Mathematical Creativity: Investigating whether Interhemispheric Communication and Conflict Solving Ability underly Incubation and Insight processes among University Students

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Abstract

Current math-education is going through reformative changes. The new, successful approach to realistic mathematics education (RME) applies math-problems to real-world contexts and aims to prepare students better for professional life. Despite its essential role for the success of RME, mathematical creativity received little attention by research. In this study, the roles of conflict solving ability and interhemispheric communication were examined as potential cognitive mechanisms underlying the subconscious math-creativity processes of incubation and insight. Participants ($N = 7$) were categorized as mathematically gifted (MG) with high math-intelligence and creativity or mathematically intelligent (MI) only with high math-intelligence. Measures of interhemispheric communication (finger tapping paradigm) and conflict solving (Eriksen flanker task) have been assessed for between-group differences and were correlated with performance on insight-based tests each including an incubation break. Results suggest that the finger tapping paradigm was invalid for assessment of interhemispheric communication and that conflict solving ability was related to two types of insight-gaining strategies. One was fast-paced based on intuition, the other was slower and analytical. No meaningful results have been observed in relation to incubation. Further, no results were significant due to a small sample size. Further research should try to clarify processes underlying incubation and insight. This way, RME curricula can be optimized and training for related cognitive capacities can be developed to improve students' math-creativity.

Keywords: mathematical giftedness; creativity; insight; incubation; corpus callosum; cingulate cortex; university students; realistic mathematics education

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Mathematics education is currently going through a major reformative change. Traditional mathematics education which focused on drill and practice to solve a multitude of isolated problems is outdated (Mann, 2006). Generations of students taught with this approach have been adept at mathematical computation yet lacked the ability to solve real-world problems.

As a reaction to this problem, a reformative approach called Realistic Mathematics Education (RME) was, and is continued to be introduced (Gravemeijer & Doorman, 1999). The significance of this reform was underlined by studies showing that RME lead to higher math-achievements than the conventional approach (Laurens et al., 2017).

RME stresses the importance of applying mathematical computational ability to a real-world context. This is becoming more important today, since modelling for real-world applications among a broad field of studies has led to drastic innovations (Sriraman, 2005). To achieve this, creativity is an essential part of the learning process (Sitorus, 2016). Today, computational ability is more and more replaced by technological tools. Therefore, higher-order mathematical thinking skills like creativity, as advocated by RME research are of high relevance (Mann, 2006). Especially for developing innovative technologies in the future, an adequate mathematics education based on creativity will be needed (Leikin & Pitta-Pantazi, 2013).

Although RME curricula based on creativity have been beneficial, their impact was still less than expected. This was attributable to a task-propensity of teachers, tests and textbooks which focused on integrating fast-to-solve problems in their RME curricula (Gravemeijer et al., 2016). However, more complex and advanced understandings of math must be generated by utilizing more complex problems. Supportive technologies have supplemented RME curricula and made the process easier for students already (Bray et al., 2015). Resulting from the current study, information is gained to possibly support students accordingly for the RME reform by identifying trainable cognitive mechanisms involved in creativity in mathematics. This way, in the future not only the teachers, but also the students will be equipped with adequate skills to engage in RME.

Mathematical Creativity

Creativity is an essential skill for students in general. From 2015 to 2020, creativity has moved from rank 10 to rank 3 of the major 21st century skills reflecting its emerging importance (Soffel, 2016). This led to a research wave about creativity in many different studies. However, creativity research in mathematics has been neglected until recently (Leikin & Pitta-Pantazi, 2013; Sriraman, 2004). An underappreciation of creativity in math is a serious threat, because without creativity, many students lose their enthusiasm for math (Mann, 2006). RME has been identified as an incubation and insight-based approach relying on unconscious or pre-conscious processes (Sitorus, 2016; Gravemeijer & Doorman, 1999). Based on a model which successfully defined the creative process in mathematics, the sub-processes of incubation and insight are examined further (Sriraman, 2004).

If, after trying to solve a complex problem, a student reaches an impasse, the incubation period begins. Incubation is the process of subconscious processing and internalization of the problem while not actively working on the task or consciously thinking about it. This finally leads to insight, the well-known “aha-moment”, which breaks the deadlock and results in new innovative knowledge related to the problem (Sitorus, 2016).

Incubation and insight distinguish creative problem solving from ordinary problem solving (Liljedahl, 2013). Thus, it is not surprising that both processes are relevant also in RME (Sitorus, 2016). However, due to its uncertain nature there was still a lack of incubation training after an impasse and thus deprived students of the rewarding experience of gaining insight after a creative struggle (Mann, 2006; Sriraman, 2005). In fact, Yuan and Sriraman (2011) have shown that insight due to incubation is a transformative experience for students, sparking enthusiasm about mathematics. Gaining insight is special in this regard since its affective component can motivate students and is unique among other mathematical experiences (Liljedahl, 2013). Improving this could counteract the lack of math-skills currently existent (Peña-López, 2016).

Another problem is the unsupportive environment for productive failures in creative math and the inability of students to cope with impasses in math-education (Savic, 2016). However, the processes of incubation and insight closely mirror activities of real pure and applied mathematicians and should be supported and taught by math-education (Sriraman, 2005). For RME to be successful, this should not be ignored and ways to train the underlying mechanisms of incubation and insight should be implemented to equip students with the creative skill to strive in RME.

Cognitive Mechanisms of Incubation and Insight

Many studies have so far supported the existence of an incubation effect resulting in insight, however due to their unconscious nature the related cognitive processes are still unclear (Sawyer, 2011). The brain is known to be continuously very active during incubation to find a solution (Savic, 2016; Sitorus, 2016). Specifically, the default mode network (DMN) of brain activity involved in mind-wandering has been identified as a brain state corresponding to incubation processes (Sawyer, 2011).

Mathematically gifted students also performed better and faster on insight-based problems than mathematically intelligent students who lack creativity (Leikin, Waisman & Leikin, 2013). To investigate processes underlying mathematical creativity, it is possible to generalize from the extraordinary math-creative abilities of mathematically gifted (Sriraman, 2005; Subotnik et al., 2011).

Trainability of cognitive processes

A meta-analysis by Zhang et al. (2017) implied that there are real, measurable differences in cognitive abilities and brain mechanisms between normal and mathematically gifted people. For example, math-gifted students had a different brain activation pattern during mental-rotation tasks resulting in improved performance (Zhang et al., 2017). However, contradictory to normal beliefs, math-gifted students are no born geniuses, although they may have a slight natural disposition towards math-creativity. Only about 1/3 of creative abilities are embedded in any person's genes, while the other 2/3 are gained through education (Sitorus, 2016). Thus, the differences between gifted and non-gifted students may be closed by training the non-gifted.

