a scientific problem; and creative achievements to socially recognised achievements, such as winning awards. In another study, the correlations between different measures of creativity, a cognitive task, self-reported measure, and behavioural inventory, varied from r = .14 to .31 - indicating weak inter-relationships (Batey et al., 2010).

The poor construct validity of creativity construct based on cognitive tests, self-reports, and behavioural inventories can be partly explained by differences in the level of measurement. For example, cognitive tests aim to estimate a rudimental cognitive ability, whereas self-reports rely on a compilation of factors. For example, depending how self-reported questions are formulated, the participants may be thinking specific behaviours in comparison to broader assessment of one's own thinking style. A previous study reported a weak correlation of r = .22 between a divergent thinking task, a measure of idea fluency, and self-reported creativity (Batey et al., 2010). Similar findings, with small correlations between cognitive tests and self-reports, have been reported in intelligence research among student samples (Paulhus et al., 1998). This may indicate that the self-evaluation of one's own cognitive skills is difficult and perhaps biased by several reasons, such as basing an evaluation of specific situations. For example, people who are interested in scientific topics may show poor estimation of their own intelligence when compared to their actual performance in standardised batteries of intelligence tests. Such people may, for example, especially underestimate their fluid intelligence as this tends to be associated with novel and creative thinking, rather than learned information. Similar dissonance is likely to happen when trying to evaluate one's own creative cognition.

Despite the weak inter-correlations between creativity measures, findings, based on a single measure, are often generalised as appropriate proxies for creativity as a whole. This approach is sometimes taken even if a test measure assesses a very specific ability, such as one's ability to come up with alternative uses for an object – a divergent thinking task. Some researchers have proposed that cognitive creativity tasks, such as measures of divergent thinking and associative ability, are relevant to creative behaviours across different areas (e.g., Mednick, 1962; Runco et al., 2011). Others argue that creative thinking does not rely on any specific cognitive processes that would only apply to creativity, only general factors combining creativity at different areas are intelligence and motivation (Kaufman & Baer, 2004).

The weak, even negligible, inter-relationships between different creativity measures may be due for several reasons. The associations may reflect sample-specific reasons and not be generalisable. However, it is also possible that they are tapping into different aspects of a latent, multidimensional creativity construct that are only loosely connected. Furthermore, another explanation could be that different creativity measures tap into separate constructs, not on a latent creativity construct. It could be that such a construct does not exist.

Research questions

To investigate the structure of creativity and the relationship of domain-specific and general abilities in creativity, research presented in this chapter, builds on the previous findings to investigate the latent structure of creativity in 3 ways: (1) by exploring the underlying component structure among 13 creativity measures; (2) by investigating whether creative activities or creative achievements are more strongly associated with domain-general (self-reported and cognitive) creativity measures vs. domain-specific measures (self-reported creativity in science, social, visual, verbal and sports domains) with; (3) by investigating whether domain-general creativity measures are associated with domain-specific measures of self-reported creativity in scientific, social, visual, verbal and sports domains. Specifically, the research questions for the present study are:

1. What is the component structure among 13 creativity measures?
2. Are creative activity and creative achievement inventories associated with any general creativity measures or with self-reported creativity in science, visual, verbal, social and sports domains?
3. Are self-reported creativity measures in science, visual, verbal, social and sports domains associated with six domain-general creativity measures?

Methods

Sample

In total, 188 participants took part in the study. However, the sample size for one of the measures was lower (n = 157) due to attrition. The participants ranged in age from 18 to 57 (m_{age} = 23.79; SD= 8.66). The sample included 135 women (m_{age} = 22.28; SD = 7.01) and 53 men (m_{age} = 27.62; SD = 7.01). Participants were recruited online, through social media, and through the 1st year psychology undergraduate student's participation scheme at Goldsmiths, University of London. A description of the study with a link and a personal password were emailed to participants.

The data collection took place between March 2017 – January 2018. The data collection was completed on-line using personal computers. Participation was open to everyone who was 18 years or older and fluent in English. Most participants were undergraduate students in the UK. Due to the length of the battery (approximately 60 minutes), the participants could interrupt at any point and return at a later date by using their personal ID. Ethics were granted for this study by the ethics board at the Department of Psychology, Goldsmiths, University of London.

Measures

The study included a selection of diverse creativity measures, commonly used in creativity research. The aim was to select psychometric creativity measures, which are measuring creative activities, self-reported creativity and creative cognition. The measures were also aimed to capture both domain-general and domain-specific aspects. The selection was based on literature research, conducted by the author. The selection of the measures was not based on any systematic selection method.

The thirteen measures included;

two behavioural inventories:

1) the Creative Behaviour Inventory (CBI; Dollinger, 2011; Hocevar, 1979),
2) the Creative Achievement Questionnaire (Carson et al., 2005);

eight self-reported creativity measures:

3) Creative Self-Efficacy (CSE; Beghetto, 2006),
4) Runco Ideational Behaviour Scale (RIBS; Runco et al., 2001),
5) Use of Creative Cognition in Studying (UCCS: Rogaten & Moneta, 2015),

Short Self-Reported Creativity (SSRC; Hughes et al., 2013) in:

6) science,

7) social,

8) visual,

9) verbal, and

10) sports;

and three cognitive tasks:

11) the Remote Associates Test (RAT; Bowden & Jung-Beeman, 2003; Mednick, 1962),

12) the Alternative Uses Task (AUT; Guilford, 1967); and

13) the Figural Divergent Thinking Task (fDT; Runco, 1986).

Creative Behaviour Inventory

The Creative Behaviour Inventory (CBI) is an inventory of 28 items of everyday creativity activities (Dollinger, 2011). The CBI is a shortened form of Hocevar's (1979) creative achievement and activity scale, only retaining the activity measures. Participants are asked to indicate how often they engage with specific activities on a 4-point scale (1 = not at all, 2 = monthly, 3 = weekly, 4 = daily). Examples include: 'made your own holiday decorations' and 'wrote a short story'. Previous research has shown a unifactorial structure underlying the items (Dollinger, 2011). The internal consistency for the scale was Cronbach's alpha (α) = .87.

Creative Achievement Questionnaire

The Creative Achievement Questionnaire (CAQ) measures creative achievements in ten domains: visual arts, music, dance, architectural design, creative writing, humour, inventions, scientific discovery, theatre and film; and culinary arts (Carson et al., 2005). The CAQ measures socially recognised creative achievements and, by virtue of only considering rarer creative achievements, produces a highly skewed distribution in a normal population (Silvia et al., 2012). As people tend not to excel in more than one or two domains, within a normal population the total CAQ score is not informative, since the 10 domains do not form a single factor (Carson et al., 2005). For example, by creating a total sum, a person who would have received an international award for their creative achievement in one domain might be scored similarly with a person who had several low-level achievements in various domains. However, some studies have used factor scores, based on a 2 or 3-factorial structure, as indications of latent factors underlying the 10 dimensions (Carson et al., 2005; de Manzano & Ullén, 2018).

The measurement scale for the CAQ is 0-7. If the highest score of 7 is chosen, participants are also asked to report the frequency of the item (e.g., receiving a national award). The frequency is used as a multiplier for the item score of 7. However, in this sample, no participant reported the value of 7 for any of the items.

The present study utilised a summed score among all 10 domains as very few high scores among the participants were observed. This resulted in extremely skewed scores in all 10 domains with a large proportion of 0 values. The heavily skewed data was likely due to participants' young age. The internal consistency for the scale was α =.41.

Creative Self-Efficacy (CSE)

Creative self-efficacy (CSE) refers to a person's belief of being creative (Tierney & Farmer, 2011). In the present study, CSE was measured by 3 items on a five point scale (Beghetto, 2006). The items were (a) "I am good at coming up with new ideas," (b) "I have a lot of good ideas," and (c) "I have a good imagination". Each participant was assigned a summed total of the three items. The internal consistency for the scale in the present study was α = .82.

Use of Creative Cognition in Studying (UCCS)

The Use of Creative Cognition in Studying (UCCS) consists of 5 items about students' use of creative cognition in studying, measured with a five point scale (Rogaten & Moneta, 2015). The UCCS measures how frequently the participant engages in each behaviour during their study (or work), measured with items such as 'I find effective solutions by combining multiple ideas' and 'While working on something, I try to generate as many ideas as possible'. The measure was originally intended for university students. Items which referred to studying were adapted in the present study to also apply to work situations. Each participant was given a summed total of the five items. The internal consistency for the scale in the present study was α =.77.

Runco Ideational Behaviour Scale (RIBS)

The Runco Ideational Behaviour Scale (RIBS) is a self-reported measure of creative ideation consisting of 23 items (Runco et al., 2001). Participants are asked to evaluate on a 5-point scale "How well the following statements describe you?" Statements include items such as "I come up with a lot of ideas or solutions to problems" and "Friends ask me to help them think of ideas and solutions". The validation study of the RIBS established a two-factorial structure for the 23 items (Runco et al., 2001). The present study included the 17 items loading highly on the first factor, which measures self-evaluated creative thinking (Runco et al., 2001). The internal consistency for 17 items in the present study was α = .93.

Short Self-Reported Creativity (SSRC)

The Short Self-Reported Creativity (SSRC) measure requires participants to rate their creativity in comparison to others in five domains: visual, verbal, scientific, social and sports (Hughes et al., 2013). For each of the five questions, participants use a scale of 1 to 7 in their self-evaluations. The 5 items are not treated as a unitary scale, which is also reflected in the low internal consistency of α =.41.

The Remote Associates Test (RAT)

The Remote Associates Test (RAT) is a measure of associative ability that is often used as a proxy for creative cognition (Bowden & Jung-Beeman, 2003a; Mednick, 1962). In the RAT, participants are shown three words and asked to come up with a fourth that creates a compound word with the three stimuli words. For example, the three stimuli words "cake" "swiss" and "cottage" would form compound words with the word "cheese". The score was the sum of correct responses, out of 30 items. The 30 items were selected to cover a range of items with different level of difficulty, based on the normative data of 144 items, reported in previous research (Bowden & Jung-Beeman, 2003a; Mednick, 1962). The internal consistency for the scale in the present study was α =.62.

The Alternative Uses Task (AUT)

The verbal version of the Alternative Uses Task (AUT) is a measure of divergent thinking (Guilford, 1967). The measure included three trials during which the participants are shown a word of a common household object (a brick, a paperclip and a newspaper; Webb et al., 2017). The participants were instructed to come up with as many alternative uses for each item as they could think of within 2 minutes.

In the present study, the AUT total score was the mean value of the scores based on all three stimuli. The score for each individual stimulus was based on the total number of responses per item. For example, if a participant came up with 6 alternative uses for a brick, 9 for a paperclip and 12 for a newspaper, the total score for the task would be 9 (27 / 3 = 9). The present study only utilised the frequency score for the AUT task due to limitations in resources for evaluating the creative originality of individual responses. This was deemed sufficient since this study was an initial exploration of the relationships across the various creativity measures listed above. Also, previous research has shown that frequency score (the number of given responses) is highly correlated with the originality score of the responses (Batey et al., 2010). The internal consistency for the frequency scores of three conditions was α = .86.

The Figural Divergent Thinking Task (fDT)

Figural Divergent Thinking (fDT; Runco & Acar, 2012) is a similar measure to the AUT. In this task participants are shown unfinished drawings with only a few lines or curves and asked to come up with ideas what the image may represent. Participants were instructed to come up with as many responses as they can in 2 minutes. The fDT total score was calculated similarly to the AUT as a mean value of the scores based on each three stimuli. The score for each individual stimulus was based on the total number of responses per item. The internal validity for three items was α = .88.

The measures are also shortly summarised in the Table 2.1.

Table 2.1. The study measures (name, number of items, scale, Cronbach's alpha, example of items, and reference).

Name of the measure	Number of items	Scale per item/stimuli	Cronbach's alpha	Example items	Reference
Creative Behaviour Inventory (CBI)	28	1-4	.87	Made your own holiday decorations; Wrote a short story; Wrote the lyrics to a song	Dollinger, 2011; Hocevar 1979
Creative Achievement Questionnaire (CAQ)	10	0-7 (if 7 is selected, the score will be multiplied based on the frequency of the event)	.41[1]	Creative achievements in visual arts, music, dance, architecture, creative writing, humour, inventions, scientific discovery, theatre and film, and culinary arts. I have no training or recognized talent in this area; I have taken lessons in this area; People have commented on my talent in this area; My work has been critiqued in national publications.	Carson et al., 2005

Creative self-efficacy (CSE)	3	1-5	.82	I am good at coming up with new ideas; I have a lot of good ideas; I have a good imagination	Beghetto, 2006
Use of Creative Cognition in Studying (UCCS)[2]	5	1-5	.77	I find effective solutions by combining multiple ideas; While working on something, I try to generate as many ideas as possible; I try to act out potential solutions to explore their effectiveness.	Rogaten & Moneta, 2015
The Runco Ideational Behaviour Scale (RIBS)	17	1-5	.93	I come up with a lot of ideas or solutions to problems; Friends ask me to help them think of ideas and solutions; It is important to be able to think of bizarre and wild possibilities.	Runco et al., 2001
Short Self-Reported Creativity (SSRC)	5	1-7	.37[3]	In relation to others, how creative are you in visual, verbal, scientific, social and sports areas?	Hughes et al., 2013
Remote Associates Test (RAT)	30	0-30	.62	In the RAT, participants are shown three words and asked to come up with a fourth that creates a compound words with the three stimuli words. For example, the three stimuli words “cake” “swiss” and “cottage” would form compound words with the word “cheese”.	Bowden & Jung-Beeman, 2003
Alternative Uses Task (AUT)	3 trials	0-30	.86, based on the total scores of 3 trials	The measure included three trials during which the participants are shown a word of a common household object (a brick, a paperclip and a newspaper). The participants were instructed to come up with as many alternative uses for the object as they can think of in 2 minutes.	Guilford, 1967
Figural Divergent Thinking Task (fDT)	3 trials	0-30	.88, based on the total scores of 3 trials	In this task participants are shown 3 unfinished drawings with only a few lines or curves and asked to come up with ideas what the image may represent. The participants are instructed to come up with as many responses as they can in 2 minutes. The score is the mean of the three items.	Guilford, 1967; Runco & Acar, 2012

[1]CAQ is not designed to be used as a composite score (Carson et al., 2005); however, due to very low frequencies in each achievement domains, a composite was created to account for creative achievement in general
[2]The measure was originally intended for university students. Items which referred to studying were adapted in the present study to also apply to work situations.
[3]The items are not expected to form a unitary scale

Results

The descriptive statistics for the thirteen measures are presented in Table 2.2.

Table 2.2. Descriptive statistics of thirteen creativity measures.

	N	Range	M	Sd	Skew	Kurtosis
CBI	185	28-112	48.25	12.21	0.67	0.53
CAQ total	188	0-70	6.22	4.33	1.11	1.65
CSE	167	1-15	11.26	2.16	-0.90	2.02
UCCS	172	5-25	17.42	2.86	-0.20	1.78
RIBS	176	1-5	3.36	0.70	-0.06	-0.29
SSRC science	169	1-7	3.93	1.59	-0.32	-0.69
SSRC social	169	1-7	5.28	1.44	-0.77	0.19
SSRC visual	169	1-7	4.30	1.66	-0.43	0.19
SSRC verbal	169	1-7	4.34	1.52	-0.40	-0.38
SSRC sports	169	1-7	3.44	1.82	0.19	-1.02
RAT	157	0-30	12.17	7.30	0.09	-0.99
AUT	169	0-30	11.79	5.68	0.84	0.69
fDT	169	0-30	9.10	4.48	0.69	0.31

Note. CBI = Creative Behaviour Inventory; CAQ total = total score for Creative Achievement Questionnaire; CSE = Creative Self-Efficacy; UCCS = Use of Creative Cognition in Studying; RIBS = Runco Ideational Behavior Scale; SSRC = Short Self-Rated Creativity; RAT = Remote Associates Test; AUT = Alternative Uses Task; fDT = Figural Divergent Thinking Task.

The bivariate correlation coefficients among the thirteen measures are presented in Table 2.3.

Table 2.3. Correlations among thirteen creativity measures.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1.CBI	1												
2.CAQ total	.50**	1											
3.CSE	.19*	.27**	1										
4.UCCS	.25**	.19*	.47**	1									
5. RIBS	.36**	.36**	.62**	.57**	1								
6.SSRC science	.03	.09	-.02	.12	.14	1							
7.SSRC social	.15	.19*	.23**	.20**	.28**	-.04	1						
8.SSRC visual	.49**	.37**	.22**	.21**	.17*	-.01	.17*	1					
9.SSRC verbal	.33**	.28**	.24**	.21**	.36**	.12	.09	.26**	1				
10.SSRC sports	.01	.13	.17*	.02	.16*	.18*	.13	.09	.09	1			
11.RAT	.09	.12	.08	.10	.06	.13	-.01	.01	-.01	-.02	1		
12.AUT	.24**	.20**	.22**	.22**	.26**	.05	.24**	.17*	.31**	.07	-.12	1	
13.fDT	.35**	.30**	.24**	.24**	.28**	.11	.29**	.16*	.29**	.04	.02	.72**	1

Note. ** p < .01; * p < .05
CBI = Creative Behaviour Inventory; CAQ total = total score for Creative Achievement Questionnaire; CSE = Creative Self-Efficacy; UCCS = Use of Creative Cognition in Studying; RIBS = Runco Ideational Behaviour Scale; SSRC = Short Self-Rated Creativity; RAT = Remote Associates Test; AUT = Alternative Uses Task; fDT = Figural Divergent Thinking Task.

Principal Component Analysis (PCA) was used as a dimension reduction method to explore the correlations among observed variables using a smaller number of components. The scree plot for the rotated component solution, based on Varimax rotation, is presented in Figure 2.1. Varimax, which is an orthogonal rotation method, was used to maximise the differences between the components. No prior predictions of the number of components or their relationships were made.

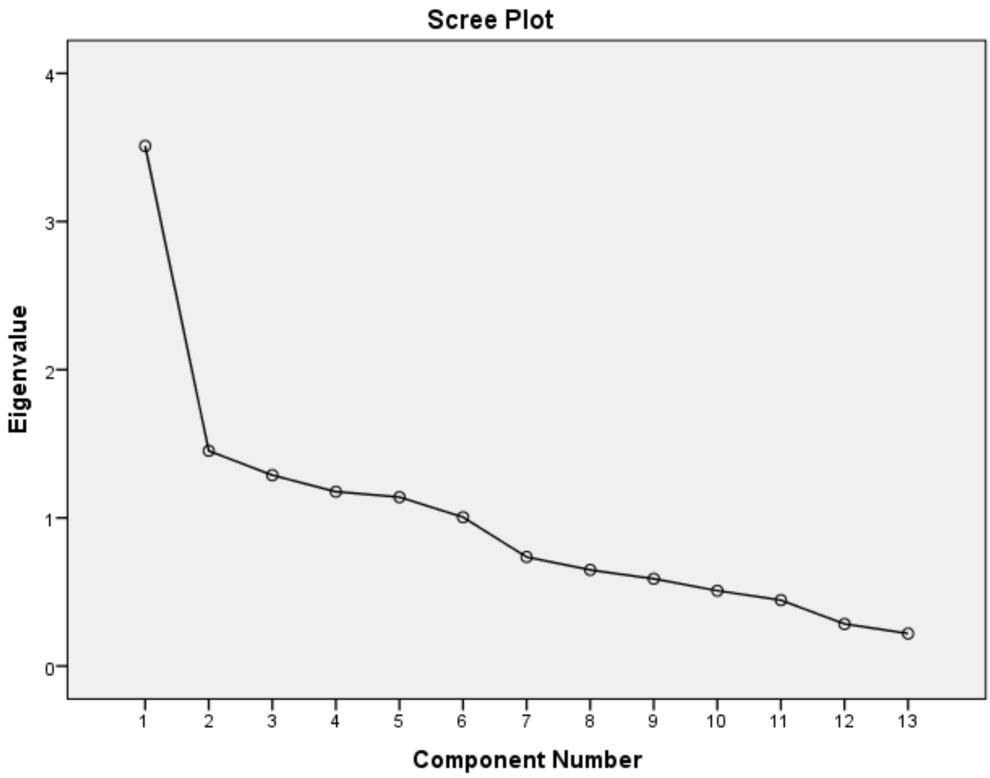


Figure 2.1. Scree plot for thirteen creativity measures.

Based on a rotated component solution, with a cut-off point of 1 Eigenvalue in a scree plot, six components emerged. The estimates for variance explained by each rotated component are presented in Table 2.4.

Table 2.4. The variance explained by rotated component solution among thirteen creativity measures.

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.51	26.99	26.99	3.51	26.99	26.99
2	1.45	11.17	38.17	1.45	11.17	38.17
3	1.28	9.90	48.07	1.28	9.90	48.07

4	1.17	9.04	57.12	1.17	9.04	57.12
5	1.14	8.76	65.89	1.14	8.76	65.89
6	1.00	7.72	73.62	1.00	7.72	73.62
7	.73	5.66	79.28			
8	.64	4.98	84.26			
9	.58	4.52	88.79			
10	.50	3.91	92.70			
11	.44	3.42	96.12			
12	.28	2.18	98.31			
13	.21	1.68	100.00			

In total, the six components, based on the rotated component solution, explained 73.62% of total variance in the outcome. The rotated component loadings, based on a Varimax rotation, are presented below in Table 2.5.

Table 2.5. Rotated component loadings of thirteen creativity measures (Varimax rotation).

	1 Visual and Verbal Creativity	2 Self-reported Creative Cognition	3 Test-based Divergent Thinking	4 Sports Creativity	5 Scientific Creativity	6 Linguistic Associative Creativity
1.CBI	**.79**	.13	.12	-.12	-.05	.10
2.CAQ total	**.65**	.17	.15	.13	-.03	.27
3.CSE	.14	**.81**	.08	.20	-.12	.01
4.UCCS	.07	**.81**	.12	-.18	.08	.08
5. RIBS	.28	**.83**	.10	.10	.03	-.01
6.SSRC science	-.04	.02	.13	.23	**.82**	.18
7.SSRC social	.09	.12	**.41**	**.42**	**-.56**	.13
8.SSRC visual	**.76**	.10	.05	.14	-.14	.05
9.SSRC verbal	**.61**	.16	.14	-.06	.31	-.27
10.SSRC sports	.05	.05	-.06	**.90**	.13	-.07
11.RAT	.08	.06	-.06	-.06	.11	**.91**
12.AUT	.14	.16	**.88**	-.01	.03	-.16
13.fDT	.17	.10	**.90**	-.03	.03	.07

Note. factor loadings >.40 are bolded.
CBI = Creative Behaviour Inventory; CAQ total = total score for Creative Achievement Questionnaire; CSE = Creative Self-Efficacy; UCCS = Use of Creative Cognition in Studying; RIBS = Runco Ideational Behaviour Scale; SSRC = Short Self-Rated Creativity; RAT = Remote Associates Test; AUT = Alternative Uses Task; fDT = Figural Divergent Thinking Task.

Four measures loaded highly (>.40) on the first component. The measures were CBI (.79), CAQ (.65), SSRC in visual (.76) and SSRC in verbal (.61) domains. The second factor had high loadings of CSE (.81), UCCS (.81) and RIBS (.83). Verbal and figural versions of divergent thinking tasks loaded highly on the same factor (AUT, .88; fDT, .90). SSRC in social domain creativity loaded highly on three components: the third - with AUT and fDT (.41); the fourth - with SSRC in sports domain (.42); and the fifth -with scientific domain (-.56). The negative component loading indicates negative association of scientific SSRC measure with the latent factor score. The RAT loaded on the sixth component, separately from the other measures.

Discussion

This study investigated the underlying component structure and inter-relationships of thirteen domain-general and domain-specific creativity measures. Two were behavioural inventories (CBI and CAQ), eight were self-reports (CSE; UCCS; RIBS; and SSRC in science, visual, verbal, social and sports) and three were cognitive tests (RAT, AUT and fDT).

What is the component structure among 13 creativity measures?

Based on a rotated component solution, six components emerged, explaining 73.62% of the variance of individual differences in creativity. The first component, *Visual and Verbal Creativity*, explained 26.99% of the total variance and included four measures: CBI (.79), CAQ (.65), SSRC in visual (.76) and SSRC in verbal (.61) domains. The results showed that self-reported verbal and visual creativity loaded highly (.76 and .61, respectively) on the *Visual and Verbal Creativity* component with the creative achievement (CBI) and activity (CAQ) measures. This may indicate that creative achievement and activity measures emphasise behaviours, which are based on verbal and visual skills. For example, the CBI does not include items that would be specific for scientific, social or sports creativity, hence being unable to capture creativity in those areas. Additionally, visual and verbal activities are commonly recognised being creative and therefore identified easily by individuals when assessing their own creativity. For example, it could be that visual creativity is easier to recognise than sports or scientific creativity.

The second component, *Self-reported Creative Cognition*, explaining 11.17% of the total variance, had high loadings of CSE (.81), UCCS (.81) and RIBS (.83). All three self-reported scales measure individuals' beliefs in their own creative thinking with different emphasises. However, some of the items are very similar which explains the associations. Additionally, some researchers have made an argument that similar measurement method between creativity measures, such as CSE; UCCS; and RIBS, may increase the associations between them (Kendler et al., 2015). However, this was a speculative claim, and no elaboration was given how this could be tested empirically.

The third component, *Test-based Divergent Thinking*, explained 9.90% of the total variance. It had high loadings of verbal and figural versions of divergent thinking tasks (AUT, .88; fDT, .90). The high correlation between the measures is likely to reflect that idea fluency is based on similar cognitive processes, regardless of whether the stimuli is in a linguistic or in visual form.

The fourth (8.77%), fifth (8.76%) and sixth (7.72%) components each had a high loading from a single measure. The measures loading on the components were, respectively, self-reported creativity in sports (.90; *Sports Creativity*), self-reported scientific creativity (.82; *Scientific Creativity*) and the performance in the Remote Associates Test (.91; *Linguistic Associative Creativity*). In addition, self-reported social creativity had weaker cross-loadings with sports creativity on the fourth component (.42) and with the scientific creativity on the fifth component (-.56). The negative relationship between social and scientific creativities could be due to many reasons, one being that those who excel in scientific creativity may be better working independently, which would reduce the number of opportunities to engage with their social creativity. Social creativity also had a weak loading on the third (*Test-based Divergent Thinking*) component (.42). It is plausible that social creativity is a more general attribute that is beneficial to other forms of creativity as well, from idea fluency to creative behaviours in sports.

Taken together, the latent structure of six components, among 13 individual level measures of creativity, indicates that creativity is not a unitary construct.

Are creative activity and creative achievement inventories associated with any general creativity measures or with self-reported creativity in science, visual, verbal, social and sports domains?

Evaluation of the results on the relationship between domain-general and domain-specific creativity measures (science, visual, verbal, social and sports) showed that only the self-reported social creativity (SSRC social) loaded highly on any of the six domain-general creativity measures (CSE, UCCS, RIBS, RAT, AUT and fDT). It had a moderate component loading (.41) on the same Test-based Divergent Thinking component with the VAU and fDT.

One possible explanation for the positive associations between social creativity and divergent thinking may also be linked to personality traits of Openness to Experience and Extraversion. Previous research has found that these personality traits were positively associated with divergent thinking (Furnham & Bachtiar, 2008). These personality traits also capture the frequency and enjoyment of social interactions which are relevant in the engagement in social creativity. Interestingly, none of the *Self-reported Creative Cognition* measures (CSE, UCCS and RIBS) loaded highly on the same factor with any self-reported creativity domains (science, social, visual, verbal and sports). This may indicate that Self-reported Creative Cognition measures are not biased towards any specific domain, or alternatively not tapping into the same latent construct.

Are self-reported creativity measures in science, visual, verbal, social and sports domains associated with six domain-general creativity measures?

Additionally, none of the domain-general creativity measures (CSE, UCCS, RIBS, RAT AUT and fDT) loaded highly with the behavioural inventory measures of creative activity (CBI) or creative achievement (CAQ). This raises a question of the ecological validity of domain-general creativity measures: are these measures beneficial to applied settings if they are not associated strongly with creativity dimensions of actual behaviours, captured as creative activities and achievements? Similarly, the self-evaluated measures of creativity in five different domains (science, visual, verbal, social and sports) did not load highly on the same components with any of the six domain-general creativity measures. It could be that evaluating one's own creativity includes such a wide range of different behaviours that this reduces the reliability of the measurement and hides any effect, if there is one to be found.

Taken together, these findings provide interesting insights into the structure of creativity. As indicated with the previous research, creativity is a complex and multidimensional construct which is not easy to define and operationalise as clearly separated elements (e.g., Agnoli et al., 2016). For example, the lack of associations between self-reported verbal creativity with a verbal measure of creative cognition (RAT) indicates that when individuals are evaluating their verbal creativity, it is not based on their ability to create linguistic associations (or compound words). It could be that participants are thinking of more complex behaviours, such as those which are recognised as being creativity in various social contexts. This also highlights that different theoretical approaches to creativity, such as cognitive and sociocultural approaches, are not necessarily accommodating one another to a great extent. This separation between the different theoretical approaches to creativity can create difficulties in the interpretation of results. In a similar vein, the lack of association between Creative Self-Efficacy and the measures of creative cognition (AUT and RAT) implies that the evaluation of creative thinking is not based on the evaluation of these specific abilities of creative cognition. Again, the self-evaluation of creative self-efficacy may cover of large array of different cognitive processes.

Limitations

The present study had a number of limitations. One problem for creativity measurement, especially in relation to self-reported measures, is how to separate creativity from a skill which it is associated with (Kaufman & Baer, 2005). It may be that when reporting self-evaluated creativity, participants instead evaluate their level of skill, instead of their creativity in the domain. On the other hand, inventories of creative activities may only measure a frequency of activity, regardless of creative input. For example, attending a pottery class may assign a person scores in the inventory even if they only repeated the actions of the course tutor. This repetitive activity would be not considered being creative.

In addition, The Creative Achievement Questionnaire (CAQ) may not be a suitable measure to use in young samples due to the low variance in the scores. Many creative achievements may reasonably be expected in higher numbers only in older participants. Also, the CAQ in its current form is not up to date with more recent technological creative areas, such as coding and graphic design. Another limitation in the present study was that the language criterion was set for fluent English skills rather than being restricted to only native English speakers. It has been shown, for example, that, in the Remote Associates Test, native speakers have advantage in comparison to non-native speakers (Estrada et al., 1994). The sample size also poses a limitation in the present study. Recommended sample size for a robust PCA with 13 measures would be 200 or higher (Comrey et al., 2013). Additionally, the sample in the present study had a high proportion of students from Arts, Humanities and Psychology.

Future directions

More studies are needed to uncover the inter-relationships of creativity measures in different samples. Better understanding of the underlying structure among the measures will enhance research in this area. Similarly, more research is needed on other cognitive tasks. For example, the Remote Associates Test has been extensively used in a verbal format, but much less work has been done with a newly developed visual version (Toivainen et al., 2019; see Chapter 2 in this thesis). Additionally, more research is needed that explores the relationship between psychological constructs, such as personality and intelligence, with different creativity measures in the same sample. Further research is also needed to find reliable ways to empirically separate the level of skill from creative output.

Conclusions

The non-unitary structure of creativity can propose difficulties for research. This should not be seen as a disadvantage. However, it has to be recognised. To address this issue, it is important is to be clear to which aspect of creativity we are referred to. As shown, creative cognition, evaluations one's creativity in certain situations or previous creative behaviours, are likely not to be indicators of same dimension of creativity construct. Alternatively, they could be indicators of completely different constructs.

Clarifying the structure of creativity and the extent to which different measures tap into its different facets, has implications also for education (Plucker, 2004). For example, in order to cultivate creativity, educational practises could focus on general creative process skills or certain domain-specific tasks, depending on our understanding of creativity (Plucker, 2004). Tailoring creative interventions or activities to the correct level and application will save time and resources.

To summarise, the findings of this study provide evidence for the variable relationships among different measures that are used interchangeably as proxies for creativity. The findings suggest that existing measures are likely to tap into different dimensions of creativity or even separate constructs. This could even mean that creativity is not a general construct but a sum of various factors which are used to associate with creativity.

As shown by the results in this chapter, the two measures of divergent thinking, the fluency scores of verbal and figural tests, were highly associated ($r = .72$). However, most creativity measures only rely on linguistic forms of a test. Further investigations are needed to investigate the role of stimuli in processes associated with creativity. Items based on visual stimuli may also aid cross-cultural research by reducing linguistic features that may benefit native speakers. Another measure that can investigated based on different modalities is the Remote Associates Test. The findings in this chapter indicated that the Remote Associates Test loaded on a separate component to the other measures. However, this finding should not be interpreted as an indication that the measure is not relevant to creativity. This result can only be interpreted as an indication that the ability to make remote associations could be somewhat different from the other cognitive and self-reported measures. To understand these underlying mechanisms better, additional research on the Remote Associates Test is warranted. The following Chapter 2 presents a study which investigates the association of a newly developed visual Remote Associates Test with its linguistic version in Russian and Finnish samples.

3 Measuring creativity: A cross-cultural investigation of linguistic and visual versions of the Remote Associates Test

Chapter summary

The Remote Associates Test (RAT) is a measure of associative ability, which is often regarded as essential for creative thinking. The most commonly used version of the test is the compound RAT. However, many RAT items do not translate directly in different languages. Additionally, a linguistic measure cannot be used to measure visual associative ability. A visual measure for associative ability that is similar to the RAT would be a useful tool for cross-cultural investigations of creativity. The present study investigated the relationship between the linguistic and a newly developed visual version of Remote Associates Test in Russian (n = 67) and Finnish (n = 67) native speakers. Both linguistic and visual measures showed good internal reliabilities in both samples (Cronbach's α = .73 - .84). The mean score in the visual task was slightly higher for the Finnish sample. The correlation between the two measures was stronger in the Russian sample (r = .56) compared to the Finnish sample (r = .28). These results are discussed in relation to linguistic and cultural differences between the samples.

Introduction

The Remote Associates Test (RAT) is a widely used measure in creativity research. The RAT was developed by Mednick (1962) to empirically test his associative theory of creativity. According to the theory, creative individuals are better at making remote associations in comparison to non-creative (Mednick, 1962). The originally proposed version of the RAT is to find a solution word for three stimuli words. According to Mednick (1962), the solution word can be associated with the stimuli by semantic association (e.g., chicken and egg), synonymy (e.g., chicken and coward) or formation of a compound word (e.g., spring chicken). The most commonly used version of the RAT is the compound Remote Associates Test (cRAT; Bowden & Jung-Beeman, 2003). In the cRAT the stimuli words form a compound word with the solution word. For example, for stimuli words "*cake*"; "*swiss*" and "*cottage*", a potential answer is "*cheese*", because it creates compound words that have new meanings: "*cheesecake*", "*swiss cheese*" and "*cottage cheese*". Traditionally, the cRAT has appealed to researchers as each item is held to have only one correct response, making scoring easy as well as taking limited time to administer (Bowden & Jung-Beeman, 2003; Lee et al., 2014). However, new computational approaches have shown that many cRAT stimuli words have more than one correct answer (Olteţeanu & Falomir, 2015).

The cRAT has been used in several languages and has provided normative data for example in English (Bowden & Jung-Beeman, 2003); Dutch (Chermahini et al., 2012); and Japanese (Terai et al., 2013). Due to the language specific rules on forming compound words, the translation of the test items is often difficult if not impossible. Also, due to high demands of vocabulary in the cRAT, native speakers have been shown to have an advantage compared to second language speakers (Estrada et al., 1994). Additionally, some researchers have argued that the cRAT is limited as a measure of remote associational ability due to its overreliance on linguistic rules (Worthen & Clark, 1971).

Another variation of linguistic RAT is the functional RAT (fRAT; Worthen & Clark, 1971). As in the cRAT, participants are asked to come up with words that are associated with the three stimuli words. However, instead of creating compound words, the response word is connected to the stimuli with semantic associations. For example, for stimuli "*bait*", "*pond*" and "*tuna*", the answer word can be "*fish*" (bait is used to catch fish, fish live in ponds and tuna is a type of fish). In the fRAT, it is likely that there are also other potential words that may connect the stimuli words semantically. A set of functional items has been created computationally (Olteţeanu et al., 2019). Additionally, a recent extension of the fRAT is the visual Remote Associates Test (vRAT). In the vRAT, participants are asked to identify a concept that is semantically linked with three presented images (Olteţeanu & Falomir, 2015).

The vRAT has many advantages. Firstly, the use of visual stimuli in the vRAT overcomes limitations of language specificity for linguistic measures. The use of the vRAT, instead of linguistic versions of the test, may reduce the advantage of native speakers over second-language participants. Secondly, the use of vRAT in combination with linguistic RAT measures, can address questions relating to domain-specificity in creativity research. Mednick (1962) argued that his measure is domain-general but other researchers have proposed that the cRAT in particular is a domain-specific measure that taps into verbal abilities linked to a general intelligence factor (Kaufman et al., 2008).

The present study examines the relationships between different versions of the Remote Associates Test by investigating the associations between visual and linguistic RAT measures in two samples of Russian and Finnish native speakers. Previous research has found a correlation of .43 between the cRAT and vRAT in an English-speaking sample (n=38; Olteţeanu & Zunjani, 2020). The moderate association were argued to be due to differences in test stimuli, so cross-culturally the associations would be expected to be similar. The present study addressed the following questions:

Research questions:

1. Is there a relation between the linguistic and visual RAT performance in Finnish?
2. Is there a relation between the linguistic and visual RAT performance in Russian?
3. Are these relations similar in the Russian and Finnish samples?

In addition, the study investigated potential difference in the vRAT between the Russian and Finnish samples. A mean difference in the visual task could be an indication of culture/language-specificity, not a cognitive difference between the samples. For example, certain images could be more relevant in some cultures than in others. However, the vRAT measure has only been administered in samples in western Europe so more information on culture-specificity of the item is needed.

Methods

Sample

The participants were members of the general public, recruited via social media. Both Russian and Finnish samples had 67 participants. The age was collected with a categorical measure, ranging from 18 to 69 (see Table 2.1. below for the breakdown of ages in both samples). The Russian sample included 17 males and 50 females, the Finnish sample 7 males and 60 females. A priori power analysis showed that a sample of 52 participants would be required to detect an effect of .43 with 80% power at significance level of 0.05 (Olteţeanu & Zunjani, 2020).

Table 3.1. Frequencies of Russian and Finnish participants in different age categories.

Age range	Russian sample	Finnish sample
18-19	3	0
20-29	47	15
30-39	15	16
40-49	1	19
50-59	1	14
60-69	0	3

Measures

Same visual items were used for both samples (vRAT). The test included 46 items. For the development of visual items, see Olteteanu et al. (2015), for further details.

The initial aim was to use the same linguistic task items for both samples. However, translation of the English cRAT items (Bowden & Jung-Beeman, 2003) to Russian and Finnish was unsuccessful due to changes in the meanings of the words. Similarly, translation of compound items between Russian and Finnish was not successful. Therefore, some Russian and all Finnish linguistic RAT (lingRAT) items were created for this study (36 Russian items were selected from a previous study; Druzhinin, 1999).

Linguistic items and test forms (cRAT, fRAT) differed between the samples. In the Finnish sample, all 47 linguistic items were in the compound form (cRAT). Due to language specific difficulties of creating compound items in Russian (compound words are not common in Russian), most items were in a functional form (1 cRAT and 47 fRAT items in Russian).

The study utilised 36 previously used Russian lingRAT items (Druzhinin, 1999). Twelve additional items were additionally created as part of this project. The items were tested by a group of native Russian speakers to make sure the items were commonly known (procedure similar to Chermahini et al., 2012).

All lingRAT items were created in Finnish as part of this project (procedure similar to Chermahini et al., 2012). Examples of the measures (in English, Russian and Finnish) are presented in Table 3.2. The full list of Russian and Finnish lingRAT items are presented in Appendix 1.

Table 3.2. Example items of cRAT, fRAT and vRAT.

Test and the form of stimuli	Task	Languag e	Stimulus 1	Stimulus 2	Stimulus 3	Example response
compound lingRAT (cRAT) Word	What word can form compound words with the three stimuli words?	English	Cake	Cottage	Swiss	Cheese
		Russian	Кино (a cinema)	экзаменационн ый (exam)	проездно й (travel)	билет (ticket; paper)
		Finnish	kirja (a book)	tori (a marketplace)	tiede (science)	kauppa (shop)
functional lingRAT (fRAT) Word	What word is associated with the three stimuli words?	English	bait	Pond	tuna	Fish
		Russian	холодная (cold)	зеленая (green)	мутная (muddy)	вода (water)

vRAT Image	What co-occurs with the three stimuli images?	English				hand

Note. lingRAT = linguistic RAT; vRAT = visual RAT; cRAT = compound RAT; fRAT = functional RAT.

In all tasks, participants were asked to provide an answer word that is connected to stimuli. Participants were shown two practice items with example answers. No time limits for the tasks were set to replicate the procedure of the previous study (Olteţeanu & Falomir, 2015). For all measures, participants could skip items they did not have an answer for.

In addition to the responses (accuracy), reaction times (RT) were recorded for all items (see Appendix 1 for reaction times for each item). RTs longer than 400,000 ms (6 minutes and 40 seconds) were coded as outliers and imputed with the new series mean method in SPSS. The cut-off point was chosen to exclude extreme outliers at this pilot stage of the project. This will be redefined in the following studies, in which, with the additional data, we can make more informed decisions regarding the cut-off for the reaction times.

Scoring

All responses (lingRAT and vRAT) were checked and scored by native Russian and Finnish speakers. This was to make sure that all correct answers were identified, since some of the items could have more than one correct answer. Correct answers were assigned 1 point, incorrect answers scored 0. The summed total was used as an Accuracy score for each participant.

Results

Descriptive statistics and frequency distributions showed that all measures (RAT scores and RTs) were normally distributed. Table 3.3. presents descriptive statistics, internal reliabilities (Cronbach's alpha), within sample correlations and the total mean time for the four measures (Russian vRAT, Russian lingRAT, Finnish vRAT and Finnish lingRAT).

Table 3.3. Mean accuracy scores (standard deviations); internal reliabilities (Alpha); skewness and kurtosis values; mean accuracy correlations; total mean times; and total mean time correlations for the vRAT and lingRAT in the Russian sample.

	m (SD)	**Alpha**	**Skew**	**Kurtosis**	**Accuracy Correlation**	**m total time (in minutes)**	**Total time *r***
vRAT	24.6 (6.8)	.79	-0.61	1.30	.56**	14.40 (5.8)	.47**
lingRAT	26.6 (6.9)	.83	-0.76	0.71		18.83 (8.3)	

Note. **p < .01, *p < .05; n=67

Table 3.4. Mean accuracy scores (standard deviations); internal reliabilities (Alpha); skewness and kurtosis values; mean accuracy correlations; total mean times; and total mean time correlations for the vRAT and lingRAT in the Finnish sample.

	m (SD)	**Alpha**	**Skew**	**Kurtosis**	**Accuracy Correlation**	**m total time (in minutes)**	**Total time *r***
vRAT	29.2 (7.1)	.84	-1.99	5.57	.28*	14.07 (6.49)	.46**
lingRAT	21.6 (5.3)	.73	0.37	0.45		29.25 (13.6)	

Note. **p < .01, *p < .05; n=67

For accuracy scores, the correlation between the lingRAT and vRAT in the Russian sample was $r(65) = .56$, $p < .001$, n = 67, and in the Finnish sample it was $r(65) = .28$, $p = .02$, n = 67. The difference between sample-specific correlations was statistically significant (Fisher's r-to-z transformation z = 1.95, $p = .03$). Additionally, there was a significant mean difference in vRAT ($t(132) = -3.78$, $p < .001$) between the Russian and Finnish samples.

The total reaction times (sum of RTs for each item) were positively correlated between lingRAT and vRAT total scores for both Russian ($r(65) = .47$, $p < .001$) and Finnish ($r(65) = .46$, $p < .001$) samples. The difference in correlations was non-significant (Fisher's r-to-z transformation z = -0.07).

Discussion

The present study was the first to explore the relationship of linguistic and visual stimuli in the Remote Associates Test in Russian and Finnish samples. Correlations between accuracy scores in the linguistic (cRAT + fRAT) and visual (vRAT) tasks differed between the samples: correlation was moderate in the Russian sample and weak in the Finnish sample. For the RT measure, a very similar moderate correlation was found in both samples.

The difference in the lingRAT stimuli sets may influence the accuracy correlation between the lingRAT and vRAT. Finnish items were all compound words whereas Russian items were mainly functional items**.** In the vRAT, all items were the same for both groups. Since the vRAT is based on semantic associations (same as linguistic fRAT items), the higher correlation in the Russian sample may reflect that the similar strategy could be used to solve items in lingRAT and vRAT. Alternatively, the lower correlation in the Finnish sample could be due to differences in measures. Whereas the vRAT tapped into semantic associations, performance in the Finnish lingRAT (all compound items) was more related to linguistic ability to form compound words than it was in the Russian sample.

Alternatively, the difference between the correlations may indicate language-specific features of how compound words are created. Due to different linguistic rules in Russian and Finnish, it may be that language specific grammatical constraints direct the selection of the words that can be used to form compound words. For example, if in Russian fRAT a stimulus word is an adjective, it will have the appropriate grammatical gender in congruence with the solution word. Potentially this will also constrain the 'search space' for the correct solution word.

The findings of mean differences between the two samples in the tasks was interesting, however, it is important not to attribute these differences (only) to cultural or linguistic influences, based on this initial study. The linguistics measures were different between the samples. In addition, the samples had some dissimilarities (e.g., age and gender). However, one of the aims for the further development of the visual RAT measure is to provide research opportunities for cross-cultural investigations in the ability of making remote associations, and this study has contributed to this endeavour. Also, the current form of the RAT is administered and scored as a cognitive task, but the further development of this measure may provide opportunities to evaluate remote associations based also on their originality and appropriateness. This additional layer could then also take into a consideration the role of sociocultural values and how original they would be valued in different social contexts. For example, the rationale, provided by participants, for the associations between two remote concepts could be evaluated for their originality, as well as for other features, such as usefulness.

In addition to the points mentioned above, future research is needed to explore whether this differences between the samples stem from methodological limitations or some culture/language specificity. The observed difference may reflect culture-specificity of certain items, when some concepts (images) may be more familiar in certain cultures. For example, a picture of Poseidon is recognizable only to participants with knowledge on Greek mythology.

Different proportions of compound vs. functional linguistic test items were a limitation in the study. Future work is planned to address this by creating comparable stimulus sets to further investigate the relationships of lingRAT (cRAT, fRAT) and vRAT between Russian and Finnish samples. In the current study, the stimuli and response words were also a mix of nouns, verbs and adjectives. In future, we will aim to produce more comparable items, based only on nouns. Additionally, an investigation is planned to explore the psychometric properties of the linguistic and visual items in more detail. Future studies should employ the same stimuli set, both in linguistic or visual form, to explore their role in associative processing. One important objective of such research is to further develop a valid vRAT measure that can be used in cross-cultural studies.

The findings of the present study show promise in the use of a vRAT across populations with different native languages. They also show that linguistic and cultural specificity may influence RAT performance. Combining linguistic and visual remote association tests in cross-cultural context will lead to better understanding of the cognitive processes underlying creativity.

As the results presented in this chapter showed, different forms of the same creativity measure are not necessarily measuring the same underlying construct. Another way to evaluate the underlying structure of creativity is to investigate how it relates to personality and intelligence. The following Chapter 4 presents a study which investigates associations of creativity, personality and intelligence among high achieving adolescent in Science and Art.

4 Predicting creativity: Investigating the links between personality, intelligence and creativity among high achieving adolescents in Science and Art & Literature

Chapter summary

Personality, intelligence and creativity influence people's educational choices and professional trajectories. However, interrelationships among these three constructs are not fully understood. This is partly due to the existence of diverse creativity measures that may tap into different dimensions or even separate constructs. Research to date has produced mixed pattern of results. For example, among adult samples, personality and intelligence have shown to have differential effects on creative achievements in the Sciences and Art. The present study extended previous research by estimating the amount of variance explained by the Big-5 personality traits and intelligence in eight measures of creativity. The study also compared these estimates between two Russian adolescent samples with high achievements in the Sciences (n = 454; m_{age} = 15.12) vs. Art & Literature (n = 298; m_{age} = 15.35). The measures were self-reported creativity in 1) science, 2) social, 3) visual, 4) verbal and 5) sports domains; 6) creative self-efficacy; and, 7) fluency and 8) originality scores of the Alternative Uses Task. The results were also compared with an English-speaking adult sample (n = 169; m_{age} = 23.33). The results supported the finding of Openness to Experience being the most robust predictor, a finding that replicated in all three samples. The results for other personality traits were less consistent. Intelligence was a poor predictor of creativity explaining some variance only in the originality score of the Alternative Uses Task. Additionally, comparison of the predictor variables between the Sciences and Art & Literature samples showed differences in two measures: Agreeableness explaining variance in self-reported social creativity, and intelligence in the originality score of the Alternative Uses Task. The results suggest that higher intelligence may only be beneficial for more complex creative behaviours, such as creative achievement and working in creative professions.

Introduction

All creative processes are influenced by personality and intelligence (Simonton, 2003). Knowledge on how these constructs are related is useful when considering interventions aimed at different dimensions of creativity, for example in education. Creativity has been an interest of gifted programs (e.g. Getzels & Jackson, 1962), but recently encouragement of students' creative potential has been emphasised as an aim of mainstream educational policies (Ferrari et al., 2009). However, difficulties in defining creativity and numerous ways in which it can be operationalised, have led to a fragmented picture of the relationship of creativity with personality and intelligence.

Personality refers to individual differences in characteristic patterns of thinking, feeling and behaving (Weiner & Craighead, 2010). A common measure of personality is based on 5 dimensions of Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. The five dimensions are based on the Big-5 model of personality which were originally derived from the vast array of trait terms people used to describe themselves and others (Allport & Odbert, 1936; John & Srivastava, 1999). The Big-5 model of personality is generalizable across measuring instruments, languages, and methods of analysis (John & Srivastava, 1999).

A systematic review on the relationship between Big-5 personality traits and creativity (measured with self-reports, cognitive tests and external evaluations) showed the highest correlation between Openness to Experience and creativity (r = .24; Puryear et al., 2017). The association with Openness to Experience seems intuitive since this trait can be described as curiosity or willingness to engage with new ideas. The second strongest association was with Extraversion (r = .14), a measure of enjoyment of social interactions, which is often viewed to be an attribute of creative individuals (Puryear et al., 2017). The meta-analysis showed negligible correlations with creativity for the other three dimensions of personality: Conscientiousness (r = .02), a trait that captures self-discipline and reliability; Agreeableness (*r* = .03), a measure of conformity and flexibility; and Neuroticism (*r* = -.04), which measures emotional instability (Puryear et al., 2017).

Research has demonstrated that relationships of personality and intelligence to creativity vary, depending on how creativity is measured. Self-rated creativity, creative self-efficacy and creative personal identity are self-reported assessments of Creative Self-Beliefs (CSBs), which are individuals' convictions about their creative abilities (Karwowski et al., 2013; Karwowski & Barbot, 2016). A meta-analysis on the relationship between CSBs and personality traits found that Openness to Experience had the strongest correlations (*r* = .47), followed by Extraversion (*r* = .26), Conscientiousness (*r* = .13), Agreeableness (*r* = .07) and Neuroticism (*r* = -.12). However, for Openness to Experience and Extraversion, the relationships are stronger with domain-general measures (e.g. creative self-efficacy), compared to self-reported creativity in specific domains (Karwowski et al., 2013). In comparison to the correlations between CSBs and five personality traits, a study has reported weaker correlations when creativity is measured as specific to certain domain. For example, the association between Openness to Experience with self-reported creativity in Math/Science was *r* = .30, and with self-reported artistic creativity *r* = .34 (Kaufman et al., 2010). For Extraversion, the correlations were *r* = .10 with creativity in Math/Science and *r* = .33 with self-reported artistic creativity (Kaufman et al., 2010). This indicates that the relevance of different personality traits to creativity vary across domains. Also, it may reflect that people associate specific skills with creativity when estimating it in specific domains.

Some personality traits are also associated with cognitive measures of creativity. For example, one study reported small to medium associations for a divergent thinking task, a cognitive creativity measure; with Openness to Experience (*r* =. 15); and with Extraversion (*r* =. 69; Furnham et al., 2008). Another study, reported that Extraversion (*b* = .49) and Agreeableness (*b* = -.30) explained variance in divergent thinking, measured with an originality score, even after intelligence was regressed out (Batey et al., 2009). However, the second experiment in the same study did not replicate the finding of personality traits explaining variance in divergent thinking performance (Batey et al., 2009).

Studies have shown that other personality traits can also be differently associated with creativity in different samples. For example, some studies have found that Neuroticism (emotional instability) is elevated in artistic populations; at the same time successful and possibly creative leaders tend to be emotionally stable (Barrick & Mount, 1991; Feist, 1998). Studies have also indicated that Conscientiousness seems to contribute to scientific excellence: a meta-analysis reported that the median score for scientists was 0.51 standards deviation higher in comparison to non-scientists (Feist, 1998). In comparison, the same meta-analysis reported that among the artists the effect was in the opposite direction: artists scored 0.49 lower in Conscientiousness in comparison to non-scientists (Feist, 1998). Based on these findings, it appears that certain personality traits as well as intelligence facilitate creativity in some specific domains, but potentially inhibit it in others (Batey & Furnham, 2006).

Taken together, the findings on the relationship between creativity and personality have shown that only Openness to Experience has a robust, positive association with various self-reported measures of creativity. The relevance to other personality traits appears to vary, often being very small or non-existing.

Research has also shown associations of different facets of creativity with intelligence. Intelligence can be described as a global cognitive capacity to act rationally and to deal effectively with the environment (Wechsler, 1944). A meta-analysis reported an overall correlation of r = .17 between divergent thinking (a cognitive creativity measure of creativity) and intelligence (Kim, 2005). Another study concluded that their association is stronger, when intelligence is measured as a higher-order latent factor, not based a single cognitive measure (Silvia, 2008). Additionally, intelligence has also been associated with creative activities and achievements. For example, one study reported a correlation of .26 between intelligence and creative activities and accomplishments (Hocevar, 1979). Another study linked intelligence with creative achievements, specifically in scientific domain (*r* = .31; de Manzano & Ullén, 2018). Some evidence has supported the idea that intelligence is a moderator between creative activities and achievements, turning small scale creative activities into more eminent, socially recognised creative achievements (Jauk et al., 2014).

The association between intelligence and self-rated creativity seems to be small. A previous study reported small, non-significant correlations between a self-reported creativity measures with Raven's Advanced Progressive Matrices, a measure of non-verbal reasoning (*r* = .11); and with General Knowledge Test (*r* = -.14; Batey et al., 2010; Raven, 1998). Another study reported a negligible correlation (*r* = .01) between self-reported creativity and intelligence (Furnham & Bachtiar, 2008).

Conceptually the relationship between creativity and intelligence seems intuitive. Intelligence is needed, for example, to distil a creative idea instead of relying on a random combinatory process. This selection is facilitated by processing capacity, mental speed and reasoning ability, all attributable to general intelligence (Penke, 2003). According to the necessary-but-not-sufficient hypothesis, intelligence is essential, but not sufficient predictor of creativity (Karwowski et al., 2016). This means that creativity cannot explained only by intelligence but that other factors are also required for creativity to emerge. This view is compatible with the idea of intelligence being relevant in evaluative stages of creative idea production. A study that showed that the evaluative stage, following divergent idea production in a creativity process, is maintained by general intelligence (Lee & Therriault, 2013). The study concluded that the role of intelligence is emphasised in the ability to identify the most relevant outcome from a large pool of creative ideas, produced by divergent thinking processes.

Previous research has shown that differences in the associations of creativity with both personality and intelligence can be partly explained to sample-specific factors. For example, certain personality traits may be emphasised in specific artistic creative activities, compared to scientific creativity (de Manzano & Ullén, 2018; Feist, 1998). One study showed that Openness to Experience, in comparison to intelligence, was twice as strong predictor of creative achievements in Arts (de Manzano & Ullén, 2018). In contrast, intelligence was a better predictor of creative achievements in science, compared to Openness to Experience (de Manzano & Ullén, 2018). Another study has shown similar results of differential effects of Intellect and Openness (two facets of the Big-5 trait of Openness to Experience) on artistic and scientific creative achievements (Kaufman et al., 2016). These results are not surprising, as Intellect is a facet of logical and abstract reasoning; whereas Openness reflects cognitive engagement with perception, fantasy, aesthetics and emotion (DeYoung et al., 2012).

One limitation of previous research into associations of creativity with personality and intelligence is that most studies have been conducted with adult samples. Investigations are needed that cover developmental samples, since the relationship between creativity, personality and intelligence is limited since the earlier studies among gifted students (Getzels & Jackson, 1962; Parloff et al., 1968). To date very few studies have been conducted with children and adolescents. One study, based on Jamaican adolescents, reported small associations, both positive and negative, between personality and creativity (r = -24 to .23; Richardson, 1985). However, personality in this study was not measured with the Big-5 traits but the 11 items were selected from various sources. Another study, a meta-analysis, established a correlation between creativity and educational achievement of r = .33 in middle school (ages 11-14) and correlation of r = .21 in high school (ages 14-18; Gajda et al., 2017). Educational achievement which correlates highly with intelligence (r = .81; Deary et al., 2007).

Research questions:

The aim of the study is to investigate the role of personality and intelligence in different facets of creativity in different samples. Specifically, the study explored the associations of five personality traits (Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism); intelligence, measured by Raven's Progressive Matrices; and eight measures of creativity in three samples (adolescent samples with high achievements in 1) Science; 2) Art & Literature; and 3) a sample of young adults). The research questions for the present study are as follows:

1. What is the proportion of variance explained by the personality traits of Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism in 8 measures of creativity?
2. What is the proportion of variance explained by intelligence 8 measures in creativity?
3. Are the associations between 8 creativity measures with personality and intelligence replicated in all three samples?
4. Are there differences in strengths of associations between high achieving adolescents in Science vs. Art & Literature?

Methods

Samples

The present study reports findings from three samples. Initially, data was collected among (1) unselected English-speaking adults. This sample was used to provide a comparison to the two main samples of interest in the present study. The main investigation was looking at the predictive power of personality and intelligence between (2a) a sample of Russian-speaking adolescents with high achievements in Science; (2b) a sample of Russian-speaking adolescents with high achievements in Art & Literature.

The Russian-speaking samples were school children attending a 24-days intensive educational programme at Educational Centre for high achieving students. Part of the centre provides activities and training for school students who have shown outstanding abilities in one of four domains: Sciences (mathematics, physics, chemistry etc.); Arts (academic music, classical ballet, academic painting etc.); Literature; and

Sports (hockey, figure skating etc.). The present study used data from students who were selected for the program based on their high achievements in Science, Art or Literature. Selecting Science, Art/Literature students ensured comparability to previous research which has reported differential relationships of personality and intelligence with creative achievements for Art and Science (de Manzano & Ullén, 2018; Kaufman et al., 2016). Artistic creative achievements in these previous studies also included creative achievements in literature. Computerised data collection took place in a research lab at the educational centre between July and October 2018.

Sample 1: The English-speaking sample (the comparison sample)

The English-speaking sample included 169 participants. The participants ranged in age from 18 to 57, with a mean age of 23.27 (SD = 4.9). The sample included 123 women (m_{age} = 22.10; SD = 6.95) and 46 men (m_{age} = 26.50; SD = 11.20). Participants were an opportunity sample recruited online and through a psychology students' research participation scheme at Goldsmiths, University of London. The data collection took place between March 2017 and January 2018. The data collection was completed on-line using personal computers. Participation was open to anyone who was 18 years or older and fluent in English. Most participants were undergraduate students in the UK. Due to the length of the battery, participants could interrupt their participation and return later using their personal ID.

Sample 2a: High achieving students in Science

In total, 454 Science students (263 males and 191 females) took part in the current research. The mean age was 15.12 (SD = 1.21). High achievement is Science is based on students' performance in academic competitions in maths, chemistry, physics, informatics or biology, or for a scientific project that a student has carried out.

Sample 2b: High achieving students in Art & Literature

In total, 298 Art & Literature students (49 males and 249 females) took part in the current research. The mean age was 15.35 (SD = 1.19). To get accepted into the Art & Literature programs, students must have shown outstanding performance in painting, sculpture, choreography, music or literature, such as winning relevant competitions.

Measures

As indicated in chapter 2, the structure underlying various creativity measures is not unitary and does not load on a single component. This finding guided the selection of measures for this study so that the relationship of personality and intelligence would cover a broad range of creativity dimensions. To cover different dimensions of creativity and to provide a more complete view of the associations between personality, intelligence and dimensions of creativity, the present study included both cognitive and self-reported creativity measures. Some were measures of general creativity and some were restricted to specific domain(s). No creative behavioural inventories were included in the data collection as these were considered unsuitable for adolescent samples (see Chapter 2 for a discussion).

The data collection for this study was part of a larger data collection effort in Sirius educational centre. The data collection had time limitations due to the daily schedules of the students.

Some measures differed between the two adolescent Russian samples and the English-speaking adult sample. First, the length of the scale was different for Short Self-Reported Creativity. Second, the number of items in the Alternative Uses Task, as well as the coding procedure of originality of responses, was also different between the samples. Third, intelligence was measured with a different number of tests between the samples. Due to these differences, straight comparisons, especially between the mean scores, should be avoided between the adolescent and English-speaking samples. Detailed descriptions of the measures, for all samples, is provided below.

Creativity measures

Short Self-Reported Creativity

The Short Self-Reported Creativity (SSRC) measure requires participants to rate their own creativity, in comparison to the others, in scientific, social, visual, verbal and sports domains (Hughes et al., 2013; Kaufman, 2006). The participants used scales of 1-7 (English Speaking sample) and 1-10 (Russian samples) in their creativity self-evaluations.

Creative self-efficacy

Creative self-efficacy (CSE) was measured by a 3-item scale (1-5; Beghetto, 2006). The items were (a) "I am good at coming up with new ideas," (b) "I have a lot of good ideas," and (c) "I have a good imagination. The score for the measure was the summed total of the three items, ranging from 3 to15. The internal validities for CSE was good in all three samples: alphas (α) = .84 to .92.

Verbal Alternative Uses Task

The verbal version of the Alternative Uses Task (AUT) is a measure of divergent thinking (Guilford, 1967). Participants were shown a word of a common household object and were asked to come up with as many alternative uses for the object as they can think of in 3 minutes per trial. The Russian-speaking samples completed five separate trials (brick, paperclip, glass bottle, newspaper and straw); the English-speaking sample completed three trials (a brick, a paperclip and a newspaper). The number of items used in previous research, ranges from 3 to 8 (Martindale & Hines, 1975; Wallach & Kogan, 1965).

Fluency and originality scores were calculated for each participant. Fluency score was the mean total number of responses for all trials. The internal validities for the fluency scores among five trials for Science sample was alpha (α) = .94 and for Art & Literature alpha (α) = .90. The internal validity for the English-speaking sample among three trials was alpha (α) = .88

The originality score was assigned by a group of independent coders. For the Science and Art & Literature samples, a top-2 scoring method was used (Silvia et al., 2008). Out of all responses the participants produced for each trial, they were asked to select their 2 most creative responses. These 10 most creative responses from each participant were coded for their originality (1-7) by two judges. Due to a large number of responses, the responses were split in four groups. In total, 8 coders scored a selection of responses (2 coders for each of the four groups of responses). The interrater reliability for the originality scores between two coders, measured as Cronbach's alpha, was (α) = .66 for the Science sample; and (α) = .70 for the Art & Literature sample. The top-2 coding method was used for the adolescent samples. This was due to the large sample sizes and the fact that, between them, participants produced over 20000 responses. Logistical limitations made it impossible to utilise all responses from these groups.

The top-2 scoring method has several benefits. It engages the participants in convergent thinking since they have to select the most creative responses from the pool of answers they have produced. This method will also reduce the labour intensity of the manual coding for originality scores. The top-2 method has been shown to be valid in relation to the traditional method of scoring all items for their creativity (Benedek et al., 2013; Silvia et al., 2008). As such, it is better suited for larger samples, such as the Science and Art & Literature samples in the present study.

For the English-speaking sample, all responses were coded for their originality (on a scale of 1-5) by three independent coders. All items were randomised before scoring. After all responses were assigned a score, the highest scores from each coder for each stimulus (a brick, a paperclip and a newspaper) were selected. The mean, based on the three highest scores from each coder, was calculated to get the score for each trial. The mean of three trials was then calculated as the total originality score for each participant. The interrater reliability for the originality scores between three coders was α =.73. Selecting only the highest scores from a pool of responses to one stimulus, would not penalise participants who listed several responses, including unoriginal ones. If the score was divided with the total number of given responses, the average would be lower for those who had given more answers.

Personality measures

Personality was measured with the Big-5 personality scale, a 44-item measure of Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism (John & Srivastava, 1999). A Russian version of the measure was administered to the two Russian-speaking adolescent samples. The total score for each trait is the mean score from the items of each subscale. In all instances, participants were asked to respond to the statement: 'I see myself as someone who'. Examples for each personality trait measure are given below (John & Srivastava, 1999).

- *Openness to Experience*: is original, comes up with new ideas; is curious about many different things; is ingenious, a deep thinker
- *Conscientiousness*: does a thorough job; is a reliable worker; perseveres until the task is finished
- *Extraversion*: is talkative; is full of energy; generates a lot of enthusiasm
- *Agreeableness*: is helpful and unselfish with others; has a forgiving nature; is generally trusting
- *Neuroticism*: is depressed, blue; can be tense, worries a lot

Cognitive ability (intelligence) measures

In both Science and Art & Literature samples, intelligence (or general cognitive ability) was measured with Raven's Progressive Matrices (RPM; Raven, 1998). Raven's measure has been shown to be a good proxy of general cognitive ability (Raven, 1998). Due to time limitations and a large number of participants in these samples, only one cognitive ability measure could be included in the test battery.

In the English-speaking sample, cognitive ability score was a regressed component score, based on the Varimax rotated primary component loadings of four cognitive measures. The measures were Raven's Progressive Matrices; Mill-Hill Vocabulary Scale; Bricks Battery of Spatial Visualisation and Rotation; and Corsi Block Measure of Working Memory (Kessels et al., 2000; Raven, 1998; Shakeshaft et al., 2016).