Now, brain structures related to learning are usually changeable by environmental experiences rather than fixed genetically-dependent cognitive abilities (Kalbfleisch, 2004). Two such brain areas related to mathematical giftedness (Zhang et al., 2017) which are changeable by the environment and trainable, are the corpus callosum and cingulate cortex (Allen et al., 2012; Lövdén et al., 2010).

Corpus Callosum

The corpus callosum is the largest white matter structure in the human brain, connecting both left and right brain-hemispheres with each other and allowing for interhemispheric (between both hemispheres) communication (Luders, Thompson & Toga, 2010). A better developed corpus callosum has been associated with a higher level of creative thinking in math (Takeuchi et al., 2010) while its underdevelopment or absence has been related to a low level of math-creativity (Hoppe, 1988; Siffredi et al., 2018). There is a consistent trend that math-gifted people displayed higher interhemispheric communication while mathematically intelligent people displayed a left-hemisphere dominance (Zhang et al., 2017). Since the left hemisphere is trained more by traditional math education, this is not surprising (Leikin, Waisman & Leikin, 2013). The left hemisphere is related more to analytical, convergent thinking necessary in traditional math-education. Meanwhile, the right hemisphere shows a coarser neural network allowing for divergent, context-dependent thinking resulting in a more coherent understanding which is related to RME (Jung & Vartanian, 2018; Jung-Beeman, 2005; Kounios & Beeman, 2014; Sitorus, 2016). It may be this balance of both conventional computational understanding as well as context-dependent thinking which makes mathematically gifted students so adept at mathematical creativity. During incubation, interhemispheric communication may lead to an integration of more conceptually distant ideas to provide for a more coherent, innovative insight (Takeuchi et al., 2010).

Cingulate Cortex

Next, the cingulate cortex is a brain structure located on top of the corpus callosum, displayed wide intrahemispheric (residing in one hemisphere) connectivity and has an error detection and other control functions (Beckmann et al., 2009; Shenhav et al., 2013). The anterior cingulate cortex has been positively associated with the occurrence of insight (Dietrich & Kanso, 2010). In gifted students, a better functioning cingulate cortex has especially been related to the DMN mentioned earlier (Zhang et al., 2017). The DMN has more often been related to creativity and especially incubation leading to insight during mind-wandering (Beaty et al., 2014; Tan et al., 2015). A potential explanation for this is the cingulate cortex' role in conflict solving. The cingulate cortex actively suppresses dominant associations in the brain which have failed to provide a right solution allowing for weaker associations to be assessed (Kounios & Beeman, 2014). As a result, more original ideas may be generated.

Common link between both brain areas

First off, both brain areas were found to be trainable and therefore worthwhile to examine. Meditation is an intervention which even after short-term meditation training resulted in increased white matter integrity and thus connectivity of the corpus callosum, as well as in an increase in neurons, fibers, myelination and glial cells in the anterior and posterior cingulate cortex (Fox et al., 2014; Hölzel et al., 2011). Furthermore, meditation was rated as enjoyable by students and increased math-creativity (Ding et al., 2014; Lin & Mai, 2018).

Another possible activity to improve connectivity of these brain areas is musical training. The corpus callosum had been shown to increase in size resulting in better interhemispheric communication after musical training (Bennet & Bennet, 2008). And the connectivity of the anterior cingulate cortex had been found to increase with musical training too (Luo et al., 2014). Besides this, music in math curricula had been found to increase students' motivation to engage in mathematics (Doyle & McCoy, 2012).

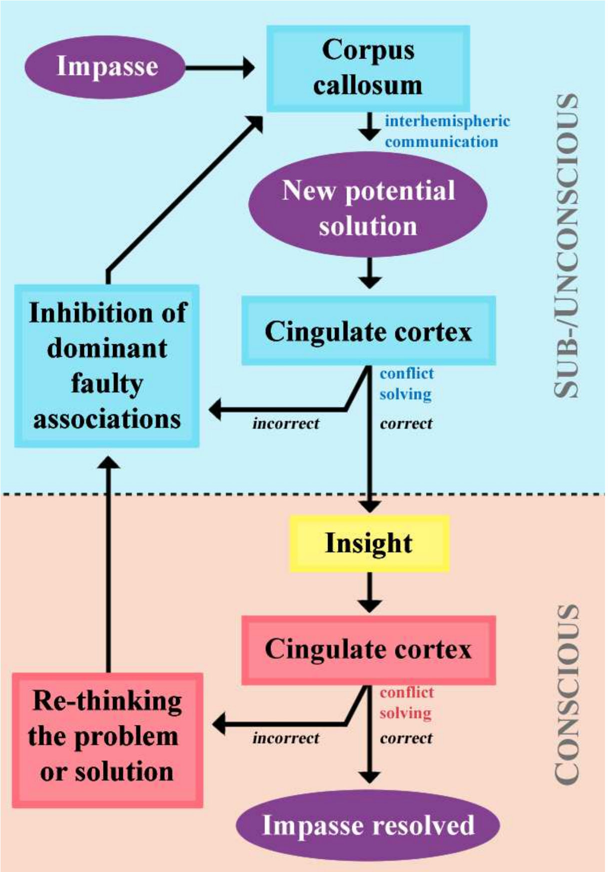
There are also three lines of research suggesting that both corpus callosum and cingulate cortex may act together. First, the math-gifted brain seems to be well-connected both inside each hemisphere as well as across them, which may reflect the broad connectivity of the corpus callosum and cingulate cortex (Prescott et al., 2010; Zhang et al., 2017). Second, two developmental studies described an early projection of cingulate cortex neurons making up the first neurons to later form the corpus callosum (DeAzevedo et al., 1997; Rash & Richards, 2001). And third, studies of patients with injury or developmental absence of the corpus callosum have also observed decreased connectivity of the cingulate cortex (Owen et al., 2013; Sharp et al., 2011).

Subconscious Incubation Processing (SIP) Model

Based on the previous literature, a potential framework for the underlying cognitive mechanisms of incubation leading to insight is proposed. This subconscious incubation processing (SIP) model is based on the conflict detection and solving function of the cingulate cortex as well as the interhemispheric communication due to the corpus callosum. For a simplification of the model, look at Figure 1 below.