Raven's Progressive Matrices

Raven's Progressive Matrices are a measure of non-verbal reasoning (RPM; Raven, 1998). Participants are shown 8 images and asked to select the missing ninth image from the selection of the potential answers to complete the stimuli pattern. For the English-speaking sample, a shortened 15-item version of the original RPM was used. For the Russian samples, for whom the RPM was the only cognitive measure in this study, the test had 21 items. For each item, participants had 45 seconds to respond. A score of 1 is given for each correct answer, a score of 0 is given for any incorrect answers. The total score was the sum of the correct responses.

Mill Hill

The Mill-Hill vocabulary scale (MH) is a measure of verbal ability in which participants have to recognise the meanings of all words by choosing the correct synonym for each from among six options (Raven, 1998). The measures consisted of 33 items. For each item, participants had 20 seconds to respond. For each item, the correct response is given a score of 1, and any other response is given a score of 0. The total score was the sum of the correct responses.

Bricks – spatial ability

The Bricks measure of spatial visualisation and rotation (Bricks) is a spatial ability measure, specifically a measure of mental rotation and visualisation (Shakeshaft et al., 2016). The complete Bricks battery consists 6 tests, a mixture of 2D and 3D tasks, but the present study used three measures that have demonstrated good reliability. The total score was the sum of the correct responses.

Corsi Block

Corsi Block (CB) is a test of working memory (Kessels et al., 2000). In the task, the participants have to repeat the sequence of highlighted squares that appear on a matrix on the screen. The items increase in difficulty as the sequences get longer. For each item, the correct response (correct sequence of blocks) is given a score of 1, and any other response is given a score of 0. The total score was the sum of the correct responses.

Results

Descriptive statistics for the eight creativity measures among three samples as are presented in Table 4.1. The intra-correlations between the measures are shown in Table 4.2.

Table 4.1. Descriptive statistics for the eight creativity measures among three samples.

	Russian speaking sample – Science					**Russian speaking sample – Art & Literature**					**English speaking sample**				
	n	**m (sd)**	**range**	**Skew**	**kurt**	**n**	**m (sd)**	**range**	**Skew**	**kurt**	n	**m (sd)**	**range**	**Skew**	**kurt**
Science[1]	453	7.40 (1.92)	1-10	-.86	.65	298	4.11 (2.41)	1-10	.42	-.69	169	3.93 (1.59)	1-7	-.32	-.69
Social[1]	453	6.55 (2.23)	1-10	-.41	-.50	298	7.03 (2.17)	1-10	-.68	-.17	169	5.28 (1.44)	1-7	-.77	.29
Visual[1]	453	5.29 (2.54)	1-10	.09	-.93	298	7.11 (2.35)	1-10	-.62	-.47	169	4.39 (1.66)	1-7	-.43	-.50
Verbal[1]	453	5.62 (2.50)	1-10	-.06	-.90	298	6.85 (2.55)	1-10	-.59	-.72	169	4.34 (1.52)	1-7	-.40	-.38
Sports[1]	453	4.58 (2.72)	1-10	.33	-1.01	298	4.37 (2.73)	1-10	.55	-.74	169	3.44 (1.82)	1-7	.19	-1.02
CSE	454	10.98 (2.61)	3-15	-.59	-.00	298	11.60 (2.52)	3-15	-.74	.46	167	11.26 (2.16)	3-15	-.90	2.02
AUT Fl	454	4.99 (2.88)	0-30	1.42	2.63	297	4.66 (2.93)	0-30	1.46	2.48	169	11.79 (5.68)	0-30	.83	.68
AUT[1] Orig	248	3.19 (0.78)	1-7	-.12	.19	153	3.37 (0.73)	1-7	.13	.63	169	3.47 (0.56)	1-5	-.65	.39
O	454	3.61 (0.65)	1-5	-.08	-.13	298	4.01 (0.55)	1-5	-.66	.08	169	3.59 (0.56)	1-5	-.122	.52
C	454	3.29 (0.72)	1-5	.05	-.44	298	3.47 (0.71)	1-5	-.36	-.06	169	3.30 (0.66)	1-5	-.08	-.45
E	454	3.31 (0.86)	1-5	-.19	-.59	298	3.36 (0.84)	1-5	-.19	-.65	169	3.06 (0.78)	1-5	.23	-.32
A	454	3.93 (0.69)	1-5	-.41	.45	298	4.10 (0.72)	1-5	-.35	.11	169	3.63 (0.61)	1-5	-.09	-.61
N	454	2.94 (0.85)	1-5	.02	-.76	298	3.23 (0.86)	1-5	-.21	-.47	169	3.28 (0.81)	1-5	-.15	-.59
g[1]	265	15.84 (3.90)	0-21	-1.89	5.01	223	15.24 (3.39)	0-21	-1.24	2.79	167	0.00(1.00)	n/a	-.02	-.06

Note. CSE = Creative Self-Efficacy; AUT fl = Alternative Uses Test – Fluency score; AUT orig = Alternative Uses Test – Originality score; O = Openness; C = Conscientiousness; E = Extraversion; A =Agreeableness; N =Neuroticism; g = Intelligence [1]The range of the measures differed between the samples.

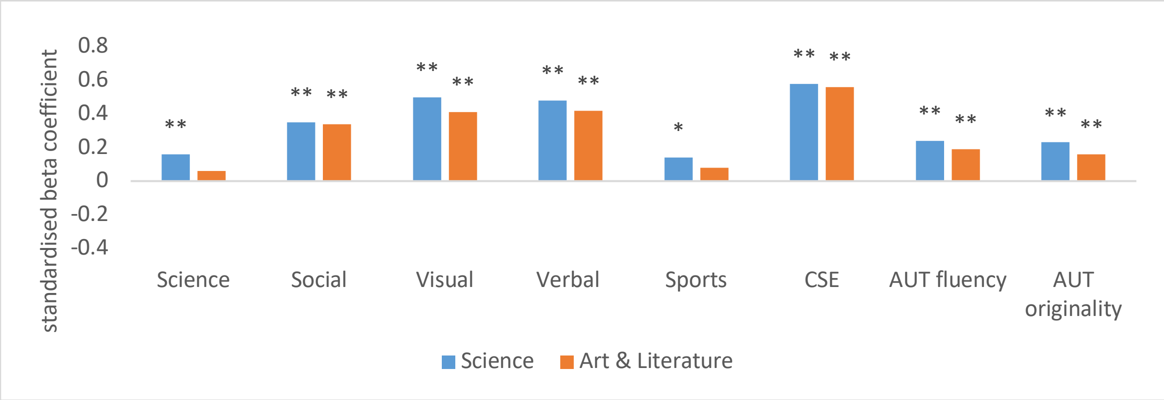
Table 4.2. The intra-correlations for eight creativity measures among three samples.

		Science	Social	Visual	Verbal	Sports	CSE	AUT fl	AUT or	O	C	E	A	N	g
Science	UK	1													
	Science	1													
	Art&Lit	1													
Social	UK	-.06	1												
	Science	.19**	1												
	Art&Lit	.18**	1												
Visual	UK	-.04	.25**	1											
	Science	.15**	.34**	1											
	Art&Lit	.16**	.37**	1											
Verbal	UK	.15	.12	.20**	1										
	Science	.19**	.43**	.50**	1										
	Art&Lit	.02	.30**	.37**	1										
Sports	UK	.14	.04	.19*	.03	1									
	Science	.19**	.38**	.21**	.26**	1									
	Art&Lit	.41**	.38**	.10	-.02	1									
CSE	UK	.11	.31**	.31**	.28**	.18	1								
	Science	.39**	.42**	.42**	.47**	.23**	1								
	Art&Lit	.11	.40**	.44**	.43**	.19**	1								
AUT fl	UK	-.07	.31**	.12	.24**	.04	.30**	1							
	Science	-.03	.08	.21**	.20**	-.10*	.11*	1							
	Art&Lit	.06	.13*	.12*	.32**	-.19**	.13*	1							
AUT orig	UK	-.04	.30**	.13	.29**	.12	.42**	.69**	1						
	Science	.03	.12	.14*	.15*	.03	.11	.45**	1						
	Art&Lit	-.05	-.02	-.03	.27**	-.19*	.06	.48**	1						
O	UK	.19*	.26**	.35**	.40**	.14	.73**	.28**	.38**	1					
	Science	.16**	.35**	.50**	.48**	.14**	.58**	.24**	.23**	1					
	Art&Lit	.06	.34**	.41**	.42**	.08	.56**	.19**	.16	1					
C	UK	.06	.15	.05	.01	.15	.13	.05	.11	.07	1				
	Science	.26**	.30**	.09	.11**	.25**	.22**	-.07	.06	.21**	1				
	Art&Lit	.16**	.25**	.21**	.12*	.25**	.29**	-.03	-.04	.25**	1				
E	UK	.02	.41**	-.10	-.09	.11	.19	.10	.05	.09	.08	1			
	Science	.16**	.57**	.16**	.27**	.30**	.33**	.03	.07	.36**	.27**	1			
	Art&Lit	.08	.52**	.11	.14*	.35**	.35**	.03	-.01	.34**	.20**	1			
A	UK	-.07	.18	-.08	-.08	-.03	-.11	.03	.03	-.10	.20**	.22**	1		
	Science	-.01	.14**	.08	.02	.04	.08	.04	.04	.20**	.23**	.22**	1		
	Art&Lit	-.07	.17**	.08	.18**	.01	.13*	.10	.11	.18**	.29**	.15**	1		
N	UK	-.11	-.32**	.02	.09	-.20*	-.26**	-.11	-.15	-.14	-.08	-.46**	-.18	1	
	Science	-.22**	-.22**	-.06	-.03	-.23**	-.17**	.07	.03	-.07	-.31**	-.40**	-.24**	1	
	Art&Lit	-.13*	-.25**	-.06	-.02	-.18**	-.12*	-.01	-.01	-.01	-.26**	-.43**	-.33**	1	
g	Uk	.29**	-.02	-.01	.15*	.04	.02	.07	.18*	.18*	-.08	-.06	-.04	-.01	1
	Science	-.06	-.05	-.02	.01	-.18**	-.05	.20**	.29**	.06	-.02	-.02	-.02	.05	1
	Art&Lit	.12	-.01	.03	.01	-.07	.02	.27**	.36**	.09	-.05	.01	.12	-.09	1

Note. CSE = Creative Self-Efficacy; AUT fl = Alternative Uses Test – Fluency score; AUT orig = Alternative Uses Test – Originality score; O = Openness; C = Conscientiousness; E = Extraversion; A =Agreeableness; N =Neuroticism; g = Intelligence.** p < .01; * p < .05

Linear regressions were run for five personality traits and for intelligence - predicting eight creativity measures. Based on the low associations between different creativity dimensions, as reported in Chapter 2, creation of a latent creativity measure, that could be used as an outcome in the analyses, was not deemed suitable. Regressions were run for the two high achieving adolescent samples, which were the main interest of this investigation. The standardised beta-coefficients for all regressions are presented in Figures 4.1. – 4.6. Standardised beta coefficients refer to the amount of variance (in standard deviations) in the outcome variable accounted for by a change of one standard deviation in the predictor variable. The values for standardised beta-coefficients reflect the total percentage of variance explained in the outcome due to each predictor. Additional regressions, with a dummy variable and interaction terms, were run to statistically compare the regression coefficients between the two samples of high achieving adolescents in Science and Art & Literature for all measures. The two statistically significant differences emerged between the Science and Art & Literature samples in Agreeableness predicting self-rated verbal creativity and in intelligence predicting scientific creativity. The differences are indicated by an asterisk (*) next to the outcome measures in Figures 4.4. and 4.6. below.

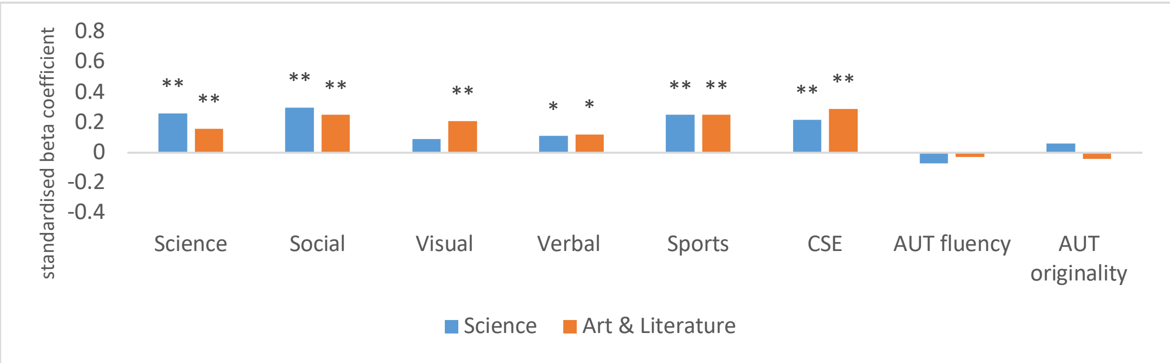
Openness to Experience was the most robust predictor of the 8 creativity measures. For six of the eight creativity measures, the associations were replicated both samples. Among the two samples, the strongest associations were found for Creative Self-Efficacy (β = .58 for Science; and, .56 for Art & Literature), followed by self-reported verbal (β = .48 and .42), visual (β = .50 and .41) and social creativity (β = .35 and .34). The associations between Openness and the Alternative Uses Task's fluency (β = .19 and .24) and originality (β = .23 and .16) scores were replicated in all three samples. Additionally, a significant association was found at least in one of the samples for self-reported scientific and sports creativity with Openness to Experience. The standardised beta coefficients for Openness to Experience explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.1.



Note. ** p < .01; * p < .05
CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.1 Standardised beta coefficients for Openness to Experience explaining variance in 8 creativity measures among the two adolescent samples.

Among the two adolescent samples, Conscientiousness was a predictor of the following five measures: self-reported scientific (β = .26 and .16), social (β = .30 and .25), verbal (β = .11 and .12) and sports creativity (β = .25 for both); as well as creative self-efficacy (β = .22 and .29). Additionally, among Art & Literature students, Conscientiousness explained variance in self-reported creativity in visual domains (β = .21). The standardised beta coefficients for Conscientiousness explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.2.

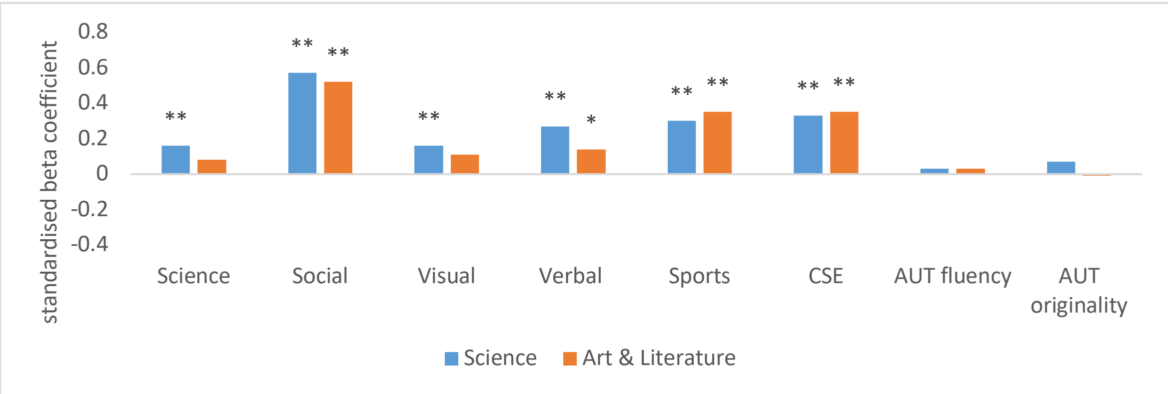


Note. ** p < .01; * p < .05

CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.2. Standardised beta coefficients for Conscientiousness explaining variance in 8 creativity measures among the two adolescent samples.

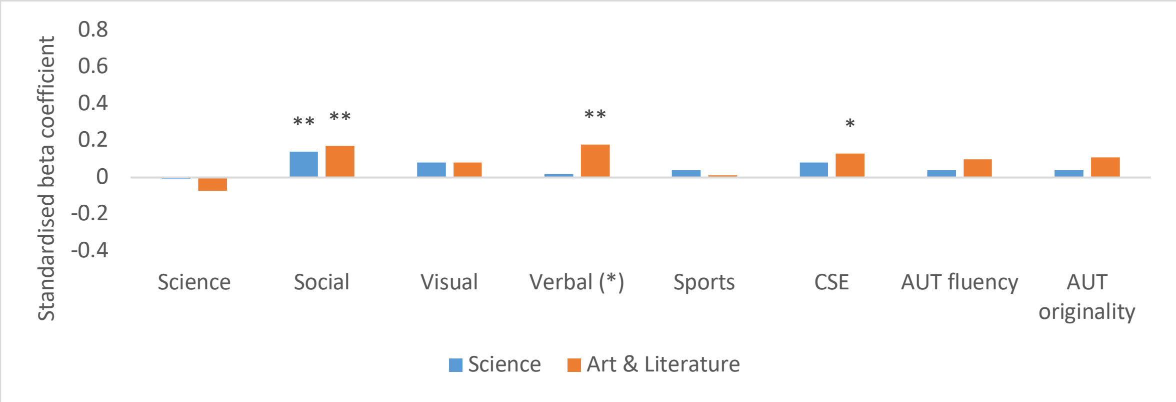
Extraversion was associated with self-reported social creativity (β = .57 and .52) and creative self-efficacy in all three samples (β = .33 and .35). Additionally, it was associated with self-reported verbal (β = .27 and .14) and sports (β = .30 and .35) creativity. Extraversion was also a significant predictor of self-reported scientific (β = .16) and visual (β = .16) creativity, but only among Science students. The standardised beta coefficients for Extraversion explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.3.



Note. ** $p < .01$; * $p < .05$
CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.3. Standardised beta coefficients for Extraversion explaining variance in 8 creativity measures among the two adolescent samples.

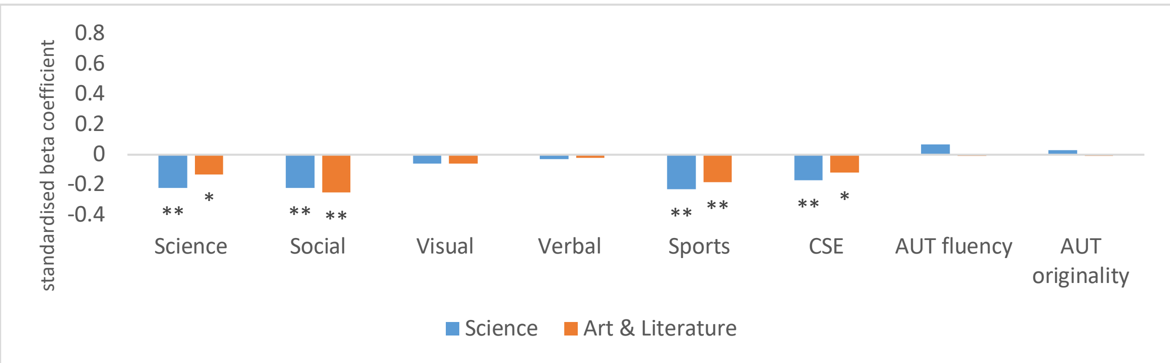
Agreeableness was a significant predictor of self-reported social creativity in both samples (β = .14 and .17). Additionally, among high achieving students in Art & Literature, Agreeableness also explained variance in self-reported verbal creativity (β = .18) and creative self-efficacy (β = .13). The dummy coded regression investigating differences in beta coefficients between Science and Art & Literature samples revealed a significant difference in Agreeableness predicting self-reported verbal creativity (β = .44, t(746) = 2.14, p = .033). For other measures, the beta coefficients between the two samples were non-significant. The standardised beta coefficients for Agreeableness explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.4.



Note. ** p < .01; * p < .05; (*) p < .05 between Science and Art & Literature.
CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.4. Standardised beta coefficients for Agreeableness explaining variance in 8 creativity measures among the two adolescent samples.

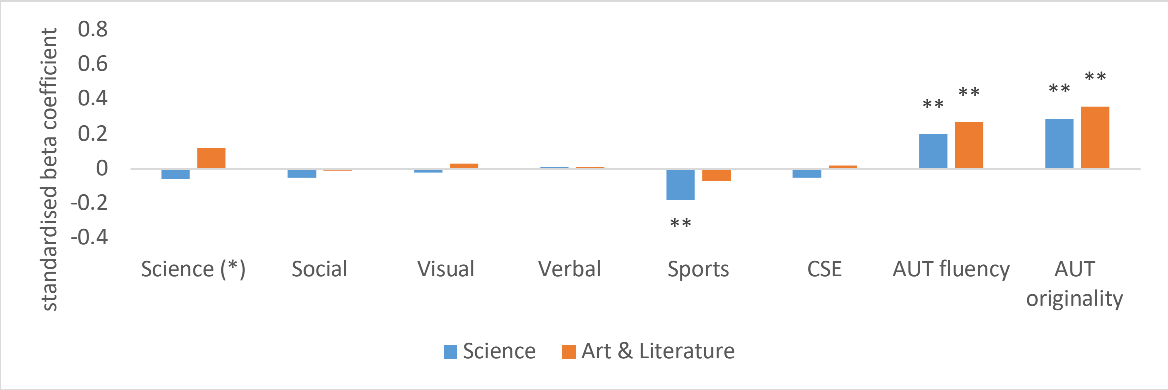
Neuroticism was negatively associated with self-reported social creativity (β = -.22 and -.13); and creative self-efficacy in both samples (β = -.17 and -.12). Additionally, Neuroticism was negatively associated with self-reported scientific (β = -.22 and -.13, respectively) and sports (β = -.23 and -.18) creativity. The standardised beta coefficients for Neuroticism explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.5.



Note. ** p < .01; * p < .05
CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.5. Standardised beta coefficients for Neuroticism explaining variance in 8 creativity measures among the two adolescent samples.

Intelligence explained variance in the originality score of the Alternative Uses Task in both samples (β = .29 and .36). Intelligence was also associated with the fluency score of the Alternative Uses Task (β = .20 and .27, respectively). Additionally, intelligence was negatively associated with self-reported sports creativity among high achieving students in science (β = -.18). The dummy coded regression investigating differences in beta coefficients between Science and Art & Literature samples revealed a significant difference in intelligence predicting self-reported scientific creativity (β = .35, t(746) = 2.11, p = .035). The standardised beta coefficients for intelligence explaining variance in 8 creativity measures among the two adolescent samples are presented in Figure 4.6.



Note. ** p < .01; * p < .05; (*) p < .05 between Science and Art & Literature
SSRC = Short Self-Rated Creativity; CSE = Creative Self-Efficacy; AUT = Alternative Uses Task.

Figure 4.6. Standardised beta coefficients for intelligence explaining variance in 8 creativity measures among the two adolescent samples.

Discussion

The present study explored the links of personality and intelligence to eight measures of creativity. The study used three samples: high achieving adolescents in Science and Art & Literature; and unselected English-speaking adults, mainly students.

Specifically, this study investigated the variance explained by the Big-5 personality traits and intelligence in five self-reported creativity measures (scientific, social, visual, verbal and sports); and in three domain-general measures of creative self-efficacy; and fluency and originality scores of the Alternative Uses Task.

As expected, *Openness to Experience* was the strongest predictor of creativity. Openness to Experience explained variance in six (out of eight) creativity measures, a mix of both self-reported and cognitive creativity tasks. This finding replicated in all three samples. Additionally, Openness to Experience was associated with sports creativity among high achieving science students and among the English-speaking adult sample. In the high achieving Science sample, Openness to Experience was linked to scientific creativity. The effect sizes varied from small to large (β = .14 - .71). The positive association between Openness to Experience and many dimensions of creativity seems intuitive since this personality traits includes attributes, such as intellectual curiosity and aesthetic sensitivity (McCrae & Costa, 1987). These are elements of creative behaviours in many domains. The association between Openness to Experience and creative self-efficacy was particularly strong and raises the question if creative self-efficacy and Openness to Experience fully overlap/tap into the same construct (Karwowski et al., 2013). Some have argued that it would be more precise to name the Openness facet (a facet of Openness to Experience personality trait) to Creativity (Martindale, 1989). Also, the shorter personality inventories, such as the one used in this study, include more items measuring of Openness facet. This may lead to undermeasurement of Intellect facet, which is another facet of Openness to Experience personality trait (Karwowski & Lebuda, 2016). The inclusion of more Openness items may increase the correlation between Openness to Experience and various creativity measures.

No differential associations were found between Openness and any creativity measures between the students in Science and Art & Literature. This finding is dissimilar to the results that reported differential associations of Openness to Experience and general cognitive ability (or Openness and Intellect) to creative achievements in Science and Arts among adult samples (de Manzano & Ullén, 2018; Kaufman et al., 2016). However, the present study has notable differences in relation to the previous studies that may explain the differences in the results. First, the present study used adolescent samples for the comparative analyses whereas the previous studies were based on adult samples. It is likely that as adolescents move into adulthood, they seek environments that are more suitable for their personalities as well as have more opportunities to express their creativity. Second, the present study used so-called little-c creativity measures, which measure creativity in common every-day activities. The creative achievement measure, which was used in the previous studies, constitutes so called Big-C creativity, which refers to socially recognised, eminent creative achievements, which are rare in the general population.

Conscientiousness was inconsistently associated with the eight creativity measures across the samples. Five self-reported domain-specific creativity measures (except visual creativity) were associated with Conscientiousness in both high-achieving student samples. The effect sizes varied from small to moderate (β = .11 - .30). Additionally, visual creativity was associated with Conscientiousness among high achieving students in Art & Literature (β = .21). This could reflect that among high achieving adolescents, self-discipline and commitment to work hard is viewed as a contributor, albeit a weak, on creativity.

Extraversion explained variance in self-reported social creativity and creative self-efficacy in all three samples, effect sizes (β) varying between .16 and .57. Additionally, among both high achieving student samples, it explained variance in self-reported verbal and sports creativity (β = .14 - .35). The positive association with creativity can be explained by description of extraverts as active and passionate, attributes that can be used to describe behaviours when engaging with creative work (McCrae & Costa, 1987). However, it is not clear why it would be only related to creativity in these two domains. Perhaps, in relation to sports, activity as a personality attribute drives creativity in some specific fields, such as in group sport activities.

Agreeableness explained variance in self-reported creativity in the social domain among all three samples. Additionally, among the Art & Literature sample, it was positively associated with verbal creativity and creativity self-efficacy. The effect sizes were small (β = .13 - .23). The association between Agreeableness and social creativity could be explained by the relevance of Agreeableness in social situations. Individuals high in Agreeableness are confirmative and comfortable working in groups. However, Agreeableness was poorly associated with other forms of creativity. This could indicate that the other creativity dimensions, apart from social creativity, capture more individualistic behaviours, for which conformity is not beneficial.

Further analyses to compare the associations of personality and intelligence with creativity between high achieving adolescent samples in Science vs. Art & Literature showed differences in two instances. The first was the relationship between Agreeableness and verbal creativity. Among Art & Literature sample, Agreeableness explained variance in self-reported verbal creativity. However, even if Agreeableness was not a significant predictor of verbal creativity among the Science students, the difference of the beta coefficients of Agreeableness explaining verbal creativity between the two adolescent samples was statistically significant.

Neuroticism was a negative predictor of self-reported social creativity and creative self-efficacy, a finding that replicated in all three samples. Also, among the two high-achieving samples, neuroticism was negatively associated with scientific and sports creativity. The effect sizes varied from small to moderate (β = -.12 to -.27). The negative association differs from some previous research which have reported positive associations between creativity and neuroticism, for example among an adult sample of artists and among professionals in advertising industry (Gelade, 1997; Götz & Götz, 1979). Another study has also shown that two facets of Neuroticism trait, volatility and withdrawal, have differential relationships with creative achievements (Clark & DeYoung, 2014). That study only identified a positive relationship between volatility and creative achievements, especially in the artistic domain. The difference in results, in comparison to the present study, could be due to differences in samples. Among the adolescent samples in this study, neurotic traits are seen maladaptive, not beneficial to creativity. It could also be that neuroticism is positively associated with eminent, Big-C creativity, not with everyday, little-c measures.

Intelligence explained variance in the originality score of the Alternative Uses Task. This finding was replicated in all three samples. Intelligence also explained variance in the fluency score of the same task, for both high achieving student samples. Additionally, intelligence was associated with sports creativity among the Science sample and with scientific creativity among the English-speaking adult sample. The effect sizes varied from small to moderate (β = -.18 - .36). These results are in-line with the previous research findings that have associated divergent thinking, measured with cognitive tasks, with intelligence (Kim, 2005). This finding can partly be explained by the similarity of divergent thinking tasks with some other cognitive tasks, which are part of specific cognitive domains, embedded in the general intelligence. For example, verbal fluency task is to certain extent similar to divergent thinking fluency. According to hierarchical intelligence models, verbal fluency is a lower tier cognitive ability, influenced by a latent *g* factor of general intelligence (Carroll, 1993).

The small effect sizes between intelligence and creativity, as reported in this study (as well as in previous research) could reflect issues with measurement, not the actual effect between constructs (Kim, 2005; Nusbaum & Silvia, 2011; Silvia, 2008). One study reported that if both intelligence and creativity are measured as latent constructs, based on the shared variance between several measures, the effect of intelligence predicting creativity was medium to large (Silvia, 2008).

The second difference between Science and Art & Literature students emerged in the relationship between intelligence and scientific creativity. Intelligence was not a significant predictor of scientific creativity among either sample, however the difference in beta coefficients between the groups was statistically significant. For the Art & Literature students, intelligence had a small positive association (β = .12) with self-reported scientific creativity. For the Science students, the relationship was negative (β = -.06). However, the effect size is small, as indicated by the small difference between the beta coefficients.

Some studies have indicated that associations of creativity with personality and intelligence may be partly driven by the format of creativity measures. A study which investigated the interrelationships of self-reported and cognitive creativity measures, in relation to personality and intelligence, argued that the underlying multidimensional structure of creativity, is partly due to the data collection methods (Kandler et al., 2016). In their study, Openness to Experience was more strongly associated with self-reported creativity measures and intelligence - with cognitive creativity tests (Kandler et al., 2016). In the present study, intelligence was also mainly associated with cognitive creativity measures. However, Openness to Experience, a self-reported measure, had associations of similar strength with the same cognitive task. This indicates that the associations are not only due to the similarities in the data collection method.

Limitations

The present study had some limitations. The personality measures were broad indications to five main traits. A more detailed personality inventory could have been able to reveal more finetuned associations, and perhaps differences, between the samples. Also, the analyses included in the study were based on linear relationships and not able to reveal any variation at the strength of the associations at different levels of creativity.

A common problem with self-reported creativity measures is the difficulty of separating them from abilities. The evaluations of creativity in specific areas are often associated with the level of skills in that particular area. For example, when evaluating visual skills, participants might think in narrow terms (e.g., painting, sculpture or photography) and not how visually creative they are in broader aspects. Additionally, in relation to the different creativity domains, visual and verbal creativity may be easier to conceptualise than scientific, social and sports creativity. Visual and verbal activities are also very accessible for everyone and can be associated with many everyday activities.

Furthermore, the differences between the adolescent samples and the English-speaking samples, in both measurement and sociodemographic composition, means that comparisons between them should be avoided.

Future directions

More detailed measures, beyond broad personality measures used in the present study, might reveal more differences between Science and Art & Literature adolescents. For example, previous studies have shown positive associations between dark triad personality traits (e.g. narcissism, psychopathy and Machiavellianism) with various creativity measures (Furnham, 2015; Kapoor, 2015). These relationships could be explored further among high achieving adolescent samples to get insights into the developmental emergence of the associations between dark triad personality traits and creativity. Future investigations could also look at specific cognitive abilities, such as verbal and spatial reasoning, and investigate how these relate to various creativity measures in high-achieving samples.

The findings from the present study can be applied to the use of personality and intelligence as indicators of creativity. The findings suggest that, if no other data were available, Openness to Experience would be the most robust alternative indicator of creativity. This is based on the finding that Openness to Experience was most frequently associated with a variety of creativity measures among the three samples. Additionally, the associations did not only emerge with self-reported measures but also with cognitive creativity measures. However, it is important to emphasise that the associations are not indicators of the mean differences between the groups, which was not an aim of this study. Similar associations between Openness to Experience and scientific creativity in both adolescent samples does not tell anything about what values the students in each group assign themselves (see Table 2 earlier in this chapter for group mean averages). The associations are informative how closely the two constructs are related.

Additionally, it is important for future studies which investigate the relationship of creativity with personality and intelligence to use a collection of creativity measures, which tap into the different facets of creativity. This is especially important if the studies aim to make general claims about creativity. For example, based on the results, presented in chapter, the conclusion of the role of intelligence in creativity, would be very different if creativity would be operationalised with divergent thinking task or as creative self-efficacy. Additionally, generalisations based on only one task or measure may imply that creativity is only a single, transferrable ability or attribute (Baer, 2011). This is not a good representation of creativity, which as a multidimensional construct, can be measured with many, often uncorrelated measures.

Conclusions

Accumulating knowledge on the relationship of personality traits and intelligence to various creativity measures will help improve our understanding of the structure of creativity. Advancing the understanding of the origins of individual differences in various aspects of creativity will enable us to apply that knowledge, particularly in educational contexts. For example, recognising how differences in personality contribute to differences in creative endeavours in different domains may aid the creation of teaching practises that are more suitable for these personality traits.

As the results of this chapter showed, several creativity measures are associated with Openness to Experience, a finding that has been replicated in diverse samples, now also among adolescents with high achievements in Science and Art. However, one area of creativity research, which to date has only accumulated a limited amount of research, is the aetiology of creativity. The following Chapter 5 provides a review of nine twin studies that have investigated the proportions of genetic and environmental influences on creativity.