Figure 1

Simplified SIP Model Visualization



A more detailed explanation based on an example insight-problem is given in Appendix A. It is proposed that during incubation, first solutions which are dominantly associated with a math problem but lead to the wrong solution are inhibited. Then, weaker associations of both left-hemispheric computational concepts as well as right-hemispheric context-related information are integrated coherently by interhemispheric communication. As a result, if this new idea does not conflict with the problem, insight may occur. On the other hand, if conflict is detected, the faulty associations are inhibited and even more distant associations are given rise to. When insight occurs, it can then be consciously apprehended. If the insight gained is still faulty, the conflicting associations are inhibited again and the process starts over. When the insight is correct and fits as a solution to the problem, the impasse is resolved.

Now creatively adept students, like the mathematically gifted, may more efficiently and faster integrate ideas and concepts among a broader field of relations and context which results in faster and more innovative insight solutions. Henceforth, this implies that training the cingulate cortex and corpus callosum for creativity may elevate the levels of mathematical creativity not only in math-gifted students.

Concluding, there were several ways to train and integrate insight and incubation processes into the RME classroom. Furthermore, the proposed SIP model provided a framework for trainable cognitive processes relevant to incubation and insight derived from brain differences between creative, gifted students and intelligent math students.

Research Question and Hypotheses

Based on the aim of the current study and the proposed SIP model, the main research question concerns the investigation whether the corpus callosum and cingulate cortex are related to better creative processes involved in incubation and insight. This is important to investigate in order to bring clarity about the underlying processes of incubation and insight. Derived from this, it is hoped that RME curricula can regard and improve students' capacities for insight and incubation. Means used to gain insights into this issue are the comparison of mathematically gifted and mathematically intelligent students as well as investigation of the relation between the cognitive processes, incubation and insight. Implications of these findings may improve the urgently necessary integration of incubation and insight into RME curricula and further equip teachers and students with necessary skills and motivation to develop mathematical creativity.

To answer the research question, it is first worth examining whether the difference between mathematically intelligent and gifted students really lies in the higher creative capacities of gifted students. Thus, to account for differences in normal math-ability level, a test of conventional math-ability is employed. An expected outcome is that both mathematically intelligent and gifted students display the same normal math-ability level since they are supposed to only differ in creativity and motivation. The related hypothesis to this measure is as follows:

Mathematically gifted students and non-gifted intellectuals score equally well on conventional mathematic tests.

Next, a measure of interhemispheric communication is adopted from O'Boyle et al. (1994) since interhemispheric communication is proposed to be involved in the SIP model and reflects corpus callosum activity. Also, a conflict solving measure is utilized in the current study which had been linked to cingulate cortex activation (Van Veen & Carter, 2002). Conflict solving reflects the role of the anterior cingulate cortex in the SIP model. Based on the previous literature, which demonstrated that mathematically gifted students are more creative, it is expected that those students are superior on interhemispheric communication and conflict solving performance over mathematically intelligent students. Thus, the second hypothesis is:

Levels of interhemispheric communication and conflict solving are higher in mathematically gifted than in non-gifted intellectual math students.

Lastly, it is assessed based on the SIP model whether the proposed cognitive mechanisms are really underlying better incubation effects and insights. Because of the uncertain nature of incubation, two incubation tasks are employed in this study to gain more stability in results. One is related to insight in general while the other is specifically related to creative math problem-solving (Craig et al., 2018; Segal, 2004). It is expected that interhemispheric communication as well as conflict solving are indeed related to more efficient incubation and insight processes. Resulting, the third hypothesis states:

Higher levels of interhemispheric communication and conflict solving are related to better insight problem solving in both mathematically gifted, as well as non-gifted intellectual math students.

Methods.

Participants

In total, 9 students (3 female, 6 male) from math-related study programmes at the University of Twente in the Netherlands comprised the sample in this study. Two of these students dropped out after the first session, because the program for the second part of the study did not work on their computer's operating system. These students were removed from the data and the final sample consisted of 2 female and 5 male participants. The mean age of the 7 remaining participants was 19.86 (SD = 1.21) years and 7.57 months (SD = 2.64). All selected participants were among the top 10% of their study year grade-wise. Based on this, 6 participants were categorized as mathematically intelligent (MI). Only 1 participant was categorized as mathematically gifted (MG) due to participation in a variety of extracurricular math-programs and competitions (Olszewski-Kubilius & Lee, 2004). An additional grouping criterion was a mental-rotation task, however no participants distinguished themselves on this task so no re-grouping was necessary (Zhang et al., 2017). In Table 1, further relevant descriptive statistics for all participants as well as for the subgroups of MG and MI students are given.

Table 1

Descriptive statistics of participants

Variable	Demographic data	
	Mathematically Gifted (MG)	Mathematically Intelligent (MI)
Nationality	Other (N = 1)	Dutch (N = 4), German (N = 1), Other (N = 1)
Handedness	Mixed-handed (N = 1)	Right-handed (N = 5), Mixed-handed (N = 1)
Study programme	Applied Mathematics (N = 1)	Applied Mathematics (N = 4), Electrical Engineering (N = 2)
Year of study	BSc year 1 (N = 1)	BSc year 1 (N = 3), BSc year 3 (N = 2), MSc year 1 (N = 1)
	Mental rotation data	
	Mathematically Gifted (MG)	Mathematically Intelligent (MI)
Mental rotation correctness	93.75 %	93.06 %
Std. Deviation	-	2.52
Mental rotation time	1.29 s	1.47 s
Std. Deviation	-	0.40
N	1	6

Note. As can be seen, only one participant was included in the MG group.

In the current study the MG student as well as 1 MI student were identified as mixed-handed by the Edinburgh Handedness Inventory: Short-Form (Veale, 2014). It was questionable whether this reflects Benbow's (1986) findings of a higher proportion of mixed- and left-handers among gifted students. The sample size was too small to make inferences. Furthermore, the Handedness variable could potentially explain unexpected results of the interhemispheric communication measure (Iwabuchi & Kirk, 2009; Khedr et al., 2002). If the relation of the finger-tapping score with insight and incubation measures displayed an unexpected pattern, a post-hoc analysis testing for mediation and moderation due to handedness could be conducted.

Furthermore, the claim that gifted students usually performed better on mental-rotation tasks than non-gifted students was not supported (Hoppe et al., 2012; Prescott et al., 2010; Subotnik et al., 2011). Both MG and MI students performed with similar accuracy, and although the gifted student's response time was faster, it is still within one standard deviation of the MI group. These observations may not be valid due to the small sample size.