5 Aetiology of individual differences in creativity: A systematic review of research into genetic and environmental sources of creativity

Chapter summary

Twin studies provide information on the influences that account for differences between individuals in creativity. The twin method is used to estimate proportions of variance due to genetic, shared environmental and nonshared environmental influences. Genetic influences refer to the extent of variation in creativity, which in twin studies can be based on differences in genetic similarity between monozygotic and dizygotic twin pairs. Environmental influences can be shared, which makes twins more similar to each other, or nonshared, which refers to the environmental influences that have an effect on only one of the twins. This systematic review summarises 9 twin studies, which are divided into three categories: 1) 3 early twin studies that reported only intraclass correlations for MZ and DZ twin pairs; 2) 6 studies that used univariate models to estimate the proportions of variance explained by genetic, shared and nonshared environmental influences in creativity; and 3) 2 studies (also included in the second category) that have used multivariate twin design to estimate shared aetiology of creativity with personality and intelligence. These studies report a wide range of estimates for both genetic and environmental influences, which is partly due to the diversity of the creativity measures and samples, used across the studies. Overall, in most measures, the proportion of genetic influences on creativity varied from moderate to substantial (.30 to .77), but two measures showed no genetic influences. The remaining variance was mostly explained by nonshared environmental influences (which also includes measurement error). The role of shared environment was negligible for most measures. Additionally, the multivariate studies showed that the associations of creativity with personality and intelligence were largely explained by shared genetic factors.

Introduction

One of the persisting myths about creativity is that people are either born creative or not (Plucker et al., 2004). For example, among teachers, it is a common view that creativity is a fixed, biologically determined ability (Fryer & Collings, 1991). According to this genetically deterministic view, creativity is a qualitative, binary attribute. However, genetically informative studies on creativity have shown that differences between individuals are due to both genetic and environmental factors (e.g. de Manzano & Ullén, 2018; Kandler et al., 2016; Roeling et al., 2017). Most of these studies, which use quantitative genetic methods, rely on family studies, comparing relatives who share different amounts of genetic material (e.g. adoptive and biological relatives; twins).

Quantitative genetic methods are used to decompose the proportion of phenotypic variance in a trait (e.g. creativity) in a specific population at a particular time into components of variance attributable to genetic, shared environmental and nonshared environmental factors (Visscher et al., 2008). Phenotype refers to any measurable outcome, such as different measures of creativity. In comparison to phenotype, genotype refers to all genetic information in relation to an individual. The information of the aetiology of phenotypes is relevant for several reasons. It informs on the relative contribution of genetic and environmental factors to individual differences; as well as on how the aetiology of differences vary across samples or across the life span. Additionally, genetically informed analyses provide information on the aetiological architecture of its links with other constructs.

Classic twin design as a method to estimate genetic and environmental influences

To date, the most commonly used method of quantitative genetics has been the classic twin design (Boomsma et al., 2002). Monozygotic twins (MZ), or identical twins, share all of their segregating genetic material. Dizygotic twins (DZ), or non-identical twins, share, on average, half of their segregating material. Segregating DNA are the small proportion (~0.05%) of our genetic material that influences differences among humans in different traits (phenotypes).

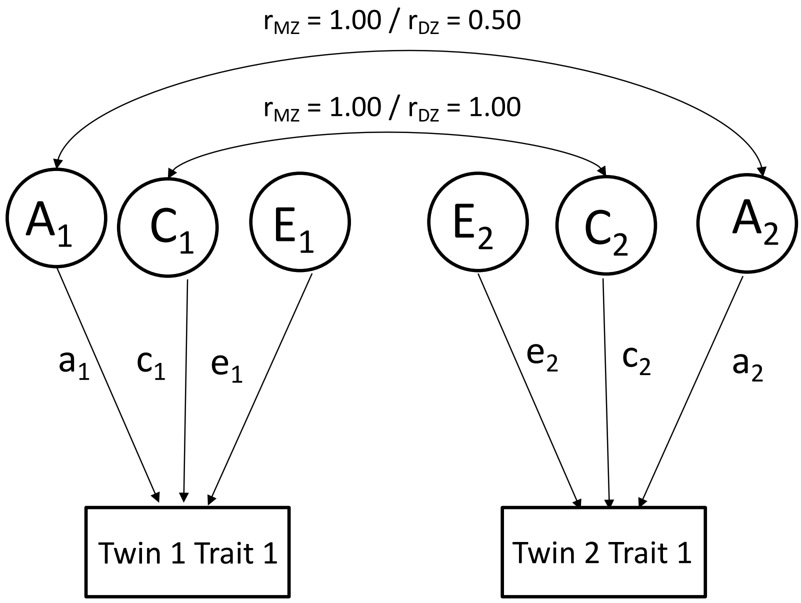
The twin method includes three assumptions: the equal environments assumption (EEA); the assumption of non-assortative mating; and the assumption that there are no non-additive genetic effects taking place (Derks et al., 2006). The EEA refers to MZ and DZ twin pairs being equally similar in the type of environments they experience, even though they differ in how genetically similar they are. The rationale for the EEA is that twins in both MZ or DZ twin pairs are the same age and both have very similar environmental experiences due to growing up in the same family. The second assumption is that no assortative mating takes place. Assortative mating refers to non-random mating patterns due to certain characteristics, such as social class and intelligence (Vandenberg, 1972). The assumption of non-assortative mating is based on the presumption that that genetic effects would be randomly assigned across the population. However, if assortative mating would happen, it would lead to underestimation of the proportion of genetic influence (heritability) in the total variance in the phenotype of interest. The third assumption of no non-additive genetic effects is based on the notion that the classic twin model will not be able to detect an effect on non-additive genetic effects, such as interactive effects of several genes.

Comparing correlations between MZ and DZ twin pairs, enables the quantification of genetic and shared environmental effects on a particular trait (Boomsma et al., 2002). Genetic effects refer to the genetic similarity between the twins whereas shared environmental factors are environmental influences that increase similarity between the twins. In comparison, nonshared environmental factors are those that do not contribute to similarities. When MZ twin pairs are found to correlate more highly on a trait than DZ twin pairs, the assumptions of the twin method mean that this higher correlation reflects the increased genetic similarity of MZ twin pairs (100%) when compared to DZ twin pairs (50% on average). Therefore, heritability, the amount of variance in a trait that can be attributed to genetic variance, denoted as h^2 or A (for Additive genetic effects), can be calculated using Falconer's formula (Falconer, 1960). This formula, given below, calculates heritability as double the difference between the MZ and DZ twin correlations:

$$h^2 = 2 * (r(\text{MZ}) - r(\text{DZ}))$$

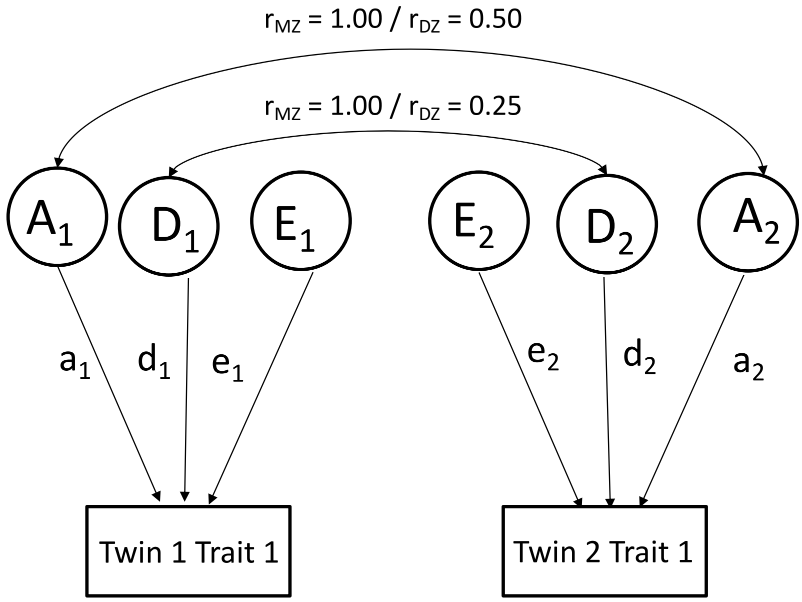
The formula for the shared environmental effects (c^2) is: $c^2 = r(\text{MZ}) - h^2$. Finally, the variance that is unexplained by h^2 and c^2 is considered to be explained by non-shared environmental effects (e^2). However, e^2 estimate also includes variance due to measurement error (Rijsdijk & Sham, 2002)

The classic twin design, comparing MZ and DZ twins does not allow for the estimation of all four sources of influence (A, D, C and E) within one model as they are confounded (Rijsdijk & Sham, 2002). Therefore, with the classic twin design it is possible to partition the variance into three sources of influences: A, E, and either C or D. D refers to Dominant genetic effects, which includes non-additive genetic effects, such as interactions, between alleles. The decision to include C or D into the model depends on the comparison of the intraclass correlations between MZ and DZ twin pairs for the same trait. If the intraclass correlation for MZ twins would a double or less that of DZ twins, shared environment is likely to have influence on the trait. Consequently, C would be included in the model, giving an ACE model (see Figure 5.1.). If the intraclass correlation for MZ twins would be more than a double of DZ twins, then an ADE model would be chosen (see Figure 5.2.).



Note. A= additive genetic, C = shared environmental, E = nonshared environmental variance components. r_{MZ} = intraclass correlation for monozygotic twins; r_{DZ} = intraclass correlation for dizygotic twins.

Figure 5.1. The univariate ACE model.



Note. A= additive genetic, D = non-additive genetic, E = nonshared environmental variance components. r_{MZ} = intraclass correlation for monozygotic twins; r_{DZ} = intraclass correlation for dizygotic twins. This model is chosen if the correlation between MZ twins is more than double that observed between DZ twins.

Figure 5.2. The univariate ADE model.

For A, the correlation between MZ twins is 1, as they share 100 % of their genes, while for DZ twins is .50, as they share 50% of their segregating genes on average. For D, the correlation between MZ is also 1, while the correlation between DZ is .25. For both MZ and DZ twin pairs, similarity is the same for both for C (r = 1) and E (no correlation). E can be estimated by the dissimilarity between MZ twins since the intraclass correlation is the product of genetic and shared environmental influences.

Distinguishing the shared and nonshared environments is not straightforward. Often shared behaviours and common environmental influences within a family unit are viewed as being factors that contribute to the similarity between family members.

However, this is often not the case. For example, research shows that adult family members do not resemble each other in weight beyond genetically influenced similarity (Grilo & Pogue-Geile, 1991). Another example is parental divorce. Despite being a family event and as such shared by siblings, research has shown that divorce often impacts siblings' behaviour in different ways (Amato, 2010). Furthermore, parenting as a whole has been shown to lead to differences rather than similarities, through differential perceptions of parenting by the children and other poorly understood mechanisms (Plomin & Daniels, 1987). Therefore, environmental factors that might intuitively seem 'shared' often are not.

Studies using the classic twin design have faced some criticism. For example, the EEA has been questioned as MZ twins are argued to be treated differently in comparison to DZ twins (e.g. Horwitz et al., 2003; Burt & Simons, 2014). However, studies have provided evidence that although MZ twins tend to be treated somewhat more similarly than DZ twins, it does not increase similarity between them. For example, one study investigated the attitudes of the parents whose beliefs of their twins' zygosity did not match the actual zygosity (Kendler et al., 1994). The study reported no differences in clinical outcomes when comparing correctly identified MZ and DZ twin pairs with twin pairs whose parents had incorrect perception of the zygosity of their twins. Therefore, the estimates of genetic and environmental factors were not biased due to any potential differences in parenting MZ or DZ twins – supporting the validity of the equal environment assumption (Kendler et al., 1994; Moffitt & Beckley, 2015).

Overall, despite limitations, twin studies produce reasonably accurate estimates of genetic and environmental influences. Research, using these method, has played an important role in establishing the role of genetic factors in almost all measurable traits, including those that were thought to be influenced mainly by environments, such as many educational outcomes (Polderman et al., 2015).

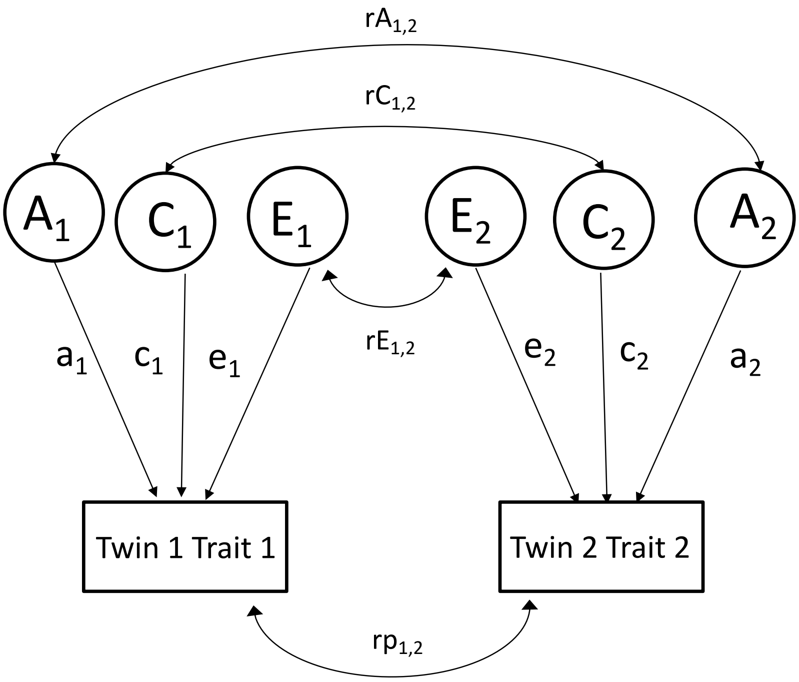
Univariate model fitting analyses using the twin design

Based on the logic of the classic twin model, structural equation modelling (SEM) has become the standard statistical method in twin studies (Neale & Cardon, 1992; Rijsdijk & Sham, 2002). SEMs offer a more sophisticated way to estimate variance (based on variances and covariances) in comparison to intraclass correlations which have low power and large standard errors, making it more imprecise method to estimate proportions of variance. Furthermore, SEMs provide goodness-of-fit statistics to test and compare alternative models; and they allow for the estimation of confidence intervals for all parameters (Rijsdijk & Sham, 2002). Based on the comparisons, the most parsimonious model will be selected (ACE, AE, CE or E).

Multivariate analyses using the twin design

Multivariate analyses allow investigations of the shared aetiology between different measures. For example, to what extent the phenotypic (observed) associations (e.g. the correlation between creativity and intelligence) are influenced by the same genetic and environmental influences. There are different parameterizations for multivariate models that can be used to complement the classic twin design to address these questions. The models include the Cholesky Decomposition; the Independent Pathway Model; the Common Pathway Model; and the Correlated Factor Solution (Loehlin, 1996). The selection of the model depends on the research question (e.g. origins of associations or the extent of shared common aetiology) and the available data (e.g. cross-sectional vs. longitudinal). The Correlated Factor Solution, which was used in the study presented in Chapter 6 in this thesis is described in detail below (for further information on other models, see Plomin et al., 2008).

The correlated factors model, is a statistical method to explore the aetiology of associations between several traits (Plomin & DeFries, 1979). The correlated factors model enables the decomposition of the covariance between two or more traits into genetic, shared and nonshared environmental sources of variance. The decomposition is based on cross-twin cross-trait similarity comparison for MZ vs. DZ twin pairs. A higher cross-trait similarity among the MZ twins in an indication of genetic factors influencing the phenotypic relationship between the two traits. See Figure 5.3. for a correlated factors model.



Note. A = additive genetics; C = shared environment; E = non-shared environment; rA = genetic correlation; rC =shared environmental correlation; rE = nonshared environmental correlation; rp = phenotypic correlation; a c, e = standardized and squared path estimates for additive genetic, shared and nonshared environmental variance components.

Figure 5.3. The correlated factors model.

The correlated factors model also estimates the percentage of the phenotypic correlation that can be attributed to genetic, shared and nonshared environmental influences. The percentage for the shared genetic influences is known as a bivariate heritability estimate.

Selection of the studies for the Review

This chapter presents a systematic review of quantitative genetic studies that have utilised univariate and multivariate analyses, based on the classic twin design, to estimate the genetic and environmental influences on various creativity phenotypes.

Systematic searches were performed using the online databases PubMed and Web of Science. The literature search was conducted on the 7th of February 2020. The following search terms were used: "Creat* AND herit* AND twin". No constraints were set for the publication year. The search was conducted in English.

The search in Web of Science showed 27 results that fitted the search criteria. The same search terms in PubMed provided 106 results. The manual inspection of the abstracts narrowed the pool down to 7 studies which had investigated creativity utilising a twin design. Most studies included several creativity measures. Manual inspection of the reference lists of the selected 7 studies, revealed an additional 2 twin studies that were not captured by the search terms in Web of Science and PubMed. These 2 early studies were also included in the review.

Results

The research reported in the nine studies, included in this review, was split into three categories. The first category included earlier studies (year 1973 to 1992; n = 3) which reported only intraclass correlations (without univariate or multivariate model fitting). The second category included research from studies (n = 6) that reported genetic and environmental influences on different creativity phenotypes, based on univariate model fitting. The third category included research in two of the studies from the second category that used multivariate modelling in addition to the univariate modelling.

Early studies comparing intraclass correlations

The three studies reported intraclass correlations for MZ and DZ twins (Grigorenko et al., 1992; Nichols, 1976; Reznikoff et al., 1973). The studies in this category had small sample sizes (n < 246) in comparison to more recent twin studies on creativity. Further details of the studies are provided in Table 5.1. Out of thirteen measures included in the studies, 10 reported genetic influences taking place, the highest estimate reported at $h^2 = .74$.

Table 5.1. Early twin studies comparing intraclass correlations (n = 3).

Study & Sample	Creativity measure	Age m (sd)	**rMZ**	**rDZ**	***h²***
Reznikoff et al (1973)		13-19			
	Remote Associates Test (RAT)		.78	.43	.70
US	The Franck Drawing Completion Test (FDCT)		.48	.59	.00
n = 234	The Associational Fluency Test (AFT)		.66	.56	.20
	Expressional Fluency Test (EFT)		.71	.63	.16
	Revised Art Scale (RAS)		.18	.42	.00
	Alternative Uses Test (AUT)		.72	.37	.70
	Possible Jobs Test (PJ)		.56	.24	.44
	The Plot Titles Test (PT)		.49	.31	.36
	The Obscure Figures Test (OFT)		.27	.48	.00
	The Similes Test (ST)		.59	.22	.74
	The Quick Word Test (QW)		.83	.57	.52
Nichols (1978) Not specified	Divergent thinking; a mean for 10 studies conducted before 1971	Not specified	.61	.50	.22
Grigorenko et al (1992) Russia n = 246	Torrance Tests of Creative Thinking – verbal measures	16.2 (0.82)	.86	.64	.44

Note. Confidence intervals for the intraclass correlations were not reported in the publications. Heritability (h^2) was calculated using the formula: $h^2 = 2 * (r(MZ) – r(DZ))$.

Univariate twin models to establish the genetic and environmental influences in creativity

Six twin studies have utilised SEM as the statistical method to separate the variance due to genetic, shared environmental and nonshared environmental effects of diverse creativity phenotypes. Creativity was measured with cognitive tasks, self-reported and peer-report assessments, as well as with behavioural inventories. The studies were based on Dutch, Italian, American, German and Swedish twin samples (mean ages of the samples 17.70 – 45.40 years). The study details are presented in Table 5.2. Out of 21 measures, 19 indicated genetic effects, ranging from .23 to .70. Two measures showed no genetic effects, the best fitting model being CE. The role of shared environment is negligible for most measures; the AE model provided the best fit for the data for 14 out of 19 measures.

Table 5.2. Univariate twin models estimating the genetic and environmental influences in creativity (n = 6).

Study and sample	**Creativity measure**	**Age m (sd)**	**rMz (CI)**	**rDz (CI)**	**Model[1]**	**A (CI)**	**C (CI)**	**E (CI)**
Vinkhuyzen (2009)								
Netherlands; NTR n = 3370	Creative writing	17.7 (2.3)	.83 (.28 - .98)	.38 (-.25 - .79)	AE	.43 (.35 - .50)	/	.57 (.50 - .65)
Piffer & Hur (2014)				.				
Italy n = 338	Total Creative Achievement (TCA)	26.3 (6.6)	.64 (.50, .76)	32 (.12, .49)	AE	.61 (.48, .72)	/	.39 (.28, .52)
Italy n = 338	Scientific Creative Achievement (SCA)	26.3 (6.6)	.49 (.31, .64)	.19 (-.02, .38)	AE	.43 (.27, .57)	/	.57 (.43, .73)
Italy n = 338	Artistic Creative Achievement (ACT)	26.3 (6.6)	.70 (.56 - .79)	.33 (.14, .50)	AE	.67 (.55, .77)	/	.33 (.23, .45)
Velazguez et al. (2015)								
USA: MISTRA n=244	Creative personality	42.31 MZ (12.82) 45.40 DZ (13.12)	.52 (.30, .69)	.12 (-.17, .40)	AE	.50 (.32, .64)	/	.50 (.36, .68)
USA: MISTRA n = 244	Draw-a-Person (DAP; scored by an artist)	42. 31 MZ (12.82) 45.40 DZ (13.12)	.38 (.16, .57)	.15 (-.12, .40)	AE	.38 (.20, .52)	/	.62 (.47, .80)

USA: MISTRA n = 244	Draw-a-Person (DAP; (scored by an non-artist)	42. 31 MZ (12.82) 45.40 DZ (13.12)	.45 (.24, .62)	.23 (-.04, .47)	AE	.47 (.31, .60)	/	.53 (.40, .69)
USA: MISTRA n = 244	Draw-a-House (DAH; scored by an artist)	42. 31 MZ (12.82) 45.40 DZ (13.12)	.29 (.05, .51)	.26 (-.02, -.51)	AE	.26 (.08, .43)	/	.74 (.57, .92)
USA: MISTRA n = 244	Draw-a-House (DAH; scored by an non-artist)	42. 31 MZ (12.82) 45.40 DZ (13.12)	.10 (-.15, .34)	.26 (-.02, .51)	AE	.23 (.04, .40)	/	.77 (.60, .96)
Kandler (2015)								
Germany; BiLSAT, 2nd wave n = 806	Self-reported creativity	n/a	.33	.15	AE	.33	.00	.67
Germany; BiLSAT, 2nd wave n = 806	Peer-reported creativity	n/a	.29	.17	AE	.27	.03	.70
Germany; BiLSAT, 2nd wave n = 806	A composite of self and peer-reported creativity	n/a	.62	.31	AE	.62	.00	.38
Germany; GOSAT n = 300	Video-based creativity rating	34.3 (12.6)	.57	.38	ACE	.36	.20	.44
Germany; BiLSAT, 3rd wave n = 307	Elaboration	39.1 (12.6)	.48	.46	CE	.05	.42	.53
Germany; BiLSAT, 3rd wave n = 327	Originality	39.1 (12.6)	.32	.27	CE	.08	.28	.64
Germany; BiLSAT, 3rd wave n = 327	A composite of elaboration and originality	39.1 (12.6)	.50	.37	ACE	.25	.24	.50
Roeling et al. (2016)								
Netherlands n = 8802	Working in creative profession	38.42 (11.98)	/	/	AE	.70	/	.30
De Manzano & Ullen (2018)								

Sweden n = 9357	Creative achievement in arts	41.0 (7.8)	.66 (.60, .72)	.46 (.32, .57)	ACE	.37	.32	.32
Sweden n = 9357	Creative achievement in science	41.0 (7.8)	.66 (.57, .73)	.31 (.09, .49)	AE	.68	.00	.32

[1]The best fitting model in the analyses

Multivariate twin models to establish the genetic and environmental influences on the relationship between creativity and other measures

Only two twin studies have investigated the shared aetiology of creativity with personality and intelligence (de Manzano & Ullén, 2018; Kandler et al., 2016). One study, based on a German twin sample, investigated the shared aetiology of seven creativity measures with personality traits of Openness to Experience and Extraversion, as well as with intelligence. Intelligence was measured as a primary factor score of three cognitive measures: Leistungsprüfsystem (a measure of seven subtests), Advanced Progressive Matrices and a battery of brainteasers (Kandler et al., 2016). The study used genetically informative multivariate regression analyses to estimate genetic and environmental influences in 7 measures; the ACE estimations were based on the residual variances for shared variance between creativity with intelligence and personality. For two test-based measures, the models also indicated the role of shared environments as mediator of the associations. The role of nonshared environmental influences was the strongest explaining the shared aetiology in all 7 creativity measures with Openness, Extraversion and intelligence (.31 - .64). Genetic effect also mediated the associations between the measures in three self and peer-reported measures (.24 - .47) as well as in the video-based creativity rating (.15). For two test-based measures, elaboration and composite scores in a divergent thinking task, the models also indicated the role of shared environments as a mediator of the associations (.25 - .37). Shared environmental influences also influences the phenotypic associations between video-based creativity rating, Openness, Extraversion and intelligence (.16).

The second study, based on a Swedish twin sample, utilised multivariate genetic analyses to estimate the shared aetiology of creative achievements in the Arts and Sciences with the personality trait of Openness to Experience as well as with intelligence. Intelligence was measured with Wiener Matrizen Test (de Manzano & Ullén, 2018). The results showed that the AE model provided the best model fit for the data. The results from the two multivariate studies are reported in Table 5.3. below. The results showed that phenotypical associations were mediated with genetic and nonshared environmental influences.

One of the multivariate studies (de Manzano & Ullén, 2018) did report the estimates of genetic influences on phenotypic correlations. Further analyses, conducted specifically for this review using the reported path estimates in a trivariate Cholesky model, showed that genetic effects explained from 81% to 89% of the phenotypic associations (r_{ph} = .24 - .49) between creative achievements, personality and intelligence.

Table 5.3. Multivariate twin models to establish the genetic and environmental influences on the relationship between creativity and other measures (n = 2).

Study and sample	**Creativity measure**	**The measure associated with creativity**	**r_{ph}**	**Model; statistical model for multivariate analysis**	**Bivariate A**	**Bivariate C**	**Bivariate E**
Kandler et al. (2015)							
Germany; BiLSAT, 2nd wave N = 806	Self-reported creativity	Extraversion and Openness to Experience (both entered in the regression)	/	multivariate genetically informative regression analysis; ACE for residual variance, not accounted for the predictors in the multiple regressions R^2 = .10**	.26**	.00	.64**
Germany; BiLSAT, 2nd wave N = 806	Peer-reported creativity	Extraversion and Openness to Experience (both entered in the regression)	/	As above R^2 = .10**	.24**	.00	.66**
Germany; BiLSAT, 2nd wave N = 806	A combination of self and peer-reported creativity	Extraversion and Openness to Experience (both entered in the regression)	/	As above R^2 = .22**	.47**	.00	.31**

Germany; GOSAT N = 300	Video-based creativity rating	Extraversion, Openness to Experience and intelligence (both entered in the regression)	/	As above $R^2 = .29^{**}$	.15*	.16*	.40**
Germany; BiLSAT, 3rd wave N = 327	Elaboration	Openness to Experience and intelligence (both entered in the regression)	/	As above $R^2 = .10^{**}$	.02	.37**	.51**
Germany; BiLSAT, 3rd wave N = 327	Originality	Openness to Experience and intelligence (both entered in the regression)	/	As above $R^2 = .15^{**}$	.13	.17	.55**
Germany; BiLSAT, 3rd wave N = 327	A composite of elaboration and originality	Openness to Experience and intelligence (both entered in the regression)	/	As above $R^2 = .12^{**}$	.15	.25*	.48**
De Manzano & Ullen (2018)							
Sweden N = 9357	Creative Achievement in the Arts	Openness to Experience	.49	AE; 3-variate AE Cholesky decomposition	.81	/	.19
Sweden N= 9357	As above	Intelligence	.24	As above	.89	/	.11
Sweden N = 9357	Creative Achievement in science	Openness to Experience	.43	As above	.85	/	.15
Sweden N =9357	As above	Intelligence	.42	As above	.88	/	.12

Note. r_{ph}=phenotypic correlation; Bivariate A, C and E refer to the proportion of the phenotypic covariance that is due to genetic, shared or nonshared environmental factors; R^2 = the variance explained by the predictor variables in the regression model.
**p < .05, *p < .01

Discussion

Twin studies have shown that that variance in creativity is explained by both genetic and environmental influences. For most creativity measures, the proportion of genetic influences varied from moderate to substantial. The role of shared environmental influences was small for most creativity measures. In some studies, the best fitting model enabled the removal of C, indicating negligible effect of shared environmental influences. Additionally, nonshared environmental explained variance most creativity phenotypes. The multivariate studies showed that the aetiology of phenotypic associations for creativity, measured with self-reports and cognitive tests, with Openness to Experience, Extraversion and intelligence were mainly mediated by nonshared environmental influences. The phenotypic associations for creative achievements with the same three measures were largely maintained by genetic influences.

The first twin studies on creativity, gave indications of both genetic and environmental influences on creativity. The studies used cognitive and self-reported creativity measures and reported only intraclass correlations for the MZ and DZ twins. The first study reported higher intraclass correlations among MZ twin pairs when compared to DZ twins in 8 out of 11 measures – indicating the role of genetic factors (Reznikoff et al., 1973). However, for 3 measures the correlations were higher for DZ twin pairs. This finding could be due a violation of the Equal Environments Assumption, for example if parents of MZ treat their twins differently, in comparison to DZ twin (e.g. enrolling them to different schools), which could lead DZ intraclass correlations being higher to MZ correlations in some measures. However, the larger DZ correlation could also be due to large error margins in these measures. The second study (Nichols, 1976) measured (and reported) creativity as a mean score of 10 divergent thinking tasks. The results showed higher correlations among MZ twin (r = .61) in comparison to DZ twins (r = .50). The study utilised data from a large student sample, in which the twins were identified based on self-reports of their zygosity. Similarly, another study on verbal divergent thinking tasks among Russian adolescents showed higher intraclass correlation among MZ twins (r = .86) in comparison to DZ twins (r = .64; Grigorenko et al., 1992).

The later studies utilised advanced statistical techniques to separate variance in creativity phenotypes due to genetic (A), shared environmental (C) and nonshared environmental (E) influences. The estimates of A, based 19 creativity measures across the 6 studies, varied between .23 (creativity score of a drawing, evaluated by non-artists) to .70 (working in a creative profession). However, in a study based on a German adult sample, two of the seven creativity measures – elaboration and originality scores for a figural creativity task – indicated negligible genetic influences (Kandler et al., 2016). The small sample size (n = 327) in this study may have influenced the significance testing between the ACE and CE model fits.

The role of shared environment is negligible among most creativity phenotypes. The AE model provided the best fit for the data for 14 out of 19 measures across the 6 studies. This indicated that excluding C from the model would provide a better model fit with the data. Shared environmental influences explained variance in four creativity measures among the German sample: in video-based creativity ratings (.20), video-based elaboration scores (.42), originality scores (.28) and a composite scores of elaboration and originality in a figural divergent thinking task (.24; Kandler et al., 2016). Additionally, shared environmental influences explained variance among a Swedish twin sample in creative achievements in arts (.32). The range of shared environmental effects, from negligible to small, on creativity is consistent with findings for many phenotypes, including adulthood intelligence and most personality traits (Haworth et al., 2010; Tellegen et al., 1988). However, this is not the case for certain psychopathologies, where shared environmental influences tend to be larger than for other psychological phenotypes, especially among developmental samples. According to a meta-analysis, during childhood and adolescence, shared environmental influences contribute up to a third of the variance to many psychopathologies, such as depression and conduct problems (Burt, 2009).

Non-shared environmental influences were stronger in comparison to shared environmental influences. This finding is in line with findings on most other human traits beyond childhood (Plomin et al., 2016; Polderman et al., 2015). In the reviewed studies, the estimates for nonshared environmental influences for 19 creativity measures, varied from .30 to .77. Some of the non-shared environmental effects may indicate measurement error, which may be smaller or larger for different measures. This, together with specificity of the measured constructs, may partly explain the differences in the ACE estimations that emerged for creativity cognitive measures vs. self and peer-report vs. behavioural inventories.

For cognitive measures of creativity, which were measured as elaboration and originality scores based on a figural divergent thinking task, the genetic influences were the weakest among all the creativity measures (.05 to .25). These measures also included a larger proportion of variance due to shared environmental influences in comparison to other creativity measures (.24 to .42; Kandler et al., 2016). These findings were different to results from twin research on cognitive abilities which have indicated moderate to large effects of genetic influences in a range of cognitive abilities, including overall intelligence (Haworth et al., 2010). The difference could be due to the subjective coding procedure, which is part of many creative cognition tasks. This will introduce additional error variance to the creativity scores. In comparison, intelligence is commonly estimated with several standardised measures. Also, the sample size for the twin study which included the cognitive creativity tasks was small in comparison to many large-scale twin studies which have investigated intelligence (Haworth et al., 2010). Larger sample sizes provide more accurate estimations, with narrower confidence intervals, of proportions attributed to genetic and environmental influences.

Self-reported creativity estimations included measures of creative writing competence, creative personality and self-reported creativity (Kandler et al., 2016; Velázquez et al., 2015; Vinkhuyzen et al., 2009). One study also included a measure of peer-reported creativity (Kandler et al., 2016). The proportion of genetic influences for all these phenotypes was moderate (.33 to .50). The variance explained by nonshared environmental effects was moderate to large (.44 to .74). Shared environments showed no influence on these measures.

Two studies also included creativity evaluations of drawings and video recordings of twins performing various creativity tasks by external, non-peer judges (Kandler et al., 2016; Velázquez et al., 2015). For these measures the genetic influences accounted for a quarter to half of the variance (.26 to .47; Kandler et al., 2016; Velázquez et al., 2015). For one of the measures, the video-based creativity rating, shared environmental influences also explained a fifth of the total variance (.20; Kandler et al., 2016).

Three studies measured creativity with behavioural inventories. The proportion of variance in creative achievements and working in creative professions, explained by genetic influences, varied from .37 to .70 (de Manzano & Ullén, 2018; Piffer & Hur, 2014; Roeling et al., 2017). The role of shared environmental effects was negligible, except for a measure of creative achievements in arts, among a Swedish twin sample (.32). Among the three studies, the role of nonshared environmental effects was moderate (.30 to .57). Two studies measured creativity with scientific and artistic creative achievements. In an Italian sample, the heritability for scientific creative achievements was reported as .43 and for or artistic creative achievements as .67 (Piffer & Hur, 2014). The opposite pattern was shown among the Swedish twin sample where the heritability for artistic creative achievements was estimated as .37 and for the scientific creative achievements, it was .68 (de Manzano & Ullén, 2018). These results may reflect the differences between the samples. The sample size for the Italian twin study was smaller. Additionally, it was younger than the Swedish sample and showed no shared environmental influences in artistic creative achievements.

Age has been shown to play a role in the aetiology estimations. Previous research on many phenotypes, such as on intelligence and social attitudes has shown that heritability increases over the lifespan (meta-analyses by Bergen et al., 2007; Briley & Tucker-Drob, 2013). This could also be the case with creativity. For example, as children grow older and have more autonomy, their genetic propensities could contribute to seeking environments where creative activities are encouraged. However, the comparison of the estimated of genetic and environmental influences is not straightforward due to several factors that need to be taken into a consideration when comparing the results. These include the sample size (small samples provide less reliable results), the age of the sample and well as the variance in creativity measurement (e.g. self-reports, cognitive tests, behavioural inventories).

The findings from the multivariate studies showed that creativity, measured with cognitive tests, self or peer-reports and behavioural inventories, partly share aetiology with personality and cognitive ability. Among the German twin sample, the majority of the genetic influences on individual differences in creativity scores overlapped with the genetic variance in intelligence and Openness to Experience (Kandler et al., 2016). However, the study did not report bivariate heritability estimates between the measures (e.g. the proportion of phenotypic covariance explained by the same genetic and environmental effects). Also, the multivariate analyses reported in this previous study, do not allow estimation of bivariate heritability since they used a common pathway model to calculate A, C and E for a latent creativity measure with reporting values for individual variables.

In the other multivariate study, on scientific creative achievements in arts and sciences among Swedish twins, the associations with Openness to Experience and intelligence were mediated largely by shared genetic influences (de Manzano & Ullén, 2018). Genetic effects explained from 81% to 89% of the phenotypic associations (r_{ph} = .24 - .49) between creative achievements, personality and intelligence. This finding is in-line with the generalist genes hypothesis, according to which there is substantial genetic overlap between broad areas of cognition, such as language, reading, mathematics and general cognitive ability (Kovas & Plomin, 2006). It is very likely that creative achievement, as well as other dimensions of creativity, are also influenced by the influence of this same set of generalist genes which are associated with many other phenotypes.

The findings of shared genetic influences between phenotypes are consistent with the pleiotropic explanation of genetic effects. Pleiotropy refers to a single genetic effect influencing many phenotypes, not only one (Plomin et al., 2007). As shown in the summary of multivariate studies, creativity shares aetiology with other constructs, such as personality and cognitive abilities. However, some of the influences can also be relatively specific to creativity.

These shared aetiologies indicate that creativity is not a unitary and separate construct, neither phenotypically nor genetically. The multivariate genetic findings also support the argument of creativity as a confluence of many factors, such as intelligence and personality.

In additional to pleiotropy, at the genetic level, the aetiology of creativity is likely to be polygenic – result from many genetic influences, each of small effect. In light of this polygenicity, less emphasis should be placed on candidate gene studies that test associations of creativity with specific genes (e.g. Reuter et al., 2006; Runco et al., 2011). Such studies are likely to overestimate the influence of single genetic markers on creativity phenotypes (Hewitt, 2012). Instead, genome wide association studies (GWAS) are needed, which identify associations between multiple genetic regions (loci) and traits. Such studies, if adequately powered, can establish many genetic loci that are associated with creativity phenotypes. These loci can then be aggregated into polygenic scores which can be used as predictor of individual's creativity levels.

No GWAS study of creativity has been conducted to date. However, it is possible to examine whether genetic markers associated with other traits can be related to creativity. To date, two studies have utilised polygenic risk scores, based on genetic markers associated with other outcomes, such as bipolar disorder and schizophrenia (based on separate GWAS studies), to predict the probability of working in a creative profession (Power et al., 2015) or self-evaluated creative thinking (Li et al., 2020). The effect sizes in these studies were small. Polygenic scores, based on GWAS studies on schizophrenia and bipolar disorder, explained 0.24% and 0.26% of the variance of working in creative professions (Power et al., 2015). In another study, the largest effect of polygenic predictor for self-reported creativity was 0.31% (Li et al., 2020). However, such small effects should not be interpreted as unimportant. First, utilising molecular genetic information to investigate creativity is based on fast developing technologies and these studies are the first to explore creativity using these methods. Second, the effect sizes based on polygenic scores are small for most cognitive traits. Third, the genetic markers, on which the polygenic predictions were based in these studies, were initially associated with other phenotypes (such as schizophrenia and bipolar disorder).

Overall, twin studies have shown that creativity is moderately heritable, with most variance explained by nonshared environmental influences. The role of shared environmental influences seems small, with inconsistent results. The available multivariate research indicates aetiological overlaps between creativity and certain personality traits and cognitive abilities. The results are in-line with the four general principles of behavioural genetics which state that: 1) human behavioural traits are heritable; 2) the effect of being raised in the same family is smaller than the effect of genes; 3) a substantial portion of the variation in complex human behavioural traits is not accounted for by the effects of genes or families; and 4) a typical human behavioural trait is associated with very many genetic variants, each of which accounts for a very small percentage of the behavioural variability (Chabris et al., 2015; Turkheimer, 2000).

The findings, based on the twin studies on creativity, provide a robust counterargument to the misconception that creativity is mainly genetically determined (e.g. that one is born creative). Understanding and applying these research findings of aetiological complexities of creativity plays a role in many real-life situations, for example in education. The findings of the twin studies presented here clearly indicate that creativity is influenced by both genes and environments and so may well be sensitive to educational interventions.

As shown by this review, genetically sensitive studies to date have been mainly conducted among adult samples. Conducting studies on developmental samples will help us to understand the trends in the aetiology over lifespan. Additionally, the previous studies have utilised a selection of self-reported and cognitive measures. To date, no twin studies have operationalised creativity as an ecologically valid creative outcome, such as in a piece of creative writing. Based on these gaps in the literature, the following Chapter 6 will investigate genetic and environmental influences on creative childhood writing, as well as its shared aetiology with intelligence, motivation and educational achievement.

6 Aetiology of Creative Expressiveness in childhood writing: A longitudinal, genetically informed investigation on creativity predicting educational achievement beyond motivation and intelligence

Chapter summary

Creativity is recognised as important in education. Previous research has linked creativity with educationally relevant constructs such as achievement, intelligence and motivation. However, very few studies have explored longitudinal links among creativity and other constructs or the aetiology of individual differences in creativity in children. The present study utilised data from a longitudinal, representative twin sample in the UK. Creativity was operationalised as a *Creative Expressiveness* score, using the Consensual Assessment Technique on stories written by 9-year-olds. *Creative Expressiveness* was associated with intelligence and motivation. It also predicted variance in achievement in writing grades at ages 9 and 16. The associations were weak, but significant, over and above intelligence, motivation and earlier achievement in writing grades. The variance in *Creative Expressiveness* was explained by genetic (35%), shared environmental (21%) and non-shared environmental (45%) influences. The phenotypic correlations with other study variables were mainly mediated genetically. The study presented in this chapter is the first adequately powered genetically informative analysis of childhood creativity indicating substantial shared environmental influences on creativity. The results from the genetic analyses are important indications on development of creativity and the aetiological architecture of its links with other constructs.

Introduction

The importance of creativity is recognised in education. There are recommendations for creativity development to be included as an objective in education (e.g. NACCCE, 1999). Creativity has been associated with many educational constructs, such as enjoyment of learning, intelligence and educational achievement (Csikszentmihalyi, 1997; Gajda et al., 2017; Getzels & Jackson, 1962). However, the link between creativity and educational achievement is not well understood, partly due to the limited number of longitudinal or experimental studies. Moreover, very little is known about the aetiology of creativity and of its links with educational achievement, intelligence and motivation.

The relevance of many creativity measures, such as divergent thinking tasks, has been questioned in educational contexts due to their narrow view on creativity (Baer, 2014; Barbot et al., 2015; Zeng et al., 2011). For example, divergent thinking test scores are often viewed as indicators of general creativity even if they, for example, only measure an ability to come up with original responses to common household objects (Baer, 2014). An alternative method of assessing creativity in educational context is to assess the creativity of a product, based on a social recognition of it being creative (Amabile, 1982). For example, previous research has measured creativity in children's musical compositions, creative play and storytelling (Hennessey & Amabile, 1988; Hickey, 2001; Howard-Jones et al., 2002).

A recent meta-analysis of 120 studies concluded that creativity, assessed using cognitive or self-reported measures, has a modest cross-sectional association with educational achievement as indicated by standardised tests or grade-point averages (r = .22; Gajda et al., 2017). However, to date, only a few longitudinal studies have investigated the relationship between creativity and educational achievement. One study has shown that, among 315 UK students (m_{age} = 12.56), creativity measured as a composite of verbal, figural and numerical cognitive tasks predicted end of the school grades (GCSEs) four years later in English (β = .25), Maths (β = .22) and Science (β = .16; Mourgues et al., 2016). However, this study did not include any control variables associated with creativity, such measures of cognitive abilities or general intelligence, which may have accounted for some variance in grades.

One important construct to consider in relation to creativity and educational achievement is intelligence. As reviewed in Chapter 4 in this thesis, previous research has associated intelligence with creativity. For example, a meta-analysis reported an overall effect of r = .17 between creativity, measured as divergent thinking, and intelligence (Kim, 2005). This positive association between intelligence and creativity could be due to more efficient cognitive processing, such as better working memory capacity or faster information processing speed. Intelligence is also the strongest individual predictor of educational achievement (Deary et al., 2007). It is therefore possible that creativity predicts educational achievement via the same processes that explain the links between intelligence and educational achievement (Deary et al., 2007).

Another psychological construct that has been associated with both creativity and educational achievement is intrinsic motivation. Intrinsic motivation drives an individual to run the extra mile and mull over a problem that requires a creative solution (Amabile, 1983). Several studies have supported the positive relationship between intrinsic motivation and creativity. For example, a meta-analysis on the relationship between intrinsic motivation and creativity of a product reported an overall correlation of r = .30 (de Jesus et al., 2013). A recent longitudinal study has shown that intrinsic reading motivation, measured as reading enjoyment, has a reciprocal relationship with educational achievement in late childhood (Malanchini et al., 2017). This suggests that the motivation is not only a predictor of educational achievement, but that educational achievement also influences motivation.

Sources of individual differences in childhood creativity are poorly understood. As discussed in the review presented Chapter 5, to date, only a few quantitative genetic studies have explored genetic and environmental influences on individual differences in creativity, as well as its mechanistic association with other constructs, such as intelligence and motivation. Specifically, there is a gap in the literature of studies that are based on developmental samples. A Dutch sample of 3370 twins (adolescents and young adults) reported a modest heritability of creative writing (Vinkhuyzen et al., 2009). However, no studies have yet investigated the aetiology of creativity in childhood.

To build on previous research, the present study uses longitudinal data, measured over 7 years, from a large twin sample in the UK to investigate how creativity, measured in written stories of 9-year-old children, relates to educational achievement, above and beyond intelligence and motivation. Additionally, the study explores the aetiology of creativity. Specifically, the present study addresses three research questions.

1. Is creativity in writing at age 9 associated with intelligence and writing motivation at the same age?
2. Does creativity in writing at age 9 explain variance in National Curriculum grades for English Writing at ages 9 and 12; as well as in English General Certificate of Secondary Education (GCSE) exam grade at age 16, above and beyond intelligence and writing motivation?
3. Does the genetic and environmental aetiology of individual differences in creativity in writing overlap with the aetiology of individual differences in intelligence, writing motivation and achievement in writing?

Methods

Sample

The participants are part of a large, longitudinal twin study in the UK, the Twins Early Development Study (TEDS). TEDS is a representative sample of the population in England and Wales (Rimfeld et al., 2019). Participants in the present study (n = 1306) were a subsample of TEDS twins whose data on the written stories were available at age 9, as well as on other study variables at ages 9 and 16; 628 (out of 1306) of these participants also completed data collection at age 12. The elicitation of stories from the children was originally designed to assess children's written language. As such, these are scores generated using post-hoc coding as a basis for creativity scores.

Of the 1306 twins, 331 were monozygotic (MZ) twin pairs and 322 dizygotic (DZ) twin pairs; 776 females and 530 males. At age 12, the sub-sample included 163 monozygotic (MZ) twin pairs and 151 dizygotic (DZ) twin pairs; 376 females and 252 males. The mean age for participants, when data for the creativity measure was collected, was 9.00 years (SD = .29).

A preliminary power calculation (with 80% power) estimated a sample size as 320 MZ and 320 DZ twin pairs needed to detect genetic influences (.20) in a univariate genetic analysis.

The sample in the present study had slightly higher standardised means in comparison to the whole TEDS sample for intelligence, motivation and educational achievement scores (see Table 6.3. in Results section for the comparisons of means with the complete TEDS sample). The differences may be due to the slightly higher attrition rates among lower SES status families taking part in later data collection waves (Rimfeld et al., 2019), since studies have reported that SES has a marked, lasting and increasing impact on cognitive development (e.g. von Stumm, 2017). This is consistent with the previous findings of attrition rates in longitudinal studies (Rimfeld et al., 2019; von Stumm, 2017).

Measures

Written stories at age 9

The children were shown three coloured pictures of animals and buildings at a farm (see Figure 6.1) with the following instructions: '*We would like you to make up a story for us. On the next page you will see three different pictures, 1, 2 and 3. Together they make a little story about a farm. Try to think hard about what you see in the pictures. After you have looked at them carefully, write your story on the next page of this book. Have fun making your story interesting, creative or even funny!*' The task was completed in family homes, with children supervised by their parents. There was no time limit for the task. All the stories were transcribed to minimise the effect of handwriting on coding.

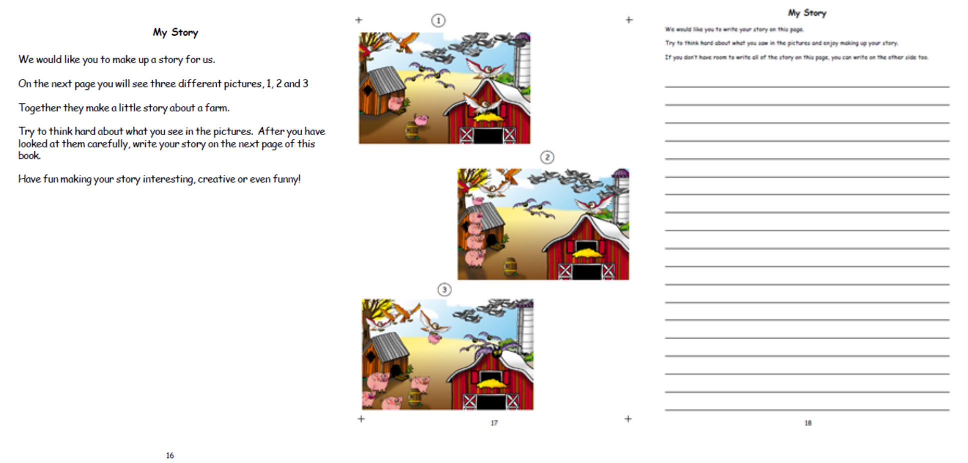


Figure 6.1. Instructions to the story writing.

The stories were coded for creativity and nine other dimensions using the Consensual Assessment Technique (CAT; Amabile, 1982). The CAT is a method to operationalise creativity of a product and can be used to measure creativity in common creative products, such as in written stories. The CAT is based on the principle that a creative product will be recognized as being creative in its social environment (Amabile, 1982). The use of the CAT has demonstrated that people can recognise and agree upon creativity even though it may be difficult to define and characterise (Hennessey, 2010). In developmental samples, the CAT has been used to evaluate creativity of musical compositions, drawings and poems (Baer, 2014; Baer et al., 2004; Hickey, 2001; Lubart et al., 2010), as well as children's oral and written stories (Badini et al., 2018; Hennessey & Amabile, 1988; Toivainen et al., 2017). The use of the CAT to evaluate creativity in children's written stories was piloted in three previous studies (Badini et al., 2018; Toivainen et al., 2017, 2018).

The same rationale, as for creativity, was used with the judgements of the nine other story dimensions. As with creativity, no detailed definitions were given to evaluate the other 9 dimensions. The present study replicated the coding dimensions and the procedure from an earlier study which investigated creativity in children's orally told stories (Hennessey & Amabile, 1988). The story codes were provided with the following instructions:

'*Using your own subjective definition of the following dimensions, how would you assess:*

1. *Creativity: the degree to which each story is creative.*
2. *Liking: how well you like the story, using your own, subjective criteria for liking.*
3. *Novelty: the degree to which the subject/plot is novel.*
4. *Imagination: the degree to which the subject/plot is imaginative.*
5. *Logic: the degree to which story events are logical, or understandably related.*
6. *Emotion: the amount and depth of emotion the story conveys.*
7. *Grammar: the degree to which the story is grammatically correct.*
8. *Detail: the amount of detail contained in the story.*
9. *Vocabulary: the level and variety of vocabulary employed in the story.*
10. *Straightforwardness: the degree to which the story is straightforward.'*

Coders were instructed to allocate a score between 1 (not very) and 7 (very) to each dimension for each story. All stories were coded for creativity first. The order for the following nine dimensions was randomised to avoid potential order effect in the coding. Additionally, stories were randomly coded such that coders did not score two stories from the members of the same twin pair consecutively.

Due to the large sample size, the stories were divided in 5 blocks of 248 - 306 stories each (in total 1306 stories). The stories in each block were coded for all 10 dimensions by 5 independent undergraduate-student judges. In total, 25 students worked on the coding. A previous study, conducted as a pilot for the present study, showed that primary school teachers and undergraduate students did not differ in their evaluations of creativity in children's stories (Toivainen et al., 2017). Another study established that five coders were sufficient to reach acceptable inter-rater reliabilities for all dimensions (Toivainen et al., 2018). The inter-rater reliabilities are presented in Table 6.1. below. For seven of the ten dimensions the inter-rater reliabilities were acceptable (e.g. for creativity dimension .81 - .90). However, the inter-rater reliabilities were lower for Straightforwardness (.55 - .75) and Logic (.48 - .75). The total score for each dimension was created by averaging the sum of the standardised scores from the 5 coders.

Table 6.1 Inter-rater reliabilities (intraclass correlation coefficient) for 10 story dimensions.

Judge subsample	n	Intraclass correlation coefficient	Story dimension	n	Intraclass correlation coefficient
Creativity_A	306	.87 [.85, .89]	Emotion_A	306	.85 [.82, .88]
Creativity_B	246	.85 [.82, .88]	Emotion_B	246	.81 [.77, .85]
Creativity_C	242	.86 [.83, .89]	Emotion_C	242	.80 [.75, 84]
Creativity_D	249	.81 [.77, .85]	Emotion_D	249	.77 [.72, .81]
Creativity_E	251	.90 [.88, .92]	Emotion_E	251	.81 [.77, .85]
	1294	**.81 - .90**		**1294**	**.77 - .85**
Imagination_A	306	.87 [.84, .89]	Vocabulary_A	306	.82 [.79, .85]
Imagination_B	246	.86 [.84, .89]	Vocabulary_B	246	.84 [.81, .87]
Imagination_C	242	.88 [.85, .90]	Vocabulary_C	242	.78 [.73, .82]
Imagination_D	249	.81 [.77, .85]	Vocabulary_D	249	.68 [.61, .74]
Imagination_E	251	.89 [.87, .91]	Vocabulary_E	251	.82 [.78, .85]
	1294	**.81 - .88**		**1294**	**.68 - .84**
Novelty_A	306	.86 [.84, .88]	Straightforwardness_A	306	.64 [.57, .70]
Novelty_B	246	.82 [.79, .86]	Straightforwardness_B	246	.55 [.45, .63]
Novelty_C	242	.87 [.85, 90]	Straightforwardness_C	242	.65 [.57, .71]
Novelty_D	249	.80 [.76, .84]	Straightforwardness_D	248	.60 [.51, 67]
Novelty_E	249	.87 [.84, .89]	Straightforwardness_E	251	.75 [.69, .79]
	1292	**.80 - .87**		**1293**	**.55 - .75**
Liking_A	306	.84 [.81, .87]	Logic_A	306	.72 [.67, .77]
Liking_B	246	.82 [.79, .86]	Logic_B	246	.66 [.59, .72]

Liking_C	242	.78 [.73, .82]	Logic_C	242	.68 [.62, .74]
Liking_D	247	.77 [.72, .81]	Logic_D	249	.48 [.37, .58]
Liking_E	251	.79 [.74, .83]	Logic_E	251	.75 [.70, .80]
	1292	**.77 - .84**		**1294**	**.48 - .75**
Detail_A	306	.87 [.85, .89]	Grammar_A	306	.77 [.73, .81]
Detail_B	246	.87 [.84, .89]	Grammar_B	246	.77 [.72, .82]
Detail_C	242	.86 [.83, .88]	Grammar_C	242	.81 [.77, .84]
Detail_D	249	.82 [.78, .85]	Grammar_D	249	.77 [.72, .81]
Detail_E	251	.89 [.87, .91]	Grammar_E	249	.84 [.80, .87]
	1294	**.82 - .89**		**1292**	**.77 - .84**

Note. A, B, C, D and E refer to five subsamples of the stories, each subsample included 246 to 306 stories.
The stories for each subsample (A, B, C, D and E) were coded by five independent judges for 10 dimensions.

The present study reported a similar two-componential structure among the coded dimensions as was found in three previous studies that were based partly on the same sample as the present study. The earlier studies used data from a smaller number of participants (n = 59 – 306) and did not include any genetically sensitive analyses (Badini et al., 2018; Toivainen et al., 2017, 2018). The two components were named *Creative Expressiveness* and *Logic*. The first component – *Creative Expressiveness* - included Creativity, Liking, Novelty, Imagination, Emotion and Detail. The second component – *Logic* – included Logic, Grammar and Straightforwardness. The Vocabulary dimension had similar loadings on both components and was therefore excluded when the component scores were computed.

The component scores for *Creative Expressiveness* and *Logic*, which were used in the analyses, were based on six (*Creative Expressiveness*) and three (*Logic*) story dimensions. The component scores were calculated using the regression method. The component loadings are presented in Table 6.2. below.

Table 6.2. The rotated principal component loadings, with Varimax rotation, for 10 story dimensions.

	Component 1 Creative Expressiveness	**Component 2 Logic**
Creativity	**.96**	.11

Liking	**.90**	.25
Novelty	**.94**	.06
Imagination	**.96**	.12
Logic	.21	**.88**
Emotion	**.85**	.25
Grammar	.39	**.78**
Detail	**.83**	.31
Vocabulary	.71	.57
Straightforwardness	-.04	**.93**

Note. The dimensions which were included in the component scores are bolded.

Intelligence at age 9

A composite of two non-verbal and two verbal tests was used. The test booklets were filled at home. The verbal tests were age-appropriate versions of Vocabulary and General Knowledge tests from the WISC-III (Kaplan et al., 1999; D. Wechsler, 1992). The non-verbal tests were Figure Classification and Shapes tests from the Cognitive Abilities Test 3 (Smith et al., 2001).

Intrinsic motivation to write at age 9

Twins and their parents responded to two questions. Children were asked 'How much do you like writing' (1-5) and parents 'How much does your child like writing' (1-5). The items were developed by the TEDS research team (Spinath et al., 2006). The average of the two measures were used as a total score. The correlation between the measures was r = .40.

Achievement in writing at age 9

Teachers commented on twins' 'current level of attainment' in writing in terms of the National Curriculum (NC). The assessment criteria were based on grammar, punctuation and spelling (NC level KS). Achievement in writing at age 9 was teacher evaluated, based on the NC scale 1 to 5, in which level 5 represents exceptional achievement and 1 represents achievement well below the expected standard for most 9-year-olds.

Achievement in writing at age 12

Achievement in writing was teacher reported, based on the NC scale 1 to 9, in which 9 represents exceptional achievement. In addition to the assessment criteria applied at age 9, the following was also assessed: accuracy, fluency, planning, drafting, editing and the effectiveness of writing (NC level KS3).

Achievement in writing at age 16

A composite grade score was created as the mean of General Certificate of Secondary Education (GCSE) exam grades for English language and English literature. The GCSE is a nationwide examination taken at the end of compulsory education in England and Wales, generally at the age 16. English is a compulsory subject. If only one exam was sat, the score was based on that grade. Out of 1306 twins, 137 sat only one exam. The grades were coded for the present study from 11 (the highest grade, A*) to 4 (the lowest pass grade, G). Two participants who did not have a grade (e.g. due to the fail), were coded as missing.

Statistical Analyses

For the non-genetically sensitive analyses, one twin per pair was randomly selected., the other allocated to a comparison sample. Splitting the whole twin sample into two independent samples eliminated the confound of genetic and environmental influences shared by twins from the same pair. In addition, this procedure creates two 'singleton' samples, a procedure that has been used in previous research (Malanchini et al., 2017). Whatever findings are indicated in the first sample can be investigated to see if they replicate in the second sample. This procedure. The regression results for both halves of the sample are presented in Tables 6.5. to 6.10.

For univariate and multivariate genetic model fitting, age and sex were added as covariates. A univariate ACE model was fitted to each of the variables. Nested models (i.e., AE, CE, E) were also fitted to examine if one (or two) components could be dropped without a significant decrease of model fit. The fit of the different models and sub-models was checked using the likelihood-ratio chi-square test and the Akaike's information criterion (AIC; (Akaike, 1987)). Assumptions of twin models were checked in the saturated models in order to check for differences in means and variances between the different groups: MZ/DZ twins and twin1/twin2 (randomly selected within each pair).

As described in Chapter 5, multivariate genetic analyses allow the estimation of aetiological correlations between variables, i.e. the extent to which the latent variables (A, C and E) correlate across two traits. These correlations (i.e., rA rC, rE) vary from -1 to +1, with 0 indicating entirely separate aetiologies; and +1 indicating a complete overlap in aetiologies of the two measures. Bivariate heritability, based on the multivariate correlations, is the proportion of the phenotypic covariance explained by A, C and E. Bivariate heritability indicates the strength of genetic mediation between two variables. The same procedure also enables the estimation of the contributions of shared and non-shared environmental factors on the correlations between two study measures.

Twin analyses were conducted using the package OpenMx (2.13.2) in R (Neale et al., 2016).

Results

Phenotypic analyses

Descriptive statistics for the study variables are presented in Table 6.3. below.

Table 6.3. Descriptive statistics for the study measures and comparison measures with the whole TEDS sample.

Variable	M	SD	Skewness	Kurtosis	m (sd) Whole TEDS sample
Creative Expressiveness at 9	-0.01	0.99	0.03	-0.57	/
Logic at 9	-0.00	1.00	-0.42	0.22	/
Age	9.00	0.29	1.11	5.38	/
intelligence at 9	0.15	0.93	-0.53	-0.07	0.00 (1.00)
Motivation at 9	3.97	0.81	-0.79	0.32	2.15 (1.13)
Writing at 9	3.04	0.68	-0.24	0.04	2.84 (.74)
Writing at 12	4.75	0.83	0.53	2.32	4.25 (1.00)
Writing at 16	9.14	1.17	-0.59	0.71	8.89 (1.23)

The inter-correlations between the study variables are presented in Table 6.4.

Table 6.4. Correlations with confidence intervals for the study variables.

Variable	1	2	3	4	5	6	7	8
1. Creative Expressiveness at 9								
2. Logic at 9	.39** [.32, .45]							
3. Sex	-.20** [-.28, -.09]	-.17** [-.24, -.09]						
4. intelligence at 9	.26** [.18, .33]	.04 [.28, .41]	.07 [-.00, .15]					
5. Motivation at 9	.25** [.17, .32]	.19** [.12, .26]	-.32** [-.39, -.25]	.07 [-.01, .14]				
6. Writing at 9	.37** [.30, .43]	.39** [.33, .46]	-.07 [-.15, .00]	.42** [.36, .48]	.24** [.17, .31]			
7. Writing at 12	.31** [.21, .41]	.34** [.24, .43]	.01 [-.10, .12]	.42** [.32, .50]	.15** [.04, .25]	.53** [.45, .61]		
8. Writing at 16	38** [.31, .44]	.36** [.29, .43]	-.15** [-.23, -.08]	.48** [.42, .54]	.21** [.13, .28]	.52** [.47, .58]	.57** [.49, .64]	

Note. Values in square brackets indicate the 95% confidence interval for each correlation.
*p < .05. **p < .01.

All variables were normally distributed. All study measures were positively correlated (ranging from *r* = .15 to .57), with the exception of no significant correlation between writing motivation and intelligence at age 9. Age, measured in years and months during the data collection at age 9, was not associated with study variables.

Three regressions for each half of the twin sample (6 regressions in total) were run to establish whether Creative Expressiveness and Logic scores measured at age 9 were independently related to educational achievement at ages 9, 12 and 16 over and above intelligence and motivation.

Tables 6.5. and 6.6. present regression results for the achievement in writing grade at age 9 for the two halves of the twin sample respectively. Both Creative Expressiveness and Logic were significant predictors, beyond writing motivation and intelligence at the same age (which were also significant). All variables had similar beta weights (0.10 – 0.16) predicting the variance in English writing grade at age 9.

Table 6.5. Regression results using achievement in writing at 9 as the criterion for the sample 1 (n = 653)

Predictor	b	b 95% CI [LL, UL]	beta	beta 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	r	Fit
(Intercept)	1.12	[-0.39, 2.63]						
age	0.16	[-0.00, 0.33]	0.07	[-0.00, 0.14]	.00	[-.00, .01]	.11**	
sex	-0.03	[-0.13, 0.07]	-0.02	[-0.09, 0.05]	.00	[-.00, .00]	-.11**	
Intelligence 9	0.16**	[0.10, 0.21]	0.20	[0.13, 0.28]	.04	[.01, .06]	.32**	
Motivation 9	0.10**	[0.04, 0.16]	0.12	[0.05, 0.19]	.01	[-.00, .03]	.20**	
Logic 9	0.15**	[0.10, 0.21]	0.22	[0.14, 0.30]	.04	[.01, .06]	.39**	
Creative Expressiveness 9	0.12**	[0.07, 0.17]	0.17	[0.09, 0.25]	.02	[.00, .04]	.34**	
								R^2 = .241**

Note. A significant *b*-weight indicates that the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates $p< .05$. ** indicates $p< .01$.

Table 6.6. Regression results using achievement in writing at 9 as the criterion for the sample 2 (n = 653).

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*R*	Fit
(Intercept)	1.80**	[0.42, 3.17]						
age	0.08	[-0.07, 0.23]	0.03	[-0.03, 0.10]	.00	[-.00, .01]	.06	
sex	0.04	[-0.06, 0.13]	0.03	[-0.04, 0.10]	.00	[-.00, .00]	-.07	
Intelligence 9	0.22**	[0.17, 0.27]	0.30	[0.23, 0.37]	.08	[.04, .11]	.42**	
Motivation 9	0.12**	[0.06, 0.17]	0.14	[0.07, 0.21]	.02	[.00, .03]	.24**	
Logic 9	0.13**	[0.08, 0.18]	0.19	[0.12, 0.26]	.03	[.01, .05]	.39**	
Creative Expressiveness 9	0.12**	[0.07, 0.17]	0.18	[0.11, 0.25]	.03	[.01, .05]	.37**	
								R^2 = .303**

Note. A significant *b*-weight indicates the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates $p < .05$. ** indicates $p < .01$.

Tables 6.7. and 6.8. present the regression results for achievement in writing at age 12 for the two samples. Out of 5 variables entered in the same model, Creative Expressiveness and writing motivation at age 9 were not significant predictors, whereas Logic, intelligence, and achievement in writing grade at age 9 were all significant predictors. The finding of Logic at age 9 being a statistically significant predictor of achievement in writing at age 12 did not replicate in the second half of the sample (see

Tables 6.7. and 6.8.) and was therefore not considered as a predictor of achievement in writing score at age 12.

Table 6.7. Regression results using achievement in writing at 12 as the criterion (n = 314).