Lastly, the research was ethically approved and every participant gave their active informed consent. All participants received compensation in form of an online shopping voucher.

Materials

Background questionnaire – mental rotation test, background questions and EHI-SF

The background questionnaire was employed to collect relevant demographic data of the participants as well as data on grouping criteria to categorize students as MG or MI. For the complete questionnaire, see Appendix B.

Included in the background questionnaire, students were referred to a mental-rotation test. This test was created by researchers of the University of Twente and allowance was given to adopt it in the current study. It could be found on the website zap.psy.utwente.nl/zaps/en/. In this test, 48 set items were included and randomly presented, each consisting of two 3D figures. These figures were presented from different angles, rotated around the vertical axis. In each trial, the figures were either the exact same just from a different angle, or the same figure but mirrored and from a different angle. When the identical figures were presented, the participant needed to press the c-key, if the figures were mirrored, the m-key. After not responding for 5 seconds, a trial was counted as wrong. For the current study, the proportion of correct trials and mean time to respond to each item were collected.

In the background questionnaire, participants were asked to indicate several demographic and grouping-relevant variables. Demographic variables included age (in years and months), gender, nationality, study programme and year of study. Now, questions were asked about participation in extracurricular math-related activities since this had been related to math-giftedness (Olszewski-Kubilius & Lee, 2004). Variables utilized as criteria for grouping participants into the MG or MI groups included participation in the “Mathematics” honours programme at the University of Twente, participation in other giftedness programmes, amount of completed math-competitions during the last two years, and participation in other math-related extracurricular activities. Grouping into MG or MI categories was based on an approximate reflection of scientific literature about activities of gifted students.

To be categorized as MG, a total of 10 points on a giftedness scale were needed. To gain these points, a multidimensional assessment was used. If a student participated in the “Mathematics” track of the honours programme at the University of Twente, this student received 10 points. Students participating in this programme needed to demonstrate high math-ability, motivation and were able to come up with innovative solutions (University of Twente, 2020a; University of Twente, 2020b) which was sufficient to be identified as MG (Subotnik et al., 2011). For the same reasons, participation in another math-giftedness programme also was awarded with 10 points. According to Olszewski-Kubilius and Lee (2004), 70% of MG students participated one year or more in extracurricular math-programmes and 46.5% of MG students participated in no competition, while about 53.5% participated in predominantly math-competitions. Based on these criteria, participation in an extracurricular math-programme resulted in 8 points, and each participation in a math-competition was worth 2.5 points with a total of four math-competitions scoring 10 points to count as MG.

Lastly, a mental-rotation measure was adopted since it had been related to math-giftedness (Zhang et al., 2017). Based on a study by Hoppe et al. (2012), gifted students performed on a mental-rotation task with a proportion of approximately 88% correct trials with a standard deviation of 9%. At the same time, control subjects without math-talent displayed a proportion of 72% correct trials with a standard deviation of about 20%. This meant that there was an overlap within one standard deviation of non-gifted and gifted students between 88-92%. Therefore, for the current study, students received 5 MG criterion-relevant points if they scored higher than 1 standard deviation above the normal-ability students, meaning 92% of correct trials on the mental rotation task, which laid within the range of math-gifted students. An overview of these criteria is given in Table 2 below.

Table 2

Grouping criteria

Criterion	Score
Participation in the "Mathematics" honours programme of the University of Twente	10 pt.
Participation in another verified math-giftedness programme	10 pt.
Participation in another math-related extracurricular activity	7.5 pt.
Participation in math-competition(s)	2.5 pt. per competition
Above 92% correct on mental rotation trials	5 pt.

Note. In total 10 pt. were needed to be classified as mathematically gifted in the current study.

Further, the Edinburgh Handedness Inventory: Short-Form (EHI-SF) (Veale, 2014) which measures handedness was included in the background questionnaire. It included 4 items concerning performance of writing, throwing, using of a toothbrush and using a spoon. As response categories, the participants could select *always right, usually right, both equally, usually left* and *always left* depending on which hand they performed the named actions with generally. All items displayed high internal reliability ($\alpha = 0.93$), model fit ($\chi^2 = 158.53$) and a confirmed underlying factor-structure (Veale, 2014). The items as well as scoring criteria can be viewed in Appendix B.

Normal math ability test – SAT-derived questions

To assess normal mathematical ability, questions were extracted from an example scholastic aptitude test (SAT) (collegeboard, n.d.). Of the problems to be solved without calculator, seven questions were sampled (Appendix C). One question had an easy difficulty level, while four had a medium and two a high difficulty level as judged by the website they were derived from (collegeboard, n.d.). For the scoring criteria on this test included in the current study, refer to Appendix C.

No reliability data were available for this particular set of questions and for the current study, no reliability test could have been conducted because the test results were not fit to conduct a reliability analysis. The resulting Cronbach's alpha was negative ($\alpha = -0.23$) due to too little variance.

Participants were instructed that they could not use a calculator or internet for help. All questions were displayed consecutively and the participant could freely go back and forth between the items.

Interhemispheric communication measure – finger tapping paradigm

To assess the interhemispheric communication function of the corpus callosum, a finger-tapping task was employed (Zhang et al., 2017). In this task, students were asked to consecutively tap on a button for a period of 10 seconds with each their right- and left-hand index finger (O'Boyle et al., 1994). The test consisted of 5 trials per hand. Which hand participants started with was randomized. Each text was the beginning of a fictional story derived from the website "americanliterature.com" (see Appendix D) and was presented in a random order. Responses were collected in form of taps per second for each hand condition.

As a resulting measure for this task, the asynchrony between the tapping rate of both hands was computed. Conceptually, if the right hand was tapping slower than the left hand, this would have indicated that the left hemisphere (which controls the right hand) was occupied with processing verbal information additionally to control the finger movement. An equal tapping rate would have indicated a synchrony of both hemispheres involved in the verbal information processing. In a previous study, the first pattern was observed more for MI students and the latter for MG students (O'Boyle et al., 1994).

Conflict solving measure – Eriksen flanker task

Next, the Eriksen flanker task (Eriksen & Eriksen, 1974) was adopted for this study to measure conflict solving and anterior cingulate cortex activity (Van Veen & Carter, 2002).

In this task, for each trial a 5-digit stimulus was presented based on the pattern "ZZXZZ". The numbers used to compose these patterns were 1, 3, 8 and 0. What mattered for the response was the middle number in place of "X". The numbers in place of "Z" were the flanker stimuli. If the number in place of "X" was a 1 or 3, the participant was instructed to press the q-key as fast as possible. If this number was an 8 or 0, the participant should have pressed the p-key, also as fast as possible.

Now there were three different conditions of trials. In the first congruent (CO) condition, all numbers were the same, like “88888”. In the second (RO) condition, both numbers of the same button-press response condition were shown, like “11311” or “00800”. Lastly, in the third incongruent (RI) condition, numbers from different response conditions were displayed, like “11811” or “00300”.

When presented to participants, the screen first displayed a fixation cross in place of “X”, to focus one’s eyes on. Then in a randomized interval between 500ms and 1500ms, the stimuli were presented until the q-key or p-key was pressed. Following this, the fixation cross appeared again and after the same randomized time interval as before, the next stimulus was presented. In total, 160 such trials have been administered with a proportion of 50% of CO trials and 25% for each the SI and RI condition trials.

Especially in the RI condition, the incongruence between the response digit and flanker stimuli resulted in longer reaction times and corresponded to activity in the anterior cingulate cortex during conflict detection and resolution (Van Veen & Carter, 2002). Therefore, the derived measures of importance in the current study were task accuracy and reaction time on the RI condition as opposed to the CO and SI conditions.

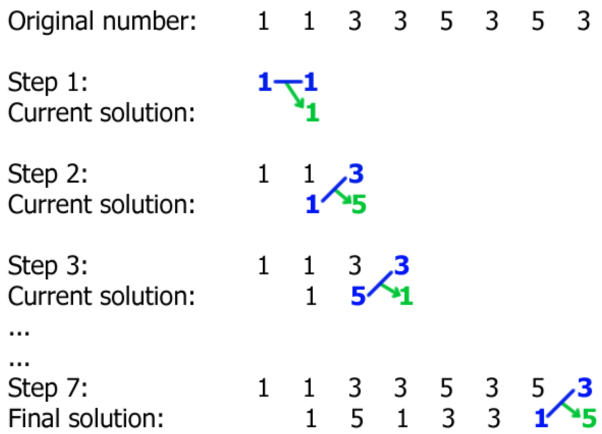
Insight and Incubation measure 1 – Number reduction task

Next, the first measure to assess incubation effects in terms of resulting insight was the number reduction task (NRT). In this task, participants were given a set of three different numbers. Then multiple trials were given, each with eight digits made up of three numbers comprising the current set. Each set included 10 trials. From each eight-digit number, a seven-digit solution had to be inferred based on 2 rules which were given to the participant: First, two identical numbers resulted in the same number again. Second, two different numbers gave the third number in the set. View Figure 2 for an example trial on how to solve the task.

However, there was also a third hidden rule not stated to the participant. In this rule, the last three digits of the solution always mirrored the three digits before (digit 2, 3 and 4). Once a participant found this hidden pattern, the rule was revealed by insight and the next trials were solved faster. This point could be traced in the data and indicated when insight had occurred (if it had occurred).

Figure 2

Number reduction example trial



Note. This Figure represents the way the number reduction task can be solved based on two rules. The first rule stated that two same numbers resulted in the same number again (Step 1). The second rule stated that two different numbers resulted in the third number of the set (Step 2, 3 and 7). Note that Step 1 is slightly different because the first two original numbers were used to derive the first solution number. Afterwards, digit 3 of the original number was compared with digit 1 of the solution which resulted in the second digit of the solution. This pattern was continued and digit "x" of the original number was compared with digit "x-2" of the solution to result in digit "x-1" of the solution. There was also a third, hidden rule which states that the last three numbers of the solution always mirrored the previous three (Digit 2, 3 and 4).

First, each participant received three sets which needed to be solved correctly. If the answer was wrong, the participant needed to solve the task again until it was correct. Following this, the participants were given a ten-minute incubation break in which they were instructed to just let their mind wander which had been related to higher insight (Tan et al., 2015). Then ten sets of ten trials were presented and to be solved without indication whether the answer was correct or not. From this point onwards, wrong answers were also collected as data.

Task performance was measured based on time to complete the trials and correct responses. And the incubation measure was based on the time it took for insight about the third hidden rule to occur. Since insight was usually obtained after the incubation period on this task (Craig et al., 2018), the incubation measure was based on the point of time when insight occured after the incubation period.

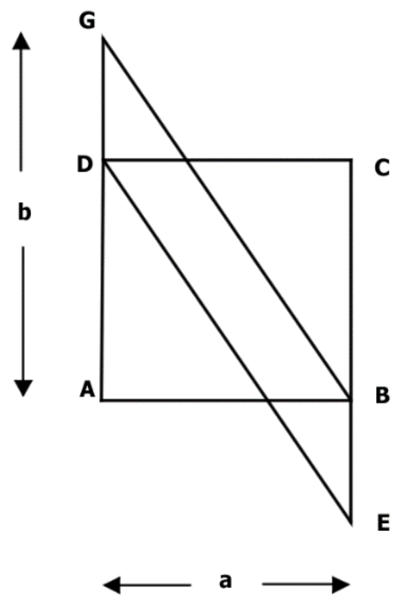
Insight and Incubation measure 2 – Creative geometric math problem

As a real mathematical insight task, a geometric problem was adopted for the current study from Segal (2004) who adopted it from Ohlsson (1984) (see Figure 3). The problem was presented as follows: "*Given that* $\overline{AB}$ *= a and* $\overline{AG}$ *= b, find the sum of the areas of square ABCD and parallelogram EBGD*" (Segal, 2004, p. 145).

In this specific problem, the way of wording the problem directed attention to a wrong way of solving it, namely using a parallelogram and a square to solve it. However, it was only solvable by viewing the problem as involving two triangles. This insight was crucial for solving the task correctly. And the resulting solution was "*The sum of their areas is 2 x ab/2 = ab*" (Segal, 2004, p. 144), but for the current study, just indicating "ab" as an answer was correct.

Figure 3

Creative math problem



Note. Original in Ohlsson (1984).

Students were first given theoretically infinite time to solve the problem. They were instructed to take an incubation break which involved reading of a few newspaper articles for 10 minutes after they reached an impasse (see Appendix E). Students could freely decide to take this incubation period. The responses were collected based on correct trials, the point of time where insight was gained and the mean time needed to solve trials before and after the incubation period. Later, it could have then been compared whether certain students who reached an impasse had a more effective incubation period than others. This was based on time difference in solving the trials before and after incubation as well as faster gaining of insight after incubation (Segal, 2004).