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit
(Intercept)	4.39**	[1.69, 7.10]						
age	-0.16	[-0.45, 0.13]	-0.05	[-0.15, 0.04]	.00	[-.01, .01]	.00	
sex	0.03	[-0.15, 0.22]	0.02	[-0.08, 0.12]	.00	[-.00, .00]	-.00	
Intelligence 9	0.18**	[0.08, 0.28]	0.19	[0.09, 0.29]	.03	[-.00, .06]	.35**	
Motivation 9	0.07	[-0.04, 0.18]	0.06	[-0.04, 0.16]	.00	[-.01, .01]	.16**	
Writing 9	0.50**	[0.35, 0.64]	0.38	[0.27, 0.49]	.11	[.05, .16]	.51**	
Logic 9	0.15**	[0.04, 0.26]	0.16	[0.04, 0.27]	.02	[-.01, .04]	.39**	
Creative Expressiveness 9	0.02	[-0.08, 0.12]	0.02	[-0.08, 0.13]	.00	[-.00, .00]	.25**	
								R^2 = .334**

Note. A significant *b*-weight indicates that the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates *p*< .05. ** indicates *p*< .01.

Table 6.8. Regression results using achievement in writing at 12 as the criterion for Twin 2 (n = 314).

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit
(Intercept)	3.86**	[1.51, 6.21]						
age	-0.06	[-0.31, 0.20]	-0.02	[-0.11, 0.07]	.00	[-.00, .00]	.01	
sex	0.07	[-0.10, 0.23]	0.04	[-0.06, 0.14]	.00	[-.01, .01]	.01	
Intelligence 9	0.17**	[0.07, 0.26]	0.19	[0.09, 0.30]	.03	[-.00, .06]	.42**	
Motivation 9	-0.01	[-0.12, 0.09]	-0.01	[-0.11, 0.08]	.00	[-.00, .00]	.15**	
Writing 9	0.46**	[0.33, 0.60]	0.39	[0.27, 0.50]	.09	[.04, .14]	.54**	
Logic 9	0.04	[-0.05, 0.13]	0.05	[-0.06, 0.16]	.00	[-.01, .01]	.34**	
Creative Expressiveness 9	0.07	[-0.02, 0.16]	0.08	[-0.02, 0.19]	.01	[-.01, .02]	.31**	
								R^2 = .330**

Note. A significant *b*-weight indicates the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates *p* < .05. ** indicates *p* < .01.

Tables 6.9. and 6.10. present the regression results for English GCSE grade at age 16 for the two samples. Creative Expressiveness at age 9 explained additional variance to that explained by intelligence at age 9, as well as achievement in writing grades at ages 9 and 12. Logic and motivation to write at age 9 were not significant predictors of educational achievement at age 16 with all other variables included in the model.

Table 6.9. Regression results using English GCSE at 16 as the criterion (n = 653).

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit
(Intercept)	4.56**	[1.71, 7.40]						
age	0.15	[-0.16, 0.45]	0.04	[-0.04, 0.12]	.00	[-.00, .01]	.07	
sex	-0.19	[-0.39, 0.00]	-0.08	[-0.17, 0.00]	.01	[-.01, .02]	-.12*	
Intelligence 9	0.25**	[0.14, 0.36]	0.21	[0.12, 0.30]	.03	[.00, .05]	.49**	
Motivation 9	0.06	[-0.06, 0.19]	0.04	[-0.04, 0.13]	.00	[-.01, .01]	.25**	
Writing 9	0.39**	[0.21, 0.56]	0.24	[0.13, 0.34]	.03	[.00, .06]	.58**	
Writing 12	0.40**	[0.27, 0.53]	0.29	[0.20, 0.39]	.06	[.02, .09]	.57**	
Logic 9	0.01	[-0.09, 0.12]	0.01	[-0.08, 0.11]	.00	[-.00, .00]	.40**	
Creative Expressiveness 9	0.17**	[0.07, 0.28]	0.15	[0.06, 0.24]	.02	[-.00, .04]	.43**	
								R^2 = .502**

Note. A significant *b*-weight indicates that the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates $p< .05$. ** indicates $p< .01$.

Table 6.10. Regression results using English GCSE at 16 as the criterion for Twin 2 (n = 653).

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit
(Intercept)	4.56**	[1.71, 7.40]						
age	0.15	[-0.16, 0.45]	0.04	[-0.04, 0.00]	.00	[-.00, .01]	.07	
sex	-0.19	[-0.39, 0.00]	-0.08	[-0.17, 0.00]	.01	[-.01, .02]	-.12	
Intelligence 9	0.25**	[0.14, 0.36]	0.21	[0.12, 0.30]	.03	[.00, .06]	.49**	
Motivation 9	0.06	[-0.06, 0.19]	0.04	[-0.04, 0.13]	.00	[-.00, .01]	.25**	
Writing 9	0.39**	[0.21, 0.56]	0.24	[0.13, 0.34]	.03	[.01, .06]	.58**	
Writing 12	0.33**	[0.27, 0.53]	0.29	[0.20, 0.39]	.06	[.02, .09]	.57**	
Logic 9	0.01	[-0.09, 0.12]	0.01	[-0.08, 0.11]	.00	[-.00, .00]	.40**	
Creative Expressiveness 9	0.17**	[0.07, 0.28]	0.15	[0.06, 0.24]	.02	[-.00, .04]	.43**	
								R^2 = .502**

Note. A significant *b*-weight indicates the beta-weight and semi-partial correlation are also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. *r* represents the zero-order correlation. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. R^2 represents the total variance explained by the predictors.
* indicates $p < .05$. ** indicates $p < .01$.

To summarise the regression results, the strength of the predictors was similar to that found in the first half of the sample; with the exception of *Logic* at age 9 not explaining variance in achievement in writing at age 12 in the replication sample.

Quantitative genetic analyses

All the twin-cotwin phenotypic correlations were higher in MZ than DZ pairs (the details of the quantitative statistical analyses are described in Chapter 5). Genetic factors accounted for a substantial proportion of the variance in Creative Expressiveness (35%; 95% CI: .13- .57). Shared environmental factors also accounted for a significant proportion of the variance in creativity (20%; 95% CI: .01- .39). The remaining variance in Creative Expressiveness was explained by non-shared environmental influences (45%; 95% CI: .38- .52). Intelligence, motivation, achievement in writing at 9, 12 and 16 were influenced by genetic factors ranging from 25% to 68%. Logic at 9 did not show a significant genetic influence. For Logic, a CE model indicated that shared environment explained 34% (95% CI: .27- .41) of the variance. Intraclass correlations and univariate model fitting results are presented in Table 6.11. below.

Table 6.11. Intraclass correlations and univariate model fitting results.

	Model	Model for comparison	A (95% CI)	C/D (95% CI)	E (95% CI)	df	-2LL	AIC	DiffLL	Diffdf	P	rMZ	rDZ
Creativity at 9												.55 [.48, .63]	.38 [.28, .47]
	ACE	**saturated**	**.35 [.13, .57]**	**.20 [.01, .39]**	**.45 [.38, .52]**	**1293**	**3451.52**	**865.52**	**4.26**	**6**	**.641**		
	AE	ACE	.57 [.50, .63]	/	.43 [.37, .50]	1294	3455.59	867.59	4.07	1	.044		
	CE	ACE	/	.47 [.40, .53]	.53 [.48, .60]	1294	3461.22	873.22	9.70	1	.002		
	E	AE	/	/	1 [1, 1]	1295	3619.87	1029.87	164.27	1	<.001		
Logic at 9												.35 [.26, .45]	.33 [.23, .42]
	ACE	Saturated	.03 [.00, .29]	.32 [.10, .41]	.65 [.57, .73]	1293	3568.66	982.66	5.95	6	.429		
	AE	ACE	.39 [.31, .46]	/	.61 [.54, .69]	1294	3576.75	988.75	8.09	1	.004		
	CE	**ACE**	**/**	**.34 [.27, .41]**	**.66 [.59, 73]**	**1294**	**3568.69**	**980.69**	**0.04**	**1**	**.846**		
	E	AE	/	/	1 [1, 1]	1295	3648.79	1058.79	72.05	1	<.001		
g at 9												.75 [.70, .80]	0.61 [.54, .68]
	ACE	**saturated**	**.25 [.12, .40]**	**.49 [.35, .61]**	**.26 [.22, .30]**	**1300**	**3073.45**	**473.45**	**13.22**	**6**	**.040**		
	AE	ACE	.75 [.71, .79]	/	0.25 [.21, .29]	1301	3108.54	506.54	35.10	1	<0.001		
	CE	ACE	/	.68 [.64, .72]	.32 [.28, .36]	1301	3086.86	484.86	13.41	1	<0.001		
	E	AE	/	/	1.00 [1.00 ,1.00]	1302	3497.90	893.90	387.10	1	<0.001		
Motivation at 9												.48 [.39, .56]	.26 [.15, .36]
	ACE	saturated	.47 [.22, .56]	.02 [.00, .22]	.51 [.44, .60]	1300	2942.11	342.11	4.06	6	0.67		
	AE	**ACE**	**.49 [.41, .56]**	/	**.51 [.44, .59]**	**1301**	**2942.14**	**340.14**	**0.03**	**1**	**.873**		
	CE	ACE	/	.37 [.30, .43]	.63 [.57, .70]	1301	2955.84	353.84	13.72	1	<.001		
	E	AE	/	/	1 [1, 1]	1302	3049.57	445.57	107.43	1	<.001		
Writing at 9												.63 [.57, .69]	.43 [.34, .52]
	ACE	**saturated**	**.42 [.23, .62]**	**.22 [.03, .38]**	**.36 [.31, .42]**	**1299**	**2470.49**	**-127.51**	**5.99**	**6**	**0.42**		
	AE	ACE	.65 [.60, .70]	/	.35 [.30, .40]	1300	2475.78	-124.22	5.28	1	.022		
	CE	ACE	/	.53 [.48, .59]	.47 [.41, .52]	1300	2489.20	-110.80	18.71	1	<0.001		
	E	AE	/	/	1 [1, 1]	1301	2707.82	105.82	232.05	1	<.001		
Writing at 12												.70 [.59, .77]	.46 [.26, .60]
	ACE	saturated	.35 [.03, .72]	.32 [.00, .60]	.33 [.26, .43]	622	1517.43	273.43	5.43	6	.491		
	AE	**ACE**	**.68 [.58, .75]**	/	**.32 [.25, .42]**	**623**	**1520.12**	**274.12**	**2.69**	**1**	**.101**		
	CE	ACE	/	.60 [.51, .68]	.40 [.32, .49]	623	1522.10	276.10	4.67	1	.031		
	E	AE	/	/	1 [1, 1]	624	1609.97	361.97	89.85	1	<.001		
Writing at 16												.87 [.84, .89]	.53 [.45, .61]
	ACE	**saturated**	**.66 [.52, .82]**	**.21 [.05, .34]**	**.14 [.11, .16]**	**1298**	**3519.23**	**923.23**	**2.85**	**6**	**.827**		
	AE	ACE	.86 [.84, .89]	/	.14 [.11, .16]	1299	3525.58	927.58	6.35	1	.012		
	CE	ACE	/	.71 [.67, .74]	.29 [.26, .33]	1299	3639.63	1041.63	120.40	1	<.001		
	E	AE	/	/	1 [1, 1]	1300	4089.99	1489.99	564.41	1	<.001		

Note: A, additive genetic influence; C, shared environmental influence; E, non-shared environmental influence; -2LL, negative 2 log-likelihood; AIC, Akaike's information criterion; CI, confidence interval; df, degrees of freedom; P-value, significance value of the likelihood-ratio chi-square test; rDZ, dizygotic correlations; rMZ, monozygotic correlations. Bold text indicates best fitting models.

The results from seven univariate genetic analyses, based on the best fitting models (either ACE, CE or AE) are summarised in Figure 6.2.

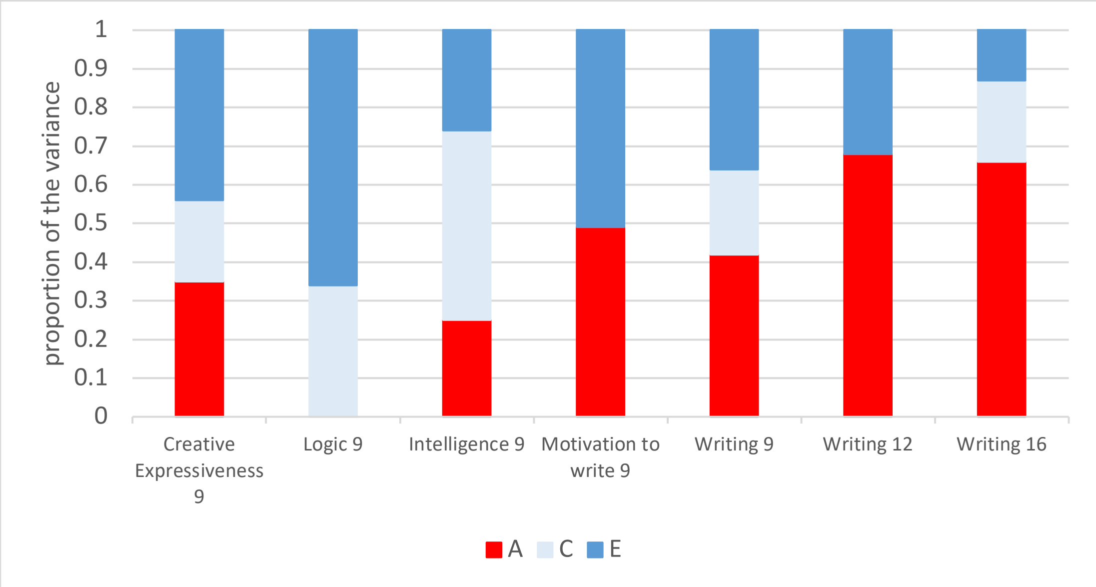


Figure 6.2. Model fitting results for additive genetic (A), shared environment (C), and non-shared environment (E) components of variance for Creative Expressiveness *and six other study variables.*

Figure 6.3. presents the results of six bivariate models exploring the aetiology of the phenotypic correlations between Creative Expressiveness and the other 6 variables. The bivariate heritability estimates are presented in Figure 6.3. The figure shows the proportion of additive genetic (A), shared environmental (C), and non-shared environmental (E) influences on the phenotypic correlations between Creative Expressiveness and the other six study variables (bivariate correlations). An ACE model provided the best fit for associations between Creative Expressiveness and Logic at 9, intelligence at 9, achievement in writing at 9 and 12. An AE model provided the best fit for the associations between Creative Expressiveness and motivation at 9 and achievement in writing at 12. The genetic influences explained between 26% and 84% of the total co-variance between each of the six pairs of variables. Shared environmental effects mediated correlations of Creative Expressiveness with: Logic (31%); intelligence (35%); achievement in writing at age 9 (23%); and English at age 16 (31%). Non-shared

environmental influences also contributed to the observed overlap between Creative Expressiveness and all other measures.

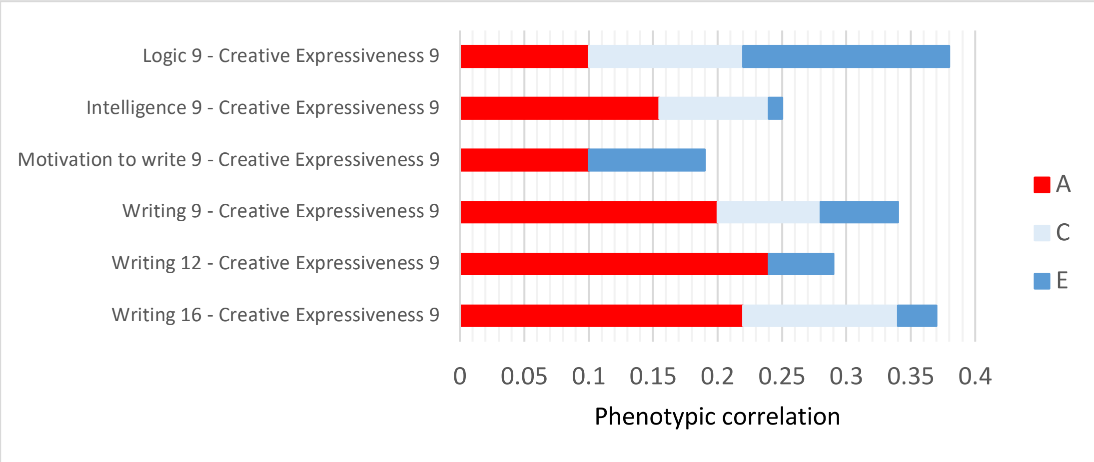


Figure 6.3. Bivariate estimates for additive genetic (A), shared environmental (C), and non-shared environmental (E) contributions to the correlations between Creative Expressiveness *at age 9 and the six other variables. The total length of the bar indicates the phenotypic correlations.*

All the genetic correlations between creativity and the other variables were significant ranging from 0.19 (motivation) to 0.54 (intelligence), see Table 6.12. below. The shared and non-shared environmental correlations were generally of lower magnitude than the genetic correlations and not always significant. The genetic correlation for Creative Expressiveness and Logic at age 9, based on the ACE model, was 1. However, the confidence interval included zero, probably due to negligible genetic influences on the Logic score at age 9 for which the univariate CE model provided the best model fit. As with the univariate models, all multivariate models in the present study were compared with nested models showing that the ACE model had the best fit for *Creative Expressiveness* and *Logic*. Univariate and multivariate model fittings are separate statistical procedures. The best fitting univariate models can differ from the best fitting multivariate models.

Table 6.12. Bivariate models for Creative Expressiveness at age 9 with the other study variables.

Additive genetic, common shared and non-shared environmental overlap between phenotypes		Proportion of the phenotypic correlation explained by additive genetic, common shared and non-shared environmental factors
Creativity at 9 with		
Logic at 9 (ACE model)	rA=1 [-1, 1] rC=.46 [-0.25, 1] rE=.31 [.21, .38] rPH=.38[.33, .43]	A=.26 [-.17, .73] C=.31 [-.09, .66] E=.43 [.29, .59]
g at 9 (ACE model)	rA=.54 [.12, 1.00] rC=.27 [-.14, .86] rE=.01 [-.09, .12] rPH=.25[.19, .31]	A=.63 [.13, 1.00] C=.35 [.00, .78] E=.02 [.00, .17]
Motivation at 9 (AE model)	rA=.19 [.07, .31] rE=.18 [.09, .28] rPH=.19 [.13, .24]	A=.54 [.23, .78] E=.46 [.22, .77]
Writing at 9 (ACE model)	rA= .52 [.15, .93] rC= .38 [-1, 1] rE=.15 [.04, .25] rPH=0.34 [.28, .39]	A=.59 [.15, 1] C=.23 [.00, .61] E=.18 [.05, .31]
Writing at 12 (AE model)	rA=.40 [.26, .52] rE=.13 [-.03, .28] rPH=.29 [.22, .37]	A=.84 [.63, 1] E=.16 [.00,.37]
Writing at 16 (ACE model)	rA=.46 [.21, .77] rC=.56 [-.10, 1] rE=.13 [.03, .23] rPH=.37 [.31,.42]	A=.60 [.26, .97] C=.31 [.00, .62] E=.39 [.02, .17]

Note. A, additive genetic influence; C, shared environmental influence E, non-shared environmental influence; rA= additive genetic correlation; rC=common-shared environmental correlation; rE non-shared environmental correlation; rPH phenotypic correlation from the model best fitting model

Only results from the best fitting model are presented; the best fitting models are specified next to the variable names.

Discussion

The present study investigated creativity in relation to educational achievement, intelligence and motivation. Creativity, operationalised as a *Creative Expressiveness* score, based on written stories at age 9, was associated with tests of intelligence and self-reported motivation at the same age. *Creative Expressiveness* also explained variance in achievement in writing over and above intelligence and motivation, including longitudinally. Furthermore, the study indicated modest genetic and moderate environmental (shared and non-shared) influences on creativity in writing at age 9. The associations between creativity and other study variables were mainly mediated genetically.

As the present study shows, creative content in writing can be detected in primary education. As was reported in three previous studies, based partly on the same sample as the present study, a two-componential structure emerged among the ten story dimensions (Badini et al., 2018; Toivainen et al., 2017, 2018). Five dimensions (Liking, Novelty, Imagination, Emotion and Detail) loaded highly on the *Creative Expressiveness* component with creativity. This indicates that creativity in childhood storytelling is not a discriminant dimension. This makes sense conceptually. For example, imagination is regarded to be an element of creative childhood writing. Additionally, a reader is likely to view a text written by a child as creative if it is novel, filled with detail and has a strong emotional content. However, the finding of strong associations between creativity and other dimensions is different to the previous study which reported weak associations between the independently coded story dimensions (Hennessey & Amabile, 1988). The difference may be partly explained by different forms of data collection. In the previous study the stories were told orally by the children, whereas in the present study, the stories were handwritten.

Our measure of creativity, *Creative Expressiveness*, was positively associated with intelligence and motivation. This relationship has been widely reported within adult samples (e.g. Kim, 2005; Neves de Jesus et al., 2015). The present study has shown that these relationships are also evident in childhood, as are relationships between creativity and educational achievement. *Creative Expressiveness*, as well as *Logic*, intelligence and motivation were all associated with achievement in writing at age 9. However, the association between motivation at age 9 and educational achievement disappeared when investigated longitudinally in relation to achievement in writing at age 12 and English end-of school exam grade at age 16. The finding that writing motivation at 9 is not linked to achievement in writing at age 12 may suggest that writing differs from other literacy skills. For example, a study reported a correlation of r = .26 between reading motivation at age 9 and reading achievement at 12 (Malanchini et al., 2017). The different finding with the present study may be due to differences between reading and writing. Reading is more commonly practised, everyday skill in comparison to writing, which may be limited only to school hours among nine-year-olds.

The results showed that *Creative Expressiveness* at age 9 was a significant predictor of achievement in writing at ages 9 and 16, beyond intelligence, motivation, and prior achievement in writing. A smaller, non-significant, effect of creativity was found on achievement in writing at age 12. However, the results at age 9 did not account for any earlier grades that may have explained some of the variance in the achievement in writing at age 9. Effect sizes for creativity predicting achievement in writing at ages 9 and 16 were small (sr^2 = .02). The squared semi-partial correlation coefficient (sr^2) represents the unique amount of variance that the predictor variable brings to the model. However, the effect of Creative Expressiveness on English at age 16 was similar in magnitude to that of intelligence or achievement in writing, both measured at age 9 (both sr^2 = .03). The results indicate that creativity in childhood writing can be associated with educational achievement, even later in adolescence.

Establishing the positive associations between *Creative Expressiveness* and educational achievement at different points of education is important. Firstly, since creativity, intrinsic motivation and achievement are intertwined, undervaluing creativity and emphasising only technical aspects of writing, may decrease the motivation to write creatively and, consequently, writing in general. Secondly, National Curriculum criteria differ at different ages, as indicated by the predictive value of creativity: creativity was associated with achievement in writing at age 16 even when accounted for earlier achievement in writing at ages 9 and 12. This highlights the fact that a set of skills, relevant for specific educational subjects, may not be equally taught/emphasised across school years. Technical skills are valued from the early school years onwards, but creative expressiveness in writing may be emphasised only some years later. It is understandable that in the early school years emphasis is often placed on developing basic writing and reading skills. However, this does not have to be at the expense of encouraging creative expressiveness in writing.

Genetically sensitive analyses were run to investigate the proportion of variance explained by genetic and environmental factors in *Creative Expressiveness*. Univariate analysis showed that 35% of the variance in *Creative Expressiveness* is explained by genetic factors; with 20% attributable to shared and 45% to non-shared environments. The proportion of genetic influences in the present study is somewhat lower in comparison to previous twin studies on creativity (e.g. 42% in Vinkhuyzen et al., 2009; and 70% in Roeling et al., 2017). However, these previous studies utilised different creativity measures and (mostly) adult samples.

Interestingly, the variation in the Logic component score showed negligible genetic effects. In comparison, a previous study, also based on the TEDS sample, when the twins were 4.5 years old, showed that genetic influences explained 29% of the variance, shared environmental 26% and non-shared environmental 45% in a grammar score (Kovas et al., 2006). The grammar score in the previous study was based on a cognitive test, whereas in the present study it was evaluated subjectively in comparison to the other stories. However, it should be noted that the confidence intervals were wide for the study, based on the sample of 4.5-years-olds, which is common with cognitive measures among young children. However, the result of negligible genetic effects in this study are likely to be due to large error margins due to lower interrater reliabilities among Logic and Straightforwardness dimensions. These judgments, together with the Grammar dimension, formed the Logic factor score. This is further supported by the fact that the non-shared environmental estimate (which includes measurement error) was the highest of all study measures.

Genetic investigation of the sources of co-variance between the measures, utilising multivariate genetic analyses, showed that a large proportion of all phenotypic correlations is mediated genetically. Genetic influences explained 26% to 84% of the co-variance between creativity and other study measures. This finding is in line with previous findings that differences between children in many educationally relevant constructs are partly influenced by the same genetic effects (Plomin & Kovas, 2005).

The results of the present study indicate that creativity can be detected already in childhood writing. Furthermore, creativity plays a role in educational achievement, albeit with a small effect. Currently creativity in primary education, for example the creative content of childhood writing, may be undervalued. The somewhat low heritability of creativity at age 9 may reflect the lack of creativity promoting environments that enable opportunities of genetic potential to be expressed. This conclusion is in line with the sociocultural approach to creativity which emphasises the relevance of social context for creativity. However, it is important that first creativity is recognised and encouraged early in primary education, since it may guide students' education, and by extension, professional trajectories.

7 Conclusions

This thesis took an explorative approach to address questions about the measurement, structure, aetiology and prediction of creativity, at the level of the individual. The empirical studies presented in this thesis were not based on a single theory but incorporated various theoretical approaches which have also guided the operationalisation of many commonly used creativity measures. Several of these measures were also used in the studies which are presented in this thesis. The findings of these studies suggest the following main conclusions:

(1) Creativity is not a unitary construct.

(2) As such, there is no single measure for general creativity.

(3) Openness to Experience is the most robust personality predictor of creativity.

(4) Creative content can already be detected in childhood writing.

(5) Individual differences creative childhood writing is influenced by both genes and environments, with a substantial proportion attributable to shared environmental influences.

The new knowledge reported in this thesis has implications for research and can inform how dimensions of creativity might be measured and/or applied in areas such as education and employment. The following sections provide an analysis of these findings and of the implications to educational and work contexts. The chapter also discusses limitations and future directions for research.

Creativity is not a unitary construct

Research findings in this thesis supported the view that creativity is not a unitary structure. Chapter 2 identified that the variance based on thirteen creativity measures was distributed over six latent components. No principal component of general creativity, which would have captured a large proportion of the variance, was found among the measures. This finding could be partly related to the different approaches that are used to conceptualise creativity. Multidimensional structures emerged from the data that were collected with different measures, some of which tapped into specific cognitive processes (cognitive approach) whereas others were based on sociocultural conceptions of creativity (such as the behavioural inventories). This finding may indicate that until there is a more holistic theoretical basis of creativity, which incorporates different theoretical approaches, the empirical evidence will only be able to demonstrate that creativity is a non-unitary construct.

The non-unitary structure of creativity differs from that of intelligence, which has a hierarchical structure. The positive associations between the lower tier subcomponents are maintained by a latent *g* factor. It could be argued that to a certain extent, the structure of creativity is more similar to personality than it is to intelligence. Both personality and creativity cover diverse dimensions which are weakly associated, if related at all (i.e. the Big-5 personality traits are broadly unrelated). This is the case with many creativity measures (e.g. divergent thinking and creative self-efficacy). Due to unrelated dimensions covered by terms personality and creativity, they are not useful alone, for example, to be used as a basis of predictions. For any application of information relate to these constructs, they need to be specified with more detailed terms – as a personality trait or a dimension of creativity.

Potential indications of non-unitary structure were also indicated by the findings, presented in Chapter 3. The analyses showed only moderate associations between visual and linguistic forms of a same creativity measure, the Remote Associates Test. This suggests that the ability to make remote associations may also depend on individual differences in visual and linguistic skills. It could be that the commonly used linguistic version of the measure, is only tapping into a limited view of associative processing and should not therefore be interpreted as a proxy for an underlying creativity construct.

The multivariate genetic analyses, presented in Chapter 5, provided insight into the genetic architecture of creativity. The bivariate genetic and environmental correlations showed the proportion the phenotypic correlation that can be attributed to the shared genetic, shared and nonshared environmental influences. High bivariate genetic correlations were found between creativity and educational achievement as well as with creativity and intelligence. This means that the association between childhood creativity and intelligence is mainly influenced by the same set of genes. This was indicated by multivariate genetic analyses which showed that the main proportion of the phenotypic correlation was maintained by shared genetic effects between creativity and intelligence. This finding is another indication that creativity is intertwined with other measures, not a separate construct. It appears that intelligence is associated strongly with creative content in writing in childhood, not only phenotypically but also genetically.

Two alternative hypotheses could explain the lack of unitary structure underlying creativity. First, creativity could be a multidimensional construct with loosely associated dimensions (similar to personality). The dimensions captured by this multidimensional structure could include some creativity specific processes (e.g ability to come up with original ideas), but which the current research is still not able to detect and specify in sufficient detail. Additionally, it could be that psychometric measures and cross-sectional, quantitative analytical methods are not suitable to establish these relationships. For example, dimensions of creativity that have been studied cross-sectionally in this thesis may take place longitudinally, but at different times as part of a same process. Second alternative could be that creativity is not a construct at all, but an outcome of various already known cognitive, personality and environmental attributes. Creativity may only be an umbrella term for a collection of heterogenious processes, most of which are captured by other domains of cognition and personality. This, perhaps a more radical hypothesis, would require us to re-evaluate the use of creativity term, especially in research context.

This inconclusive evidence on the structure of creativity, whether it might be multidimensional or can even be considered a construct at all, is also reflected in the terminology in relation to creativity. Throughout the thesis, I have described various attributes and processes related to creativity as dimensions and aspects. However, as more research and critical evaluation on creativity accumulates, it may become evident these are not appropriate ways of describing creativity. This diversity on the views on the underlying structure, or the lack thereof, also guides the operationalisation of creativity measurement and hence plays a role on what creativity research is focused on. This was also a further focus of research presented in this thesis.

There is no single measure for general creativity

As creativity has a non-unitary structure it must follow that there cannot be a single measure for general creativity. A range of measures was covered in the empirical research presented in this thesis. As indicated by the results of Chapter 2, the measures are not comparable as they seem to measure different dimensions of creativity or perhaps even different constructs entirely. As an example, two measures of creative cognition, the Alternative Uses Task and Remote Associates Test, which are measures of creative cognition, showed negligible associations. However, this is not surprising since one of them is based on fluency to think about different uses for an object, the other is asking the participants to think of a single word that creates compound words with three other words. Additionally, as shown by the results in Chapter 3, similar measures, based on different forms of stimuli (linguistic vs. visual) are not perfectly overlapping but only moderately correlated. The poor intercorrelations with various creativity indicators demonstrates that they cannot be used to estimate the same construct. This variety of measures proposes difficulties to comparisons of research findings. As reviewed in

Chapter 5, the diversity in creativity indicators is one factor that makes the comparisons of twin studies difficult.

Research on the use of new measures, such as the study on the newly developed version of the Remote Associates Test (RAT) presented in Chapter 3, may provide more accurate tools that are better when used in applied settings. The creation of precise and valid instruments will increase the predictive validity of the measures. For example, without any visual RAT measures, no research can be done to compare similar processes based different forms of stimuli. The development and initial uses of the visual version of the RAT has also emphasised the problems that the commonly used compound version of the RAT (cRAT) has proposed. It could be that the cRAT is not necessarily a measure of semantic associations, but of memory on linguistic structures. However, the cRAT has been the main choice of associative ability measures in creativity research. This is likely to be due to convention and substantial normative research of a long list of items to be used in measurement.

Openness to Experience is the most robust personality predictor of creativity

The investigation of the relationships between personality, intelligence and creativity, presented in Chapter 5, support the view that individual personality and intelligence predictors, overall, have similar associations to many creativity dimensions. None of the personality and cognitive ability measures showed great discrepancies in their associations to 8 creativity measures. For example, all personality and intelligence predictors were either positively or negatively associated with the creativity measures (or not associated at all). Out of all measures, and replicating previous findings, Openness to Experience showed the strongest associations with all 8 creativity measures.

The finding from previous research that intelligence is more strongly associated with scientific creativity and Openness to Experience with artistic creativity was not found in the study presented in Chapter 4. The results showed that the predictive power of Openness to Experience and intelligence in relation to creativity was similar in two samples of adolescents with high academic achievements in different areas (Science and Art & Literature). This is likely for two reasons. First, previous research has reported the results from adult rather than adolescent samples. Second, in previous research, the outcomes were creative achievements in Science and Arts rather than self-assessments of creative behaviours or measures of creative cognition as used in the present study. Replication of this study with a new cohort should provide further clarification on the validity of the results.

One explanation of the robust relationship of Openness to Experience to many aspects of creativity is that they are partly tapping into the same construct. Some items, in both personality inventories and creativity measures, are very similar. For example, an item 'I am good at coming up with new ideas' is included in both measures of Openness to Experience and creative self-efficacy. However, it must be emphasised that the ability of coming up with ideas is not the same as generating original ideas. As shown by the findings in Chapter 4, Openness to Experience was also associated with originality of ideas not only to the number of generated ideas.

Creative content can already be detected in childhood writing

As concluded above, there are various measures to tap into different dimensions of creativity. As described in Chapter 6, the Consensual Assessment Technique provides another method to evaluate creativity, based on creative products, such as childhood writing. As shown by the results, independent judges agree which stories were creative and which were not. However, creativity was not a stand-alone dimension of the stories but strongly associated other dimensions, such as imaginative and emotional content. The information of the dimensions associated with creativity may provide guidance how to encourage creative writing among children. For example, to make more creative stories, they should engage with their imagination and add some emotional content to the stories. Furthermore, the results showed that the creativity score, based on the stories, explained a small amount of variance in achievement in writing longitudinally beyond intelligence and motivation. Even if the effect size was small, this may suggest that creative content in writing is not captured by the writing assessments in earlier school years.

The evaluation of creative content already in childhood writing is important. It may be that creative writing ability is currently overlooked, especially in formal educational assessment and that expressive, creative writing is more integrated in the assessment criteria only in later school years. However, it is a skill that can be detected and honed much earlier. Also, if technical skills are overemphasised in comparison to creative storytelling abilities it may divert the interest of some children who may excel with creative aspects of writing but are not yet strong with their grammar and punctuation.

Creative content in childhood writing is influenced by both genes and environment with a substantial proportion attributed to shared environmental influences.

The study presented in Chapter 6 was the first adequately powered genetically informative analysis on any dimension of childhood creativity. This method provided new insights into the role of genes and environments in the development of creativity. The Creative Expressiveness score, a compilation score of several story features, was based on written stories by nine-year-old children. The results showed that genetic effects explained a third, shared environmental influences a fifth, and nonshared environmental influences almost a half of the total variance in creativity in childhood writing. This finding provides new information on the development of creativity, since previous twin studies on creativity have focused mainly on adult samples. The finding is similar to those of many other cognitive measures, such as intelligence; i.e. that shared environmental influences tend to play a role in the developmental stages but that these diminish in adulthood. This trend could be due to the fact that as getting older and gain more autonomy, children seek environments that are better suited for their genetic propensities, also in relation to creative activities.

As the result from the multivariate genetics analyses in Chapter 6 showed, the phenotypic associations between creativity, educational achievement and intelligence were largely explained by shared genetic influences. This finding of genetic mediation of phenotypic associations is in line with previous literature on associations among educationally relevant traits (Plomin & Kovas, 2005). As proposed by the Generalist Genes hypothesis, the same set of generalist genes have a strong influence on diverse cognitive abilities (Kovas & Plomin, 2006). The findings of this chapter support the conclusion that also childhood creativity, measured as creative content in writing, is likely to be influenced by these same generalist genes.

Educational implications

The research findings presented in this thesis have several potential implications for educational practice. The first suggestion, based on the conclusion that creativity is a non-unitary structure, is that individuals and educational organisations must specify specific interests when aiming to discuss, investigate or enhance creativity. This is often lacking when strategic goals are set, ignoring the fact that the meaning and operationalisation of creativity differ widely. As concluded earlier, there is no single, valid measure that can serve as a proxy for creativity (as, for example, Raven's progressive matrices for intelligence). The non-unitary structure also has important implications for any interventions that may be planned to enhance creativity. Different interventions would be needed to achieve improvements in different areas: idea fluency; creative problem-solving; creative self-efficacy; or creative group performance based on each individual's personality characteristics. For example, when designing creativity interventions and evaluating their efficacy, it is necessary to identify which creativity-specific skills and abilities are targeted - completely different approaches may be needed to enhance cognitive problem-solving skills vs. creative self-efficacy. An intervention aimed to enhance creative cognition may be very different to one targeting divergent thinking. The former might encourage open ended responses, the latter remote associations. Consequently, conceptualising creativity as non-unitary means that comparisons should be avoided across studies that operationalise creativity differently. However, the non-unitary structure of creativity may be the very thing that allows for specific, targeted and effective interventions to be developed.

Further knowledge on individual differences in different aspects of creativity will inform creative learning and creative teaching, which are commonly used terms in educational literature (Kovas & Plomin, 2006). For example, one area that could benefit from research on creativity is the transference of Art & Design teaching practises to Science, Technology, Engineering and Mathematics subject (STEM to STEAM) - in order to increase creative skills (Connor et al., 2015). Some research in this field has shown that artistic teaching methods can, for example, increase trial-and-error exploration among coding students that also have a positive impact of educational achievement (Yee-King et al., 2017). Further research, including the development of creativity measures, will be beneficial for the evaluation of educational practises aimed at enhancing creativity.

Other educational interventions could be based on the finding that creative content in children's writing can already be detected in primary school. Creative expressiveness in writing is associated with other educationally relevant constructs concurrently and longitudinally. Creativity at this age is often not recognised, at least not formally. However, the findings of the thesis suggest that creativity accounts for additional variance in English end-of-school grades, beyond that accounted for by previous grades. The emergence two factors, *Logic* and *Creative Expressiveness*, could mean that at least some children, who are 'grammatical writers' at age 9, would be more rewarded (e.g. by feedback and grades) than 'creative writers'. This finding suggests that more emphasis should be placed on acknowledging various aspects of creative behaviours in early childhood. For example, curricular that are focused on technical, skill-based writing in young children may disengage young creative storytellers. Striking the balance, between the technical skills and creative content in writing, may not be easy. However, since creative content is emphasised in later school years, the development of this ability should start early on.

The results from the genetically informative analyses also provide educational implications. Understanding that individual differences in creativity emerge due to genetic and environmental factors that are partly overlapping with other educational traits, dismantles the myth that some people are 'born creative'. The findings also suggest that current educational environments, especially in primary education, may not be adequately tailored to the needs of children's individual creative capabilities. This may be indicated by the somewhat low heritability of creativity at age 9. This low heritability may result from the lack of creativity promoting environments that enable opportunities of genetic potential to be expressed. Tailoring the environments to correspond to individual differences depends on identifying creative capabilities at an early age.

The findings of this thesis also have implications outside of education. Creativity is in-demand in many businesses. Individual differences in many aspects of creativity are important when employers seek out those who have the attitude, ability, skill and motivation required for a particular post. Additionally, many organisations are interested in how to improve creative idea production of their employees. However, to understand the processes better, creativity researchers need to investigate factors related to idea formation and articulation, as well as which environmental factors (if any) may support or hinder these processes (Glăveanu, 2013). However, as previously noted, outcomes need to be clearly defined.

Limitations

The studies presented in this thesis had limitations. One limitation was the differences in measures which reduced the comparability between samples. Similarly, the differences between samples, especially cross-culturally, were also limiting factors when it comes to making substantial claims. The unequal gender split in the studies reported in this thesis (more females than males) is another potential limitation. Not necessarily because of gender differences in creativity, but because this may reflect bias in the data collection. These are issues that will be carefully considered in extensions of the work presented in this thesis.

Also, some measures that were included in testing were not very detailed in their instructions. For example, several measures of creativity are based on subjective assessment without clear definition of what aspects the terms cover. This may be problematic for self-rated creativity measures in specific domains. For example, participants asked to rate their scientific 'creativity' may conflate this with other aspects such as their interest in science or skill to carry out scientific experiments. Further research is needed to investigate these potential issues.

Another problem, common for many open-ended measures, was the subjective and labour-intensive nature of coding the correct answers for the Alternative Uses Test and the semantic items for the Remote Associates Test. Stringent evaluations were applied to minimise errors and improve inter-rater reliabilities. Acknowledging the limitations in relation to the research presented here, will guide the direction for my future research.

Future directions

The research presented in this thesis has posed as many questions as it has answered. Fortunately, the large datasets, which I have collected, processed and managed throughout my PhD will enable several further questions to be addressed. I am therefore planning to create a small team of students to help with my postdoctoral research. As a first step to further clarifying the construct and nature of 'creativities' I plan to explore mediation and moderation links across various measures of individual differences.

Development of novel measures will be one interesting avenue to address in my future work: to create new, more ecologically valid measures, perhaps using new technological platforms, with validation in various samples. The research on validating a new measure of visual associative ability, presented in Chapter 3, is a research direction that I will explore further.

Another topic, based on the research presented in this thesis, which I am planning to investigate further, is creative content in children's writing. I am also planning to expand the genetic analyses to include molecular genetic methods, particularly exploring existing polygenic risk scores for educational and other phenotypes in relation to creativity measures. I also plan to explore the stories in more detail with semantic analytic software. For example, to explore what kind of linguistic features are associated with creative writing in childhood.

As indicated in limitations, exploring gender differences further will be another interesting research direction. Further research on creativity among developmental samples, will help to understand if the observed gender difference in creative writing in childhood, as reported in Chapter 6, is related to gender differences in writing skills at this age or if they could be an indication of differences in creative thinking.

Based on the increased knowledge and research findings from the PhD research, my aim is to widen the scope of research questions, in relation to creativity, to also include *how*, not just *what* and *why*. One way to pursue this avenue would be to investigate processes playing a role in different aspects of creativity, and ways to potentially influence them. For example, how do creative activities turn into achievements? Or, what interventions, if any, could be beneficial for creative thinking? In working towards these goals, I am looking forward to exploring new avenues of psychological research, particularly neuroscientific and social processing paradigms. During my PhD research, I have also created international research collaborations which I am planning to continue when moving on into my postdoctoral research.

Overall conclusion

Most people have views and opinions on creativity. Scientific research on individual differences of creativity aims to provide reliable knowledge to support or update such opinions. The role of research findings, including those produced as part of my PhD research, is especially important when planning and executing effective interventions and policies. As emphasised in this thesis, individuals and organisations need to think about what aspect of creativity to focus on – for example, should it be divergent thinking or associative ability; creative self-efficacy or skills to produce socially recognised creative products? The differentiation is important: the evidence in this thesis, coupled with a review of the literature, suggests that creativity may only be a culturally maintained semantic category: a collection of unrelated behaviours and characteristics. However, the absence of evidence is not evidence of absence and therefore more empirical work is needed in this area.

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Appendices

Appendix 1. items, responses and reaction times for Russian and Finnish linguistic RAT.

Russian RAT items					
Item	Stimuli	Response	Correct answers (n = 67)	Mean RT and sd in seconds for correct answers	Mean RT and sd in seconds for all answers
Training 1	**громкая, правда, медленно**	Говорить			
Training 2	**холодная, зелень, мутная**	Вода			
1.	**прошлое, море, друзья**	Вспомнить	19	25.50 (28.1)	24.99 (30.5)
2.	**зоркий, ресница, стеклянный**	Глаз	60	13.71 (19.4)	12.68 (18.6)
3.	**свежая, английская, новости**	Газета	51	11.80 (18.0)	13.42 (18.3)
4.	**кино, экзамен, проездной**	Билет	52	12.72 (13.4)	16.85 (19.3)
5.	**комната, положение, река**	Войти	4	34.82 (25.8)	52.44 (69.0)
6.	**трудное, истекло, золото**	Время	57	10.59 (7.9)	11.99 (95.6)
7.	**мундир, городок, билет**	Военный	33	27.90 (42.4)	28.50 (35.5)
8.	**неожиданно, человек, улица**	Встреча	45	18.78 (21.8)	21.10 (22.3)
9.	**холодная, дым, жестокая**	Война	19	30.20 (54.6)	34.17 (39.4)
10.	**умная, косы, свежая**	Голова	25	33.33 (44.5)	32.44 (39.8)
11.	**прошлый, время, трудный**	Год	61	18.45 (17.9)	18.33 (17.9)
12.	**дедушка, очки, добрая**	Бабушка	40	20.23 (24.5)	23.61 (29.7)
13.	**долго, вечер, друзья**	Ждать	36	24.74 (29.1)	24.92 (32.3)
14.	**плохо, глаза, море**	Видеть	16	21.03 (13.6)	25.69 (31.3)
15.	**слон, дом, великан**	Большой	40	23.14 (61.3)	22.73 (48.9)
16.	**навсегда, домой, назад**	вернуться	37	22.48 (27.1)	19.22 (21.3)
17.	**случайная, горы, долгожданная**	Встреча	36	16.57 (16.9)	22.77 (28.9)
18.	**вечерняя, бумага, стенная**	Газета	47	18.09 (30.2)	22.08 (30.8)
19.	**обратно, родина, путь**	Вернуться	26	12.61 (7.1)	15.02 (13.5)
20.	**далеко, слепой, будущее**	Смотреть	23	19.80 (22.0)	30.21 (35.2)
21.	**народная, страх, мировая**	Война	61	12.95 (15.6)	14.41 (17.9)
22.	**деньги, билет, свободное**	Время	20	25.58 (24.0)	18.57 (18.5)
23.	**человек, погоны, завод**	Военный	25	21.20 (15.0)	25.56 (22.3)
24.	**дверь, доверие, быстро**	Войти	6	13.36 (6.0)	35.16 (33.1)
25.	**друг, город, круг**	Родной	25	22.41 (14.2)	37.05 (37.9)
26.	**поезд, купить, бумажный**	Билет	63	9.49 (5.4)	9.41 (55.2)
27.	**цвет, заяц, сахар**	Белый	52	13.96 (18.2)	14.84 (18.0)
28.	**ласковая, морщины, сказка**	Бабушка	58	12.04 (9.3)	16.80 (33.7)
29.	**детство, случай, хорошее**	Настроение	29	22.09 (45.3)	35.88 (60.7)
30.	**воздух, быстрая, свежая**	Струя	24	26.26 (24.0)	29.05 (32.5)
31.	**певец, Америка, тонкий**	Голос	34	30.46 (35.1)	42.42 (51.3)
32.	**тяжелый, рожденье, урожайный**	Год	59	15.10 (16.5)	15.92 (17.1)
33.	**много, чепуха, прямо**	Говорить	37	14.05 (10.3)	16.75 (15.3)
34.	**кривой, очки, острый**	глаз	38	17.86 (17.5)	21.97 (36.5)
35.	**садовая, мозг, пустая**	Голова	34	15.04 (13.9)	29.53 (34.1)
36.	**гость, случайно, вокзал**	встреча	37	22.75 (26.5)	27.64 (33.7)
37.	**Броня, пуля, дыра**	Бронебойный	27	18.79 (14.4)	21.54 (20.6)
38.	**Вода, течь, высота**	Водопад	50	15.69 (21.9)	22.52 (39.8)
39.	**Вода, дыра, кружить**	Водоворот	48	24.05 (37.5)	22.96 (32.4)
40.	**Птица, крутить, шея**	Вертишейка	1	8.76 (0.0)	24.15 (25.4)
41.	**Птица, нести, весть**	Буревестник	31	21.64 (34.4)	24.32 (35.1)
42.	**Собака, охота, волк**	Волкодав	19	29.21 (33.7)	27.90 (26.4)
43.	**Летать, винт, пассажир**	Вертолет	64	10.25 (7.3)	10.56 (77.5)
44.	**Мерить, насекомое, вода**	Водомерка	38	15.83 (20.9)	32.38 (49.4)
45.	**Дождь, календарный, растущий**	Месяц	24	28.82 (24.0)	32.47 (30.7)
46.	**День, заяц, цвет**	Серый	44	15.25 (21.8)	16.17 (18.7)
47.	**Невеста, жених, кольцо**	Свадьба	62	9.43 (8.5)	11.48 (18.4)
48.	**Подсолнух, солнце, масло**	Цветок	43	17.38 (23.0)	18.08 (20.3)

Finnish RAT items					
Item	Stimuli	Response	Correct answers (n = 67)	Mean RT in seconds and sd for correct answers	Mean RT in seconds and sd for all answers
Training 1	**Kauppa, hylly, paino**	Kirja			
Training 2	**Nyrkki, tie, vohveli**	rauta			
1.	**Alue, haju, sänky**	vesi	21	32.45 (32.49)	46.37 (45.4)
2.	**Apulainen, vaali, käännös**	toimisto	14	50.66 (58.96)	41.62 (40.9)
3.	**Asfaltti, koti, pako**	tie	41	13.85 (11.04)	22.38 (26.6)
4.	**Asia, lyhty, ruutu**	paperi	12	54.79 (27.60)	61.71 (70.2)
5.	**Etä, kauppa, paikka**	kauppa	51	11.08 (6.59)	17.68 (18.9)
6.	**hanhi, hätä, hirviö**	meri	17	41.89 (42.86)	57.05 (65.5)
7.	**Harja, vuode, suoja**	vaate	18	30.08 (27.11)	33.86 (31.2)
8.	**henkilö, paikka, vero**	auto	37	19.55 (11.92)	24.86 (21.3)
9.	**Ikkuna, tiili, väli**	katto	13	40.11 (43.97)	29.54 (31.5)
10.	**Juhla, voitto, kaari**	riemu	19	41.53 (48.00)	55.32 (63.2)
11.	**Kala, avio, arpa**	onni	45	14.73 (11.24)	20.30 (17.6)
12.	**Kasa, koulu, esine**	puu	6	86.4 (85.5)	68.44 (65.9)
13.	**Käsittely, vero, sosiaali**	virasto	16	21.96 (13.84)	26.86 (19.3)
14.	**Kastike, joki, soija**	kauha	3	54.49 (34.27)	54.99 (50.6)
15.	**Kauha, hiutale, riisi**	puuro	59	14.62 (14.57)	17.15 (16.9)
16.	**Kaula, sukellus, heiluri**	Kello	35	19.92 (17.38)	28.21 (28.1)
17.	**Kauppa, tie, kalastaja**	Kylä	15	40.37 (47.77)	45.48 (50.7)
18.	**Kerros, vesi, pinna**	sänky	61	13.37 (8.48)	14.05 (8.4)
19.	**Kone, kello, aika**	peli	18	62.57 (70.80)	54.51 (55.1)
20.	**Kukka, tori, tiede**	kauppa	41	33.62 (38.96)	33.62 (38.7)
21.	**Kuoro, viini, alku**	kirkko	11	41.11 (40.4)	49.35 (53.7)
22.	**Laukku, nahka, turva**	vyö	23	50.03 (74.39)	58.98 (83.1)
23.	**Lehti, vene, aitta**	puu	42	26.28 (28.1)	36.65 (44.5)
24.	**Leike, väli, paino**	lehti	21	34.77 (28.9)	33.22 (32.4)
25.	**Leikki, puhelin, ryhmä**	seksi	9	57.23 (60.4)	41.39 (41.0)
26.	**Lukko, aisti, herne**	haju	45	25.13 (23.82)	32.88 (27.2)
27.	**Metsä, vara, kunto**	Mies	11	62.02 (103.12)	49.96 (56.9)
28.	**Mieli, kunta, tuomio**	valta	10	50.45 (39.25)	64.70 (62.4)
29.	**Mini, kahvi, jakkara**	baari	13	42.85 (47.29)	57.94 (54.0)
30.	**Muisti, synti, viini**	Lista	9	52.18 (55.61)	61.23 (51.7)
31.	**Pää, lista, öljy**	ruoka	12	58.30 (63.07)	50.16 (49.3)
32.	**Paisti, aamu, sokeri**	pala	53	19.94 (21.48)	25.96 (27.2)
33.	**Pelto, sämpylä, lese**	Vehnä	61	17.07 (15.53)	17.34 (15.0)
34.	**Poika, adoptio, ihme**	lapsi	54	13.67 (12.09)	17.67 (24.9)
35.	**Ravintola, kaula, veto**	ketju	26	37.55 (77.62)	52.71 (72.9)
36.	**Rotu, kesä, kolli**	kissa	66	12.00 (15.08)	12.11 (14.9)
37.	**Rotu, kesä, kolli**	pöytä	46	21.02 (25.98)	20.83 (23.1)
38.	**Sali, kevät, suku**	juhla	63	14.83 (15.36)	15.00 (15.2)
39.	**Sarja, kulta, veto**	ketju	18	25.78 (21.91)	38.93 (34.5)
40.	**Sarja, palvelu, hätä**	numero	40	14.42 (9.41)	21.31 (18.5)
41.	**Tentti, velka, kirja**	kirja	45	23.47 (39.21)	26.91 (38.1)
42.	**Tölkki, hana, makkara**	olut	55	20.16 (22.98)	26.13 (32.0)
43.	**Vanki, salama, sota**	sota	10	55.91 (36.7)	68.46 (64.2)
44.	**Verho, lippu, juoppo**	tanko	51	16.43 (16.51)	25.73 (32.6)
45.	**Vesi, kunto, apu**	Pyörä	18	49.82 (65.75)	33.32 (39.0)
46.	**Vyö, kaali, joulu**	ruusu	40	21.86 (30.80)	33.15 (39.5)
47.	**Yhdys, vuoro, tunnus**	sana	55	10.81 (84.5)	13.07 (10.5)

Appendix 2. Pilot Study 1: Creative storytelling in childhood is related to exam performance at age 16.

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CREATIVE STORYTELLING IN CHILDHOOD IS RELATED TO EXAM PERFORMANCE AT AGE 16

Teemu Toivainen (a), Margherita Malanchini (b), Bonamy R. Oliver (c), Yulia Kovas (d)*
*Corresponding author

(a) Department of Psychology, Goldsmiths, University of London, UK
(b) Department of Psychology, Population Research Center, University of Texas at Austin, U.S. & Social, Genetic and Developmental Psychiatry Centre, King's College, London, UK
(c) Department of Psychology, Goldsmiths, University of London, UK
(d) Department of Psychology, Goldsmiths, University of London, UK; Department of Psychology, Goldsmiths, University of London, UK; Tomsk State University, Tomsk, Russia, e-mail: y.kovac@gold.ac.uk

Abstract

Creativity is only partly recognised in education. A recent meta-analysis estimated a correlation of r = 0.22 between creativity and educational achievement across many international student samples of all educational levels. In the meta-analysis, creativity was measured with a variety of measures, including divergent thinking and remote association tasks. The differences in the measures influenced the strength of the relationship between creativity and educational achievement. More research is needed to establish reliable measures of creativity, especially in primary school children, whose creativity remains poorly evaluated. The present study measured creativity in written stories in children at age 9 using the Consensual Assessment Technique (CAT). The study employed a longitudinal design, using CAT creativity scores as a predictor of educational achievement at age 16. Each of the stories from 59 children were coded by 6 different judges for 10 dimensions, including creativity. The inter-rater reliabilities between the judges for the 10 dimensions were high (α = .76 - .95). Among the dimensions, a factor analysis revealed two factors: Creative Expressiveness and

Logic. The Creative Expressiveness factor explained an additional 7 % of variance in English grades, but not in Maths, beyond intelligence, previous achievement and personality traits associated with creativity. Overall, the study showed that CAT is a robust and reliable measure to detect verbal creativity in childhood. The results also suggest that early creativity predicts later academic achievement, calling for more attention to early creativity assessment and development.

Keywords: Creativity, education, writing, Consensual Assessment Technique

1. Introduction

Creativity has positive associations in contemporary societies. For example, creativity is essential for new ideas and innovations in business, and it is regarded as a central facet in art and design. In recent decades, the role of creativity has also been emphasised in the educational discourse (Craft, 2003). For example, recognition of creativity is listed as one of the aims of the National Curriculum in England (Department of Education, 1994).

Creative idea production is recognised as being an outcome of both divergent and convergent thinking (e.g. Cropley, 2006). However, the education system in the UK emphasises convergent thinking skills (Wilson, 2014). Convergent thinking is characterised by having one correct solution to a clearly defined problem (Guilford, 1957). Most cognitive ability tests, as well as many exams in primary education, measure convergent thinking skills (Chamorro-Premuzic & Reichenbacher, 2008; Cropley, 1967). In contrast, divergent thinking tests have dominated the field of creativity assessment for decades (Runco & Acar, 2012). Divergent thinking involves producing multiple answers or alternative answers from available information, as well as making unexpected combinations, remote associations and transforming information (Cropley, 2006). Divergent thinking is associated with exploratory learning style (Dirkes, 1978). For example, Montessori schools emphasise creative learning through activities based on imagination (Besançon & Lubart, 2008). Research has also highlighted the teachers' role as facilitators of creative learning (Jeffrey, 2006). However, more research is needed in order to establish the ideal circumstances in education for creativity to flourish.

The assessment or evaluation of creativity in education is not easy, since there are many different ways to define creativity (Plucker, Beghetto & Dow, 2004). This problem was demonstrated in a recent meta-analysis on creativity and educational achievement. The meta-analysis concluded that the differences between studies in which creativity measures were used were reflected in differences across the studies in the strength of associations between creativity and educational achievement (Gajda, Karwowski & Beghetto, 2016). In other words, different creativity measures do not correlate highly among themselves, tapping into largely different aspects of creativity. The combined, overall effect size for all different creativity measures and educational achievement in the meta-analysis was r = .2 (Gajda et al., 2016).

The creativity measures used in the meta-analysis included self-evaluations of one's own creativity, frequency of taking part to creative activities, divergent thinking and insight tasks (Gajda et al., 2016). Insight tasks present participants with unusual problems that require an alternative, new way of addressing a problem. Arriving at the solution of an insight task is associated with a sudden and clear solution through insight, the 'A-ha' or 'Eureka' moment (Bowden et al., 2005). Insight tasks correlate poorly with other creativity measures (e.g. divergent thinking and behavioural measures), and they are conceptually very similar to many convergent thinking tasks (Beaty, Nusbaum, & Silvia, 2014). The most commonly used divergent thinking task is the Alternative Uses Task, such as the Torrance tests of Creative Thinking (Torrance, Ball, & Safter, 2003). These tasks require participants to come up with alternative uses to a shown object, such as brick or newspaper. These tasks typically require external, subjective evaluations to score the answers based on their creativity. The Torrance Tests may measure divergent thinking ability in certain specific domains, but they should not be interpreted as measures of creativity in general (Baer, 2011). As the score is based on frequency of the answers, it can be considered a measure of verbal fluency, not necessarily of creativity (Silvia et al., 2008). Overall, divergent thinking tasks measure only a very limited aspect of creativity, and therefore their relevance in education has been questioned (Barbot, Besancon, & Lubart, 2015; Zeng, Proctor, & Salvendy, 2011).

In addition to the measures of creativity as an individual's ability or potential (e.g. self-evaluations, divergent thinking and insight tasks), creativity can also be measured in a product, such as creativity of a novel. Assessing creativity of a product instead of focusing on individual's ability or potential may be particularly applicable in education (Barbot, Besancon, & Lubart, 2015). Creative outcome, such as a short story or picture, is not only a product of creative potential but also reflects other factors, such as intrinsic motivation and domain-specific skills (Amabile, 1983).

2. Problem Statement

Previous research on the relationship between creativity and educational achievement has focused on creative potential measures, namely divergent thinking (see meta-analysis, Gajda et al., 2016). Creative potential measures assess individual's ability, not creative behaviours or outcomes. This study will use Consensual Assessment Technique (CAT; Amabile, 1982) to estimate the creativity of a product, namely written stories. The use of CAT to evaluate creativity in written texts has demonstrated high inter-rater reliability in a previous study (Baer, Kaufman, & Gentile, 2004). Most of the previous studies on creativity and education have applied a cross-sectional design. The longitudinal nature of the current study is a particular strength. The availability of diverse measures in our study sample also allows us to investigate the role of creativity in educational achievement in addition to intelligence and personality. Also, the stories were written at children's homes, not in the school environment, which may influence the creative expressiveness in the stories.

3. Research Questions

1. Can CAT be used as a method to estimate creativity in children's written stories at age 9?

2. Does story creativity at age 9 predict educational achievement in English, and/or in Maths at age 16 over intelligence, previous school achievement and personality measures associated with creativity?

4. Purpose of the Study

This study will add incremental knowledge on the use of CAT to evaluate creativity in written children's stories. Furthermore, this study will investigate whether creativity in writing can already be detected in primary school and whether it relates to further educational achievement.

5. Research Methods

5.1. Sample

A randomly selected subsample of 60 twins from the Twins Early Development Study (TEDS) was used in this study. TEDS is a large, longitudinal twin sample that includes more than 13,000 twin pairs, born between 1994 and 1996, representative of the population of England and Wales (Haworth et al., 2013). Only one twin per pair was selected to eliminate the effect of the shared home environment. Data from one participant was excluded from further analyses due to poor handwriting that made it impossible to transcribe the story. The final sample consisted of 40 females and 19 males.

5.2. **Measures**

The measures were collected in two different data collection waves at ages 9 and 16.

5.2.1. Written stories at 9

Stories were written at age 9. The children were shown three coloured pictures of animals and buildings at a farm. They were then instructed to write a story that was creative. The pictures and instructions for the task are shown below in Figure 01. The data collection was done in children's homes. There was no time limit for the task and it was instructed and supervised by the parents. The stories were transcribed to minimise the influence of differences in handwriting in coding. No corrections to the stories were made in the transcription so the spelling mistakes were also included.

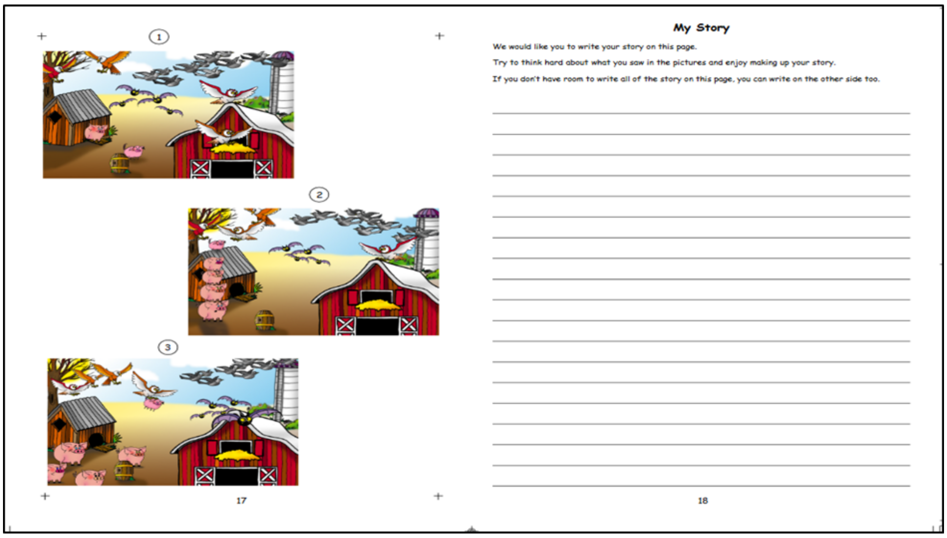

Figure 01. The pictures and instructions for the My Story task.

The Consensual Assessment Technique (Amabile, 1983) is widely used, reliable and validated creativity evaluation technique. It is based on the assumption that a group of independent judges are best able to make evaluations on the creativity of a product (Hennessey & Amabile, 1999). Creativity may be difficult to define and characterise, but as demonstrated by CAT, people can recognise and agree on it (Hennessey & Amabile, 1999). CAT has been used in different domains among primary school children, such as on musical compositions and drawings (Hickey, 2001; Lubart et al., 2010). CAT has also previously been used to evaluate creativity in children's orally told stories (Hennessey & Amabile, 1988).

In the present study, six independent judges coded the stories for 10 different dimensions each on a 5-point Likert-scale using their own subjective interpretation of creativity. As instructed by the method of CAT, no fixed criteria were presented to judges on which their scoring should be based (Amabile, 1983). The judges were instructed to evaluate creativity in the stories as follows: "Please evaluate the creativity of the story on this page in relation to the other 58 stories. Use your own subjective assessment of creativity". Nine other dimensions that the judges were asked to evaluate in the stories were: Liking, Novelty, Imagination, Logic, Emotion, Grammar, Detail, Vocabulary and Straightforwardness (Hennessey & Amabile, 1988). Three of the judges were primary school teachers, three undergraduate Psychology students. All the judges were females.

5.2.2. General cognitive ability at 9

General cognitive ability at age 9 was a combination of two non-verbal tests and two verbal tests. The non-verbal Puzzle and Shapes tests are part of the Cognitive Abilities Test 3(CAT3; Smith, Fernandez, & Strand, 2001). Verbal ability at age 9 was assessed using the vocabulary and general knowledge tests (WISC-III-UK; Wechsler, 1992).

5.2.3. English and Maths at 9

English and Maths at age 9 were standardised teacher-reported scores, each based on three different evaluations per subject. The three components evaluated in English were Speaking and Listening, Reading, and Writing. In Maths they were Using and Applying Mathematics, Numbers, and Shapes, Space and Measures.

5.2.4. Openness to Experience and Extraversion at 16

Openness to Experience and Extraversion were measured as part of 30-item personality scale (Mullins-Sweatt et al., 2006) based on the Five-Factor Model of personality. Each personality factor was assessed by 6 items.

5.2.5. English and Maths at 16

English and Maths scores at 16 are based on the results of the General Certificate of Secondary Education (GCSE), a standardised end of the school exam in the UK. English grade is the average of Language and Literature; Maths grade is the average of Maths, Statistics and Additional Maths.

6. Findings

The inter-rater reliabilities between the six judges for all the story dimensions were high (α = .76 - .95). The total score for each of the ten dimensions was calculated as a sum of the scores from all six judges. All the total dimension scores were normally distributed. To establish clusters between the ten dimensions, a Principal Component Analysis (PCA) was run with a Varimax rotation. The Kaiser-Meyer-Olkin measure was high (KMO = .90) and Bartlett's test of sphericity indicated that the correlations between the coded dimensions in the stories were sufficient for PCA ($\chi 2(45) = 851.55$, $p < .001$). The factor loadings are presented in Table 01.

Table 01. The rotated factor loadings on a Principal Components Analysis (Varimax rotation)
for 10 dimensions coded in the stories.