Procedure

All materials were administered in English and the study materials were pilot tested and optimized prior to administration. Further, before participating in the study, students received general information about the nature of the study and gave their informed consent to participate. Then they started the study.

Overall, the study was divided into two parts. The first took about thirty minutes and the second up to one hour and thirty minutes to finish. The first part consisted of the background questionnaire and was administered online via qualtrics.com, a surveying website. At least one day after this session, the participant met up with the researcher in a quiet lab-environment at the University of Twente for the second part of the study. In this part, first the conflict solving and finger tapping task were administered since they were the least demanding. Then, the creative and normal math tests were to be solved. Lastly, since this task took the longest to solve, the NRT was presented to the participant. Afterwards, the response was collected and a debriefing was given. Between each the cognitive measures, the math tests, and at the end of the NRT, a 5 to 10 minutes break was included.

Unfortunately, the data collection of the current study took place during the Covid-19 pandemic in 2020. Therefore, the second part of the study was converted into a computer program which was solved by participants at their home. No material content, presentation or order of administration changed because of this. The researcher sent the program together with instructions on how to open it, how to extract the results file and what to do in case the program crashed to participants via mail. Before each assessment in the program, proper instructions were given which have been pilot-tested with a focus on understandability of the tasks. Further, students were assigned to take their own breaks between the tasks and were allowed to save their current progress to resume another time. Also, the researcher was available to answer any questions by mail. Sending the data file back to the researcher concluded participation in this study and a sheet with correct solutions was sent to students afterwards.

Data Analysis

First, demographic data and grouping-relevant data were analyzed. For scoring and analysis of grouping criteria, refer to the background questionnaire in the Materials section.

Second, the mean scores on the normal math-test of the MG and MI students were compared to test whether there was a difference between both groups. For this, between-group means were compared and the non-parametric Mann-Whitney-U-test was employed since it best fitted the data for which a normal distribution could not have been assumed.

Third, the data related to the cognitive mechanisms of interhemispheric communication and conflict solving were compared among both groups of students. For the level of conflict solving, the relevant measures were mean reaction time and proportion of correct answers for each the CO, RO and RI conditions. Here, also reaction time was correlated with proportion of correct answers to see whether reaction time difference was related to increased or decreased accuracy. Related to interhemispheric communication, finger tapping (a)synchrony was compared. Here as well, means were compared and a Mann-Whitney-U-test was conducted also because no normal distribution could have been assumed.

Fourth, for the incubation and insight measures, a correlational framework was employed. Both finger tapping synchrony and performance on RI trials (time and correct proportion) were correlated with measures of incubation effects. In the creative math task, the incubation effect was operationalized as time needed to gain insight indicated by the point of time in which the task was solved correctly after the incubation period. And for the NRT, the incubation effect was measured as the point of time where insight about the third hidden rule was gained after incubation.

Results

Normal math ability in MG and MI students

The normal math ability as measured by an example SAT test should have indicated whether there was a difference on mathematical intelligence between MG and MI students. The MG student scored on the test with full 150 points, while the MI students had a mean score of 141.67 (SD = 13.29). A Mann-Whitney-U-test indicated that the mean scores between both groups have not been significantly different (Mann-Whitney U = 2.00; $p = 0.86$).

In total this means there was no observed difference between participants on SAT test item performance because the full score was still within reach of 1 standard deviation for the MI students.

Level of conflict solving in MG and MI students

The next measure of concern was the level of conflict solving as measured by the Eriksen flanker task which was supposed to reflect the efficiency of the cingulate cortex. In Table 3, the mean performance on the different stimuli conditions in terms of time and accuracy were displayed for both MG and MI students.

As can be seen by the results below, there were not many differences within groups on the CO and RO conditions. On the RI trials however, the MG student displayed an increased reaction time (0.57s) as opposed to the other conditions (0.51s; 0.51s) while maintaining the same proportion of correct trials (95.00%). The MI students showed the same pattern with a reaction time of 0.64s (N = 6; SD = 0.07) on the RI trials as opposed to the CO (0.61s; N = 6; SD = 0.05) and RO (0.62s; N = 6; SD = 0.07) conditions. In total, the reaction time difference was larger between groups with a collapsed mean difference of 0.90 seconds than within group with only small differences between conditions. The proportion of correct trials however was not meaningfully different between groups.

Table 3

Eriksen flanker task performance

Condition	Mean reaction time		Proportion of correct trials	
	MG	*MI*	*MG*	*MI*
CO	0.51 s	0.61 s	96.25 %	95.21 %
RO	0.51 s	0.62 s	95.00 %	96.67 %
RI	0.57 s	0.64 s	95.00 %	94.17 %
Collapsed mean:	0.53 s	0.62 s	95.42 %	95.35 %

Furthermore, a Pearson correlation between reaction time and proportion of correct trials has indicated that no correlation exists among the CO (r = -0.04; p = 0.94) and RO (r = -0.13; p = 0.78) trials. A stronger, low to moderate correlation was observed among RI trials (r = 0.49; p = 0.26). As can be seen, these correlations were insignificant. Also, a Mann-Whitney-U-test analysis revealed no significant difference between the groups on both reaction time and proportion of correct trials on all stimuli conditions (Mann-Whitney U = 0.00-2.50; p = 0.29-0.86).

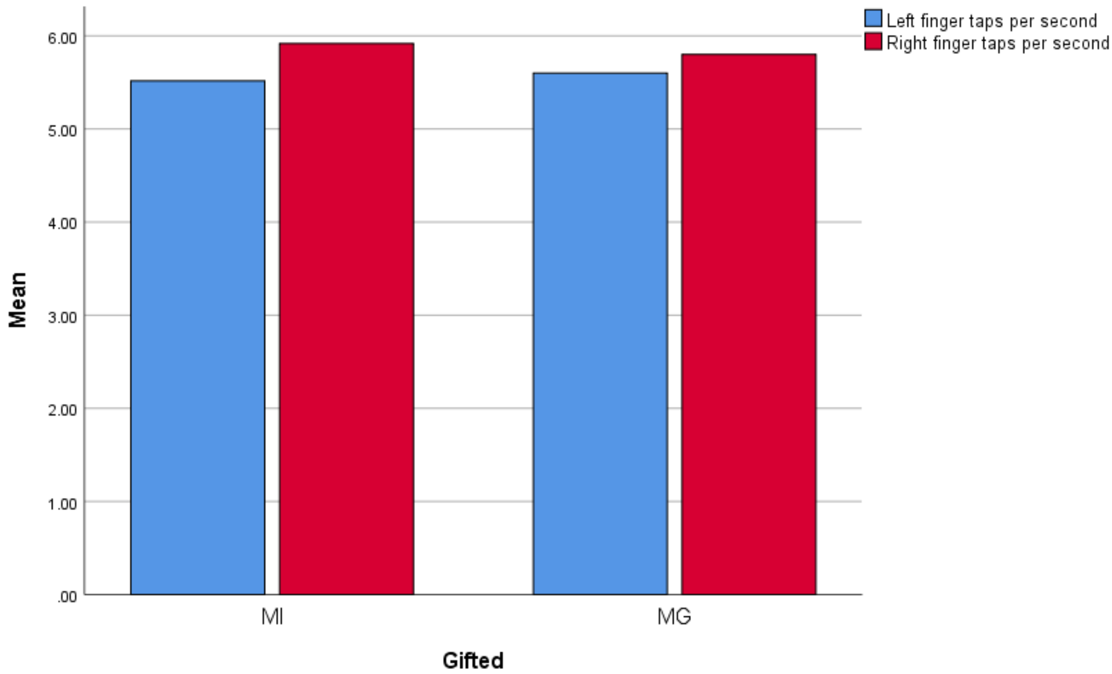
In summary, there were two main differences in performance on the Eriksen flanker task. First, the within-group difference on RI trial reaction time as opposed to the other conditions was higher for the MG student than for the MI students. And second, there was a difference of 0.9s between both groups on the collapsed mean of reaction time. These differences were not significant though.

Level of interhemispheric communication in MG and MI student

For the finger tapping task, the asynchrony of both fingers measured by difference in tapping rate between both hands was of importance. First, during reading out loud of the text presented in the finger tapping task, the MG student was tapping with the left finger about 5.6 times per second and with the right finger 5.8 times on average. The MI students on the other hand were tapping faster with a mean rate of 5.52 (N = 6; SD = 1.05) taps per second with the left hand and 5.92 (N = 6; SD = 0.95) taps per second with the right hand. This is depicted in Figure 4 below.

Figure 4

Average index finger tapping rate per second



From this figure, it emerges that there was only a slight difference in tapping rate between hands for both groups. The MG student's asynchrony score was 0.2 taps per second while the MI students had a slightly lower mean asynchrony of 0.4 taps per second. Since both asynchrony scores were positive, this meant that all students had a higher tapping rate with their right instead of their left index finger.

Next, a Mann-Whitney-U-test showed that there was no significant difference between groups (Mann-Whitney U = 2.50; p = 0.86). Furthermore, the findings from the asynchrony differences conflicted with the original study the measure was derived from where it was expected that the left-finger tapping was slower (O'Boyle et al., 1994). Thus, a post-hoc analysis was employed to test whether finger tapping asynchrony is correlated with handedness which is common in literature (Iwabuchi & Kirk, 2009; Khedr et al., 2002). In this analysis, finger tapping asynchrony and score on the Edinburgh Handedness Inventory: Short-Form (Veale, 2014) were correlated. A negative, weak Pearson correlation resulted which was also insignificant (r = -0.29; p = 0.52).

Summarizing, both MG and MI students displayed a slightly higher tapping rate with their right hand. Further, only a slight difference in finger tapping asynchrony of 0.2 taps per second was observed between both groups.

Conflict solving and interhemispheric communication level related to incubation and insight

Another analysis of concern were correlations of conflict solving and interhemispheric communication measures with indicators of incubation efficiency and insight.

For reasons of redundancy, the incubation measure from the creative math task was removed from the analysis because no participant utilized the incubation time they could use freely. Therefore, a post-hoc correlation between the time needed for insight to occur and potentially underlying cognitive measures was conducted. In this analysis, only the 4 students are included who gave the right answer on the creative math problem which was an indication of correct insight.

Furthermore, no students reported that they found the hidden rule on the NRT. This implies that no insight was observed. Therefore, another post-hoc analysis was conducted to assess the correlation of conflict solving performance and interhemispheric communication with another incubation efficiency measure. This measure involved the mean time difference to solve number reduction trials before and after the incubation phase. Table 4 displays the results of both correlational post-hoc analyses. All correlational statistics display the outcome of a Pearson correlation.

Table 4

Correlation between cognitive measures, insight and incubation measures

Cognitive measures	Solving time of the creative math problem	Before-after mean time difference of the NRT
RI (μ time)	0.81	0.32
RI (% correct)	0.82	0.12
Finger tapping asynchrony	0.14	-0.35
N	4	7

Note. No results were significant.

Based on the rule of thumb, both indicators of task performance on RI trials were highly positively correlated (r = 0.81-0.82; p = 0.14-0.19) with the solving time of the creative math problem. A weak positive correlation (r = 0.32; p = 0.48) was also found between RI mean time and the incubation effect on the NRT. Furthermore, a weak negative correlation (r = -0.35; p = 0.44) was obtained between the finger tapping asynchrony score and the incubation effect on the NRT. However, none of the results were significant.

In summary, the original measures of insight after incubation could not be employed. For the post-hoc analyses, most importantly there may have been a strong relation between performance on RI trials and time of insight on the creative math problem. All results of the post-hoc analyses were not significant.

Discussion

The overarching aim of the study was to gain clarification into underlying brain mechanisms of mathematical creativity to add to the under-researched field of creativity in math education (Leikin & Pitta-Pantazi, 2013; Sriraman, 2004). Based on this, the research question to be answered concerned whether the corpus callosum and cingulate cortex are related to better creative processes involved in incubation and insight. To answer this, interhemispheric communication by the corpus callosum and conflict solving by the cingulate cortex were proposed in the SIP model to act together to subconsciously process information during incubation giving rise to innovative insights. Based on the results of the current study, hope is to obtain insights which could lead to better suited curricula towards realistic mathematics education (RME) which regard and train the students' capacities for creative math-problem solving.

Differences in cognitive processes between groups

To see whether cognitive processes are really related to mathematical creativity, mathematically gifted (MG) and mathematically intelligent (MI) students were compared. Both groups are conceptually supposed not to differ in intelligence, but only creativity and motivation (Sriraman, 2005; Subotnik et al., 2011; Zhang et al., 2017).