Dimension	Factor 1	Factor 2
	Creative Expressiveness	**Logic**
Creativity	**.95**	.30
Imagination	**.95**	.22

Novelty	**.94**	.19
Liking	**.88**	.42
Detail	**.84**	.33
Emotion	**.80**	.35
Vocabulary	**.75**	.48
Straightforwardness	.13	**.95**
Logic	.39	**.87**
Grammar	.44	**.75**

Note. n = 59

The factor loadings revealed two separate factors: Creative Expressiveness and Logic. Factor scores for these two factors were created by combining the scores from the dimensions that had factor loading higher than 0.7 (see bolded valued in Table1 above). To investigate the relationships between all the study variables, bivariate correlations were run for the Creativity dimension (age 9); Creative Expressiveness and Logic factor (age 9); general cognitive ability (age 9); English and Maths (at age 9); Openness to Experience and Extraversion (age 16) and English and Maths GCSE grades (age 16). The correlations are presented in Table 02.

Table 02. Correlations between all the study measures (n=59).

	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
1. Creativity dimension score at 9	1									
2. Creative Expressiveness factor score at 9	.97**	1								
3. Logic factor score at 9	.59**	.62**	1							
4. General cognitive ability at 9	.18	.20	.21	1						
5. English at 9	.34**	.36**	.39**	.41**	1					
6. Maths at 9	.28*	.29*	.33**	..44**	.58**	1				
7. Extraversion at 16	-.02	-.02	.03	.05	-.05	-.05	1			
8. Openness to Experience at 16	-.07	-.08	-.12	-.01	-.08	-.11	.41**	1		
9. English at 16	.41**	.45**	.37**	.42**	.49**	.41**	-.05	-.21	1	
10. Maths at 16	.32*	.31*	.31*	.45**	.49**	.69**	-.09	-.29*	.63**	1

** *p*< .01; * *p*< .05

To investigate whether the Creative Expressiveness factor score explains variance in Maths and/or English at age 16, hierarchical linear regressions were run. General cognitive ability score at age 9 was entered as a first step into the regression model, followed by previous academic achievement at age 9 (English or Math) in the second step. In the third step, Openness to Experience and Extraversion scores at age 16 were entered to the model. In the fourth and last step, Creative Expressiveness and Logic factor scores were entered into the regression model predicting either English or Maths score at age 16. The results from the hierarchical regression predicting English achievement at age 16 are presented in Table 03, and for Maths achievement at age 16 in Table 04.

Table 03. Summary of Hierarchical Regression Analysis for Variables predicting English at age 16.

Variable	β	t	R	R^2	ΔR^2
Step 1			.42	.18	.18
G at 9	.42	3.54**			
Step2			.55	.30	.12
G at 9	.27	2.18*			
English at 9	.38	3.12**			
Step 3			.59	.33	.03
G at 9	.27	2.21*			
English at 9	.37	3.01**			
Openness at 16	-.20	-1.60			
Extraversion at 16	.04	0.32			
Step 4			.64	.40	.07
G at 9	.25	2.17*			
English at 9	.27	.27*			
Openness at 16	-.18	-1.51			
Extraversion at 16	.03	.28			
F1_Creativity at 9	.29	2.50*			
F2_Logic at 9	.01	.07			

Note. n = 59; **p*< .05; ***p*< .01

The hierarchical multiple regression revealed that at the first step, general cognitive ability contributed significantly to the regression model ($F(1,58) = 12.52$, $p < .01$) and accounted for 18% of the variance in English results at age 16. Including the previous achievement measure, English at age 9, explained an additional 12% of the variance ($F(2,58) = 12.01$, $p < .01$). Personality measures of Openness to Experience and

Extraversion were not individually significant predictors of English at 16. In the last step, adding Creative Expressiveness and Logic factor scores into the model explained an additional 7% of the variance was in the English score at 16 ($F(6,58) = 7.19$, $p < .01$). Only the Creative Expressiveness, and not the Logic, was a significant predictor.

Table 04. Summary of Hierarchical Regression Analysis for Variables predicting Maths at age 16.

Variable	β	t	R	R^2	ΔR^2
Step 1			.45	.21	.21
G at 9	.45	3.85**			
Step2			.71	.51	.30
G at 9	.18	1.76			
Maths at 9	.61	5.87**			
Step 3			.75	.56	.05
G at 9	.28	1.92			
Maths at 9	.94	5.75**			
Openness at 16	-.51	-2.34*			
Extraversion at 16	.05	.24			
Step 4			.75	.57	.01
G at 9	.19	1.81			
Maths at 9	.56	5.27**			
Openness at 16	-.23	-2.26*			
Extraversion at 16	.02	.23			
F1_Creativity at 9	.10	.86			
F2_Logic at 9	-.01	-.01			

Note. n = 59; **p*< .05; ***p*< .01

In the regression model explaining variance in Maths grade at 16, general cognitive ability ($F(1,58) = 12.52$, $p < .01$) accounted for 21% of the variation in Maths results at age 16. Including the Maths score at age 9, explained an additional 30% of the variation ($F(2,58) = 12.01$, $p < .01$). Out of the two personality measures, only Openness to Experience was a significant (negative) predictor of Maths score at 16 ($F(1,58) = 12.52$, $p < .01$). Creative Expressiveness and Logic factor scores did not explain any additional variance in the model when added in the last step.

7. Conclusion

The present study set to test the robustness of the Consensual Assessment Technique as a method to evaluate children's written stories at age 9. Our results showed that CAT is a reliable measure of creativity in the children's written stories. The inter-rater reliability for the Creativity dimension was the highest out of all coded ten dimensions. Further factor analysis on the ten dimensions revealed that Creativity loaded onto a single factor along with Imagination, Novelty, Liking, Detail, Emotion and Vocabulary (Creative Expressiveness factor). Straightforwardness, Grammar and Logic formed a second, separate factor (Logic factor).

Additionally, we aimed to investigate whether creativity, measured by CAT, is associated with later educational achievement at age 16. Our results showed that the Creative Expressiveness factor score explained an additional 7% of variance in English GCSE grade at age 16, above and beyond intelligence and English grade measured at age 9. This suggests that marking criteria in English at age 16 includes both, technical knowledge (spelling, grammar, etc.), as reflected in the English grade at age 9; and creativity (explicitly or implicitly), captured by our Creative Expressiveness measure. Our results suggest that creativity in writing is overlooked in the UK primary education marking criteria, as creativity was not captured by the English grade at age 9. It is possible that primary education focuses more on convergent and technical skills, or at least did at the time of the data collection (the stories were written in 2003-2005).

Future studies are needed to explore how to apply the CAT in the evaluation of creative expressiveness in writing, as well as other domains, such as music and arts, in children of different ages. Further research is needed to establish how the evaluation of creativity in primary education, as guided by CAT, can be done in practice. Having independent judges evaluating children's work may not be easy to organise, but the observed high level of agreement among judges suggests that, with some calibration, single judges may provide accurate evaluations. Additionally, using a bigger sample, we plan to investigate whether intrinsic motivation and/or enjoyment of writing moderate the relationship between creative expressiveness in written stories and further educational achievement. In conclusion, CAT is a promising direction for measuring creativity in children, with implications for both creativity research and educational practice.

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Appendix 3. Pilot study 2: Creative Expressiveness in children's written stories - A methodological investigation of the Consensual Assessment Technique.

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CREATIVE EXPRESSIVENESS IN CHILDREN'S WRITTEN STORIES - A METHODOLOGICAL INVESTIGATION OF THE CONSENSUAL ASSESSMENT TECHNIQUE

Toivainen T. (a), Badini I. (a), Chapman R. (a), Malanchini M. (b), Oliver B. R. (a), Matsepuro, D. (c), *Kovas Y. (a, c)

*y.kovas@gold.ac.uk

*Corresponding author

(a) Department of Psychology, Goldsmiths, University of London, UK

(b) Department of Psychology, Population Research Center, University of Texas at Austin, U.S.

(c) Tomsk State University, Tomsk, Russia

Abstract

The study investigated methodological issues relating to the use of the Consensual Assessment Technique (CAT) for measuring creativity in children's written stories. The CAT is a commonly used measure to estimate creativity of a product, based on social recognition of creativity by independent judges. Across domains, the CAT has shown high inter-rater reliability. The present study utilised the CAT to assess creativity in children's written stories. The stories were also evaluated for: Imagination, Novelty, Liking (how much the judges liked the story), Detail, Emotion, Vocabulary, Straightforwardness, Logic and Grammar. The sample consisted of 277 nine-year-olds. The results showed that to reach sufficient inter-rater reliability, 5 coders were needed.

The results gave evidence of a 2-factor structure among the 10 dimensions, indexing 'Creative Expressiveness' and 'Logic' constructs related to individual differences in writing. Girls outperformed boys on both constructs. The story length was positively correlated with the constructs, explaining 63% of the variance in Creative Expressiveness, and 42% in Logic. Creative Expressiveness was positively correlated with verbal ability (r = .20) and with teacher rating of writing (r = .28). Similarly, Logic was also correlated with verbal ability (r = .34) and teacher rating of writing (r = .44). The findings inform future research employing the CAT to measure creativity in children's storytelling.

Keywords: Creativity, Consensual assessment technique, Children's writing

Introduction

The Consensual Assessment Technique (CAT) is used to operationalize the creativity of a product (Amabile, 1982; Hennessey & Amabile, 2010). In the last decades, the CAT has been widely used in creativity research. For example, the CAT has been used to assess creativity in different artistic and verbal outputs as well as performance in problem solving tasks (Hennessey, Amabile, & Muller, 2011). The use of the CAT has demonstrated that people can recognise and agree upon creativity even though it may be difficult to define and characterise (Hennessey & Amabile, 2010). The CAT is based on the idea that creativity is dependent on social recognition; a product or response is considered creative to the extent that independent observers agree that it is creative (Amabile, 1982) .The CAT involves a group of independent judges, with some familiarity with the domain to which the product belongs, subjectively evaluating the creativity of a product (Hennessey, Amabile, & Muller, 2011). Also, the assessed products should be presented in a random order to the coders and they should be assessed in relation to each other, in a restricted sample of products (Hennessey, Amabile, & Muller, 2011). Due to its simplicity and consistency, the CAT has been regarded as particularly suitable to evaluate everyday creative outputs (Runco, 2004). With wide applicability, the CAT is commonly used in creativity research (Hennessey & Amabile, 2010).

In children, the CAT has been used to evaluate creativity of musical compositions, drawings and poems (Hickey, 2001; Baer, Kaufman, & Gentile, 2004; Lubart, Pacteau, Jacquet, & Caroff, 2010). Three previous studies have utilised the CAT to estimate creativity in children's orally told or written stories (Hennessey & Amabile, 1988; Toivainen et al., 2017; Badini et al., in press). The first study established the use of the CAT in children's stories and investigated the relationship of objective story features to creativity (Hennessey & Amabile, 1988). The study reported positive correlations between creativity and the story length (r = .28); inclusion of dialogue (r = .46); and whether the children had named the characters (r = .35). Age (range 5 – 10 years) and sex were not associated with creativity (Hennessey & Amabile, 1988). However, the study did not report the distributions of either sex or age, so further investigations into their potential role in childhood creativity are needed. A recent pilot study, investigating the relationship between creativity in writing and further educational achievement, ran an exploratory principal component analysis among 10 dimensions (see below; Toivainen et al., 2017). A summed component score, termed 'Creative Expressiveness', was based on 7 of the 10 dimensions that had high loadings on the principal component (Toivainen et al., 2017). This study found that the Creative Expressiveness score explained an additional 7% of variance in English exam performance at age 16, beyond intelligence and English grade at age 9 (Toivainen et al., 2017). Another recent study (based on the same sample as the present study) investigated early cognitive predictors of creativity in writing and reported a weak but significant association between early drawing ability and Creativity Expressiveness in writing at age 9 (r = .17; Badini et al., in press).

In the aforementioned three studies, the stories were coded for 10 dimensions: 1) Creativity; 2) Imagination; 3) Novelty; 4) Liking; 5) Detail; 6) Emotion; 7) Vocabulary; 8) Straightforwardness; 9) Logic; and 10) Grammar. The first study utilising these dimensions to assess children's orally told stories, found support for a 3-factorial structure (Hennessey & Amabile, 1988). The first factor had high loadings of Creativity, Liking, Novelty and Imagination; the second of Detail and Straightforwardness; and the third of Grammar and Logic dimensions (Hennessey & Amabile, 1988). Vocabulary and Emotion dimensions did not load on any of the three factors (Hennessey & Amabi, 1988). However, only 30 out of 115 stories were coded for all 10 dimensions, as the focus of this study was on the Creativity dimension (Hennessey Amabile, 1988).

Two recent studies that assessed the 10 dimensions gave support for a 2-factorial structure (Toivainen et al., 2017; Badini et al., in press). The first factor (Creative Expressiveness) had high loadings from the following seven dimensions: Creativity;

Imagination; Novelty; Liking; Detail; Emotion; and Vocabulary. The remaining three dimensions of Straightforwardness; Logic; and Grammar loaded on the second factor (Logic). In summary, previous studies have shown that Creativity loads on the same factor with Imagination, Novelty and Liking (Hennessey & Amabile, 1988), as well as with Detail, Emotion and Vocabulary (Toivainen et al., 2017). Based on this multidimensionality, the composite score was named as Creative Expressiveness to capture all dimensions that were associated with creativity in children's storytelling (Toivainen et al., 2017).

More research is needed into associations between creativity and domain specific- and domain-general abilities, which are prerequisites for creative outputs (Amabile, 1983). A pilot study on creativity in writing and later educational achievement found no significant correlation between Creative Expressiveness scores and general cognitive ability at age 9 (Toivainen et al., 2017). However, since the measure for general cognitive ability in the study was a composite of two non-verbal and two verbal measures, the specific role of verbal ability in creativity in writing was not evaluated. The same study also reported a positive correlation between Creative Expressiveness and English grade at age 9 ($r = .36$; Toivainen et al., 2017). Again, the English grade was a composite of teacher-reported scores of Reading; Speaking and Listening; and Writing. Further research is needed in order to evaluate the extent to which creativity in children's writing is related specifically to writing skills.

Problem Statement

The application of the CAT to children's creative writing needs to be further validated. In addition, research is needed into inter-relationship between different dimensions of written stories assessed by the CAT, and into associations between creativity and specific abilities, such as verbal ability and writing skills. Also, research on children's writing has not explored so far the relationship between the story length and creativity, which is relevant due to the variability in the lengths in writing tasks with no word limits (21 to 486 words in this sample). Furthermore, the question of sex differences in creativity in childhood writing is still unanswered.

Research Questions

1. How many coders are needed to reach sufficient inter-rater reliabilities on the 10 dimensions of the CAT?

2. Are the 10 dimensions correlated, and to what extent?

3. Does confirmatory factor analysis support2-factorial solution among the 10 dimensions, indicated in the previous pilot study?

4. Are there gender differences in factor scores?

5. Does the story length correlate with the factor scores? Is the association similar at different levels of the story lengths?

6. Are the factor scores correlated with verbal ability and teacher rating for writing at age 9?

Purpose of the Study

The present study seeks to fill a gap in the literature by investigating in detail the suitability and potential methodological issues of using all 10 dimensions of the CAT in the assessment of creativity in children's written stories. The results of this study will inform a planned future large-scale, genetically informed study (n = 1300) using the same measure. It is important to establish the validity of the CAT before coding more stories as the coding procedure is very intensive. The procedure requires transcribing and reading all the stories in a sample before coding commences. The findings will provide new insights into creativity in writing and will further evaluate construct 'Creative Expressiveness' that was suggested by a previous study (Toivainen et al., 2017).

Research Methods

The sample used in the present study is a subsample from the Twins Early Development Study (TEDS). TEDS is a large, longitudinal twin sample that includes more than 13,000 twin pairs, born between 1994 and 1996, representative of the population of England and Wales (Haworth et al., 2013). The total sample in the present study was 277 with a mean age of 9.02 years (SD = .27), ranging from 8.50 to 9.82 years. Age was recorded at the time when test booklets were returned. Only one twin per pair was selected, in order to eliminate the inflated inter-individual similarity observed in twins. The sample consisted 172 girls (Mage = 9.02, SD = .28) and 105 boys (Mage 9.02, SD = .27). The present study is part of a larger longitudinal study, which focuses on measures at ages 4, 9 and 16, so preliminary sample selection was conducted among participants who had provided data at all three collection waves. Only data from the collection at age 9 was used in the current study. Preliminary analyses were run to establish the representativeness of the selected subsample. In the present study, the mean for verbal ability was slightly higher (M = .06, SD = .98) than for the whole TEDS sample, which is representative of the population of England and Wales and has a standardised mean of 0. Further, the teacher rated scores of writing were slightly higher (M = 3.01, SD = .68) in comparison with the larger TEDS sample (M = 2.83, SD = .74).

Written stories at age 9

The children were shown three coloured pictures of farm animals and farm buildings. They were then instructed to write a story that was creative. The pictures and instructions for the task are shown below in Figure 01. The data were collected in children's homes. The stories were written in 2002-2004. There was no time limit for the task and it was instructed and supervised by the parents/guardians of the children. The stories were first transcribed to minimise the influence of differences in handwriting on coding. No corrections were made to spelling, grammar etc. during transcription. The length of the stories ranged from 21 to 486 words, with a mean of 147.99 (SD = 80.55) words.

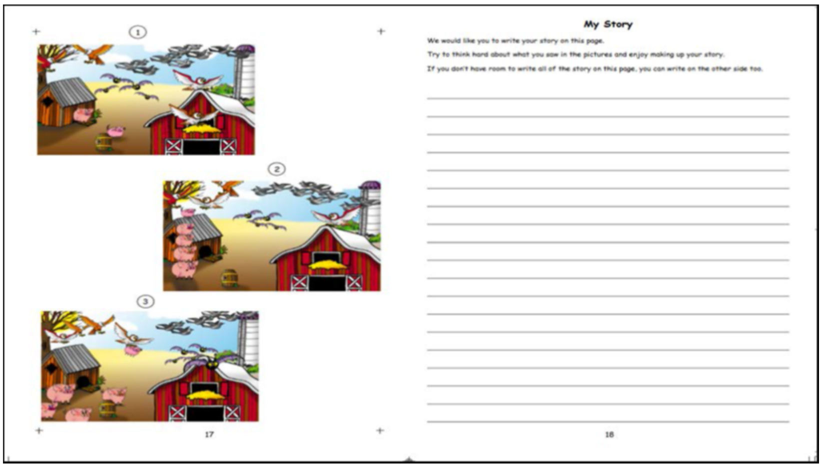


Figure 01. [The pictures and instructions for the 'My Story' task]

The stories were coded for the following 10 dimensions: 1) Creativity; 2) Imagination; 3) Novelty; 4) Liking; 5) Detail; 6) Emotion;7) Vocabulary; 8) Straightforwardness; 9) Logic; and 10) Grammar. Five independent judges coded the stories for these 10 dimensions, each on a 7-point Likert-scale using their own subjective interpretation of each dimension. For example, for the creativity dimension, the judges were instructed as follows: "Please evaluate the creativity of the story on this page in relation to the other 276 stories. Use your own subjective assessment of creativity". No other criteria and instructions were given. Firstly, all the judges were asked to code the stories only for creativity. After coding all the stories for creativity, the judges were asked to then code them for the remaining nine dimensions. For these dimensions the judges were asked to again use their subjective assessments (e.g. "Please evaluate the straightforwardness of the story on this page in relation to the other 276 stories. Use your own subjective assessment of straightforwardness."). The stories, and additional 9 coding dimensions, were presented to the judges in different orders to counterbalance for potential order effects. The judges were adults, primarily undergraduate psychology students.

Verbal ability and teacher ratings for writing, as measured at age 9

Verbal ability at age 9 was assessed using vocabulary and general knowledge tests adapted from the WISC-III-UK (Wechsler, 1992; e.g. Vocabulary: 'What does migrate mean?'; General Knowledge: 'In which direction does the sun set?'). The total score was a composite of the two tasks scores. The score for English writing was a single teacher-reported subscore of English score (the other subscores were reading; and speaking & listening). Teachers were asked to evaluate children's writing attainment (scale 1-5) in terms of the National Curriculum. Score 1 represented writing attainment well below the expected standard for most 9-year-olds, whereas score 5 was an indicator of exceptional achievement in writing, above the level expected at age 9.

Findings

How many coders are needed to reach sufficient reliabilities in the 10 dimensions?

Table 1 presents the increments of internal reliabilities for each dimension from 2 to 5 coders. For 7 dimensions (Creativity; Imagination; Novelty; Liking; Detail; Emotion; and Vocabulary), the reliabilities exceeded the recommended minimum $\alpha = 0.70$ with 2 coders (Nunnally & Bernstein, 1994). With 5 coders, 9 dimensions had internal reliabilities higher than $\alpha = 0.70$. Cronbach's alpha for Straightforwardness was 0.67.

Table 01. [Internal reliability (Cronbach's α) for the 10 coding dimensions as a function of the number of the coders]

Dimension	2 coders	3 coders	4 coders	5 coders	Δ
1. CR	.79	.85	.86	.88	.09
2. IM	.78	.81	.84	.86	.08
3. NO	.79	.82	.83	.85	.06
4. LI	.76	.79	.82	.84	.08
5. DE	.78	.79	.83	.86	.08
6. EM	.78	.82	.83	.86	.08
7. VO	.74	.78	.81	.85	.11
8. ST	.20	.40	.56	.67	.47
9. LO	.43	.56	.66	.73	.30
10. GR	.66	.69	.72	.77	.11

Note. n = 277; CR = Creativity; IM = Imagination; NO = Novelty; LI = Liking; DE = Detail; EM = Emotion; VO = Vocabulary; ST = Straightforwardness; LO = Logic; GR = Grammar; Δ = increment in α, between 2 and 5 coders.

What are the correlations between the 10 dimensions?

The bivariate correlation coefficients between the 10 dimensions are shown in the Table 2.

Table 02. [Bivariate correlations between the 10 coding dimensions]

	1. CR	2. IM	3. NO	4. LI	5. DE	6. EM	7. VO	8. ST	9. LO	10. GR
1. CR	1									
2. IM	.89	1								
3. NO	.85	.87	1							
4. LI	.83	.83	.82	1						
5. DE	.74	.73	.68	.73	1					
6. EM	.73	.73	.69	.74	.66	1				
7. VO	.66	.64	.58	.68	.70	.66	1			
8. ST	.23	.23	.25	.35	.27	.27	.35	1		
9. LO	.28	.25	.26	.42	.32	.28	.37	.68	1	
10. GR	.14	.14	.12	.19	.21	.22	.28	.34	.26	1

Note. n = 1385; All correlations are significant p < .001; CR = Creativity; IM = Imagination; NO = Novelty; LI = Liking; DE = Detail; EM = Emotion; VO = Vocabulary; ST = Straightforwardness; LO = Logic; GR = Grammar.

Most of the zero-order, bivariate correlations between the 10 dimensions were moderate to high. The inter-correlations between Creativity, Imagination, Novelty and Liking were higher than r = .82. The last three dimensions (Logic, Straightforwardness and Grammar) had lower bivariate correlations with the other 7 dimensions (highest correlation r = .42). Logic and Straightforwardness were correlated at r = .68.

Does confirmatory factor analysis support the 2-factorial solution among the 10 dimensions?

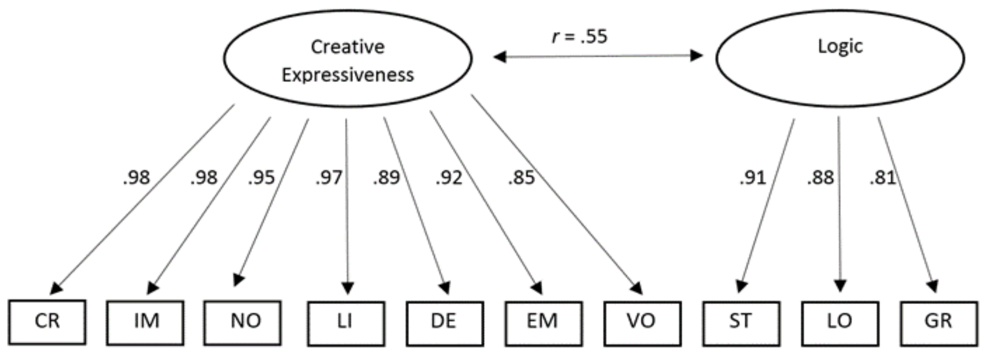
Previous pilot study using the CAT with 10 dimensions for assessment of creativity in children's written stories has suggested a 2-factorial structure (Toivainen et al., 2017). Confirmatory factor analyses (CFA) were run to test if the 2-factorial model fits the data better than a model in which all dimensions load onto a single factor. 3-factorial model, as indicated by Hennessey & Amabile (1988) was inadmissible due to the high correlations between the three latent factors and therefore the fit indices for 2-factorial model were compared with a 1-factorial model. The model fit outputs for 1 and 2-factorial models are presented in Table 3.

Table 03. [Confirmatory factor analyses fit indices for 1-factor and 2-factor solutions for the 10 coding dimensions]

Model	AIC	BIC	X^2	RMSEA	CFI	TLI	SRMR
2-factorial	13263.28	13339.31	488.93*	0.22	.90	.86	0.09
1-factorial	13640.01	13712.43	867.67*	0.29	.81	.76	0.13

Note. * $p < .001$; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index = SRMR = Standardised Root Mean Square Residual

As shown, a 2-factor model is a better fit for the data than a 1-factor model. This is indicated by the lower X2, as well as lower AIC and BIC indices; higher CFI and TLI values; and lower values of RMSEA and SRMR. The factor loadings for the 2-factor model are presented in Figure 2.



Note. CR = Creativity; IM = Imagination; NO = Novelty; LI = Liking; DE = Detail; EM = Emotion; VO = Vocabulary; ST = Straightforwardness; LO = Logic; GR = Grammar.

Figure 02. [Factor loadings (and the correlation between the latent variables) for 2-factor solution for the 10 coding dimensions]

Based on the results of the CFA, the scores for these two factors were created by combining the scores from each five judges for each dimension that had high loadings on each factor. The summed scores were used, as opposed to weighted values, due to the small differences in factor loadings on each factor (in Creative Expressiveness .85 - .98; in Logic .81 - .91). The mean total factor scores, based on the scores from 5 coders, for Creative Expressiveness (factor score) is 105.51 (SD=34.48) and for Logic (factor score) 65.67 (SD= 12.19). The two factors have different numbers of dimensions and therefore widely different means. The difference in means do not affect any of the analyses.

Are there gender differences in Creative Expressiveness and Logic factor scores?

For Creative Expressiveness, the mean difference between girls (M= 110.80, SD= 33.81) and boys (M= 96.84, SD= 33.96) was significant (t (276) = 3.33, p< .01; d = .41). Girls (M = 67.09, SD = 11.99) also outperformed boys (M = 63.34, SD = 12.22) in Logic vs.; t (276) = 2.51, p = .01; d = .31).

Does number of words correlate with Creative Expressiveness and/or Logic Factor scores?

The mean story length was 148 words (SD = 80.55). The lengths varied between 21 and 486 words. The number of words in a story had positive correlations with both Creative Expressiveness and Logic. Linear regression analyses showed that the number of words accounted for 63.2% of the variance in Creative Expressiveness and 17.4% in Logic.

Quantile regressions were run to establish if the associations between story length and factor scores (Creative Expressiveness and Logic) were similar at different levels of story length. The stories consisted of 21-91 words in the first quantile (n=70); 93-132 words in the second quantile (n=69); 133-178 words in the third quantile (n=69); and 181-486 words in the fourth quantile (n=69). The beta coefficients were similar for both measures in all 4 quantiles. Intercepts increased in-line with quantiles, indicating that the associations between the story length and factor scores, for both Creative Expressiveness and Logic, are similar in all 4 length quantiles.

Table 04. [Intercepts and beta coefficients for 4 quantiles of Story Length (number of words) predicting Creative Expressiveness]

Quantiles for Story Length	Intercept	Beta co-efficient	Confidence interval	t-value
1st	35.71	0.36	[.30, .40]	11.19*
2nd	40.69	0.40	[.36, .43]	18.53*
3rd	53.03	0.38	[.35, .43]	21.99*
4th	63.98	0.39	[.33, .50]	15.09*
Total	55.15	0.34	[31., .37]	21.74*

* p < .01

Table 05. [Intercepts and beta coefficients for 4 quantiles of Story Length (number of words) predicting Logic]

Quantiles for Story Length	Intercept	Beat co-efficient	Confidence Interval	t-value
1st	47.25	.07	[.04, .09]	5.89*
2nd	54.40	.07	[.04, .08]	5.25*
3rd	60.45	.06	[.04, .09]	7.18*
4th	66.29	.06	[.04, .08]	5.14*
Total	56.06	.06	[.05, .08]	7.62*

* p < .01

7.1. Are the factor scores correlated with verbal ability and teacher rating for writing at age 9?

Creative Expressiveness and Logic were both positively correlated with verbal ability and teacher rating for writing, as measured at age 9. As seen in Table 5, the correlations for both verbal ability and teacher rated writing were stronger for Logic than for Creative Expressiveness.

Table 06. [Bivariate correlations for Creative Expressiveness; Logic; verbal ability at 9; and teacher rating for writing at 9]

	1. Creative Expressiveness	2. Logic	3. Verbal ability at 9	4. Teacher rating for writing at 9
1.	1			
2.	.55	1		
3.	.20	.34	1	
4.	.28	.44	.37	1

Note. n = 277; All correlations are significant at p < .01

Conclusion

The present study investigated the use of the Consensual Assessment Technique (CAT) for assessing creativity in children's written stories. Creativity dimension was studied in relation to nine other dimensions: Imagination, Novelty, Liking, Detail, Emotion, Vocabulary, Straightforwardness, Logic and Grammar. Firstly, we established the number of judges needed to reach sufficient inter-rater reliabilities for the 10 coding dimensions. Secondly, we examined the correlations between the 10 dimensions and replicated the previously established 2-factor structure among the 10 dimensions. Thirdly, we explored how Creative Expressiveness and Logic factor scores relate to gender; story length; verbal ability; and teacher rated English writing score.

Our results showed that five coders are needed to reach sufficient inter-rater reliability levels for all dimensions except for Straightforwardness, for which the level of inter-rater reliability was lower (.67) than the recommended α = .70 (Nunnally & Bernstein, 1994). The lower inter-rater reliability in Straightforwardness may reflect different interpretations of the dimension among the judges. The scoring was based on the coders' subjective evaluations and not on any objective criteria. Rating 277 stories required a substantial time commitment from each coder. Moreover, reliability increments for several dimensions were small when number of coders increased. This suggests that 5 coders would be optimal for future uses of the CAT to evaluate 10 dimensions of children's writing. Factor scores were calculated as summed scores from each coder, based on the highest loading dimensions. The dimensions included in Creative Expressiveness were: Creativity, Imagination, Novelty, Liking, Detail, Emotion, and Vocabulary. The Logic factor score was comprised of the sum of scores from the Straightforwardness; Logic; and Grammar dimensions.

All the story dimensions were inter-correlated. Confirmatory factor analysis supported a 2-factor structure suggested by an exploratory factor analysis of the previous pilot study (Toivainen et al. 2017). The seminal study, which established the use of CAT for evaluation of creativity in children's storytelling, reported a 3-factorial model based on the 10 coding dimensions (Hennessey & Amabile, 1988). The difference with the factor structure found in the present study may be due to differences in data collection (oral vs. written stories). It is plausible that when children are telling stories aloud, it is easier for them to be more detailed and elaborate. Hand-written stories require additional skills not needed for oral stories, such as fine-tuned motor skills. Also, interest and enjoyment in writing is likely to influence the amount of time children are spending on the task. Participants in the earlier study also had a wider age range, 5 to 10 years, whereas the children taking part in the present study were 9-years-old. These reasons may have influenced the content of the stories and subsequently how they were scored on the 10 dimensions. Additionally, the present study used a bigger sample than the previous study in which only 30 stories were coded for all 10 dimensions.

The finding that the Logic score had a stronger positive correlation with verbal ability and teacher rating for writing reflects the dimensions that constitute the Logic Factor score: Straightforwardness, Logic and Grammar; each of which is related to logical reasoning. The scoring on these items may have emphasised technical writing skills. Verbal ability is measured by verbal reasoning tasks and teachers emphasise technical writing skills over creative expression when assessing nine-year-olds' writing skills. Therefore, several dimensions that are included in Creative Expressiveness, such as Imagination and Emotion would not be reflected in either verbal ability or in teacher rated writing scores.

Further studies on creativity in children's stories should take into consideration the role of gender and length of the stories. At age 9, girls scored higher than boys in both Creative Expressiveness (d = .41) and Logic (d = .31) factors. This result is in-line with previous research that has shown that girls outperform boys in writing at age 9 (Kovas, Haworth, Dale & Plomin, 2007). The results also showed a substantial, positive correlation between the story length and Creative Expressiveness. It is likely that shorter stories do not allow for much creative expression, for example through a sophisticated narrative structure. This may be particularly relevant in children's writing as nine-year-olds have a limited vocabulary and experience of different forms of writing. The associations between number of words and creativity were similar at different levels of Creative Expressiveness; among the shortest stories (the first quantile; i.e. fewer than 91 words) story length was still associated positively with creativity. Similarly, among the longest stories (the fourth quantile; more than 181 words), shorter ones were evaluated as being less creative.

The results of the study contribute to research on valid and reliable methods of assessing individual differences in creativity among children. These methods will improve the quality of research into aetiology of individual differences in creativity; and can be used as an educational diagnostic tool.

Acknowledgments [if any]

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