Performance on the normal math-test employed to test whether this holds true did not indicate any differences between groups on conventional math-ability. Therefore, the null-hypothesis stating that there is no difference in math-ability between MG and MI students was supported. Based on this, the differences between both student groups are not attributable to a difference in intelligence.

Results of the conflict solving measure have indicated that the MG student solved trials in all conditions faster than MI students while retaining the same proportion of correct responses. However, the MG student's reaction time increased more on trials which are associated with cingulate cortex involvement in conflict resolution than the MI students. This supports the hypothesis that conflict solving level is higher for MG than MI students in terms of reaction speed and error detection. An implication of this is that MG students process coherent information faster than MI students while detecting and resolving conflict more elaborately too.

Further, among no task condition was the reaction time in general significantly related to the proportion of correct trials. This means that accuracy among the trials is independent from the reaction time needed to respond to the trials. Therefore, different types of performance as indicated by reaction time may lead to the same accuracy.

Next, related to interhemispheric communication underlying corpus callosum activity, there is only a slightly higher synchrony of brain hemispheres observed for the MG student. Thus, the hypothesis that interhemispheric communication is higher in MG than in MI students is rejected, or only slightly supported. This would mean that interhemispheric communication does not make a meaningful difference for creativity among MG students. Perhaps this could imply that interhemispheric communication is attributable to intelligence instead of creativity since all participants displayed more finger tapping synchrony than found in the original study (O'Boyle et al., 1994). Indeed, in their study, O'Boyle et al. (1994) have compared gifted students to average-ability students not accounting for effects of intelligence, which may attribute the difference in finger tapping synchrony observed in their study rather to intelligence. Further, this may be explained by literature which has attributed a better developed corpus callosum to general intelligence (Luders et al., 2007).

What was further unexpected is the fact that both MI and MG students showed slightly higher involvement of the right hemisphere in processing of verbal information. This is opposed to a majority of the findings according to which language processing occurs within the left-hemisphere and for left- and mixed-handed students and MG students in both hemispheres at best, but not dominantly in the right hemisphere (Baldo & Dronkers, 2007; Szaflarski et al., 2002). Further, the finger tapping asynchrony outcomes were also not better explained by handedness. Based on this, the validity of the finger tapping task adopted in the current study is questioned.

For each of the three previous analyses, the observed difference was not significant and likely due to chance as indicated by Mann-Whitney-U-tests. Thus, none of the results can be generalized and are only observed within this specific study.

In summary, there is a difference between MG and MI students on conflict solving ability which indicates different types of cognitive conflict solving strategies. The strategy of gifted, creative students would be to answer with a faster response time generally and better detection of errors. These differences are not attributable to different math-intelligence levels. Furthermore, the validity of the finger tapping task is questioned because the results conflict with the study it was derived from as well as with a well-established view that language processing resides in the left hemisphere. None of the differences however were significant and interpretations of the results cannot be generalized.

Cognitive Processes underlying Incubation and Insight

In the second part of the study, it was examined whether the cognitive processes which are supposed to be related to math-creativity are related to the creative processes of incubation and insight.

Unfortunately, no student on the creative math test used the freely available incubation period which potentially could have resulted in insight for those students who did not have the correct answer. This reflects the literature which states that students have not been taught and usually have not known how to cope with an impasse (Savic, 2016). Thus, for the creative math-test a post-hoc analysis was conducted to assess whether conflict solving ability and interhemispheric communication are related to a faster gaining of insight, isolated from a previous incubation period.

The results indicate that a longer conflict resolution time together with higher conflict solving accuracy are related to a later point of insight. This supports the hypothesis that conflict solving performance is related to faster gaining of insight depending on one's interpretation. Accordingly, conflict solving by activation of the anterior cingulate cortex may be supported in the SIP model. Based on the observed pattern, students having faster conflict solving mechanisms, indicated by faster response times together with less correct responses, might gain insight faster. However, only students with the correct answer on the creative math task are involved in this analysis. Thus, it may be possible that faster conflict solving at the expense of more errors may result in faster insight, but more erroneous insight which has not been accounted for by the current study. On the other hand, students who take more time for conflict solving may gain more fruitful insight by carefully thinking about and relating information.

These two strategies to receive insight may reflect the slow and fast thinking systems (Evans, 1984) which have also been related to differences in slow and fast thinking on conventional math problems (Lin et al., 2012). Further, since both intuition and rational judgements are important in math creativity (Mann, 2006), the faster, erroneous insight-gaining could reflect an intuitive approach while the slower insight-gaining may be related to slower analytical thought. Such individual differences would be important for teachers to remember when interacting with students or developing RME curricula. Further, these results suggest that training the cingulate cortex may have some beneficial effect in improving insight-gaining, but the nature of this effect is unclear currently.

However, no important relationships were found for the interhemispheric communication measure. This rejects the hypothesis that interhemispheric communication is related to insight-gaining.

The role of interhemispheric communication is therefore questioned in the SIP model. Further, all correlations have been insignificant, which complicates the generalization of results.

Secondly, the results of the number reduction task (NRT) are also problematic since they are not suited for the original analysis. Here, the pattern is reverse: Students did engage in incubation, but they did not gain insight as a result, which was usually found in other studies employing the NRT (Tan et al., 2015). Thus, another post-hoc analysis was conducted to see whether a different incubation effect was related to conflict solving ability and interhemispheric communication, namely an improvement on solving time of trials after an incubation break.

For this analysis, only weak relations have been found, which rejects the hypothesis that the cognitive mechanisms are related to incubation and thus rejects their role in the SIP model. However, this may be explained by the invalidity of the interhemispheric communication measure adopted in this study mentioned earlier. The weak associations which were found imply that longer responses on the conflict-evoking trials and higher synchrony between both brain hemispheres are related to a higher incubation effect. This would support the SIP model, but the associations are too weak and insignificant to derive meaningful insights and the measurement of interhemispheric communication is possibly invalid.

In summary, the hypotheses aiming to confirm the SIP model have been rejected, but rather the individual role of conflict solving by the anterior cingulate cortex in creativity is somewhat supported. Two possible types of gaining insight have been observed based on conflict solving ability. One is more intuitive and faster in solving conflicts, and detects conflicts more elaborately, which would correspond to MG students and the other is more analytical and takes more time, which could be related to MI students. This suggests that creativity associated with giftedness may not be necessary to gain insight (at least in the current study) but can result in faster insight. However, the results in the study were insignificant and cannot be generalized.

Limitations and further research

Methodological concerns

The first and most obvious flaw of the current study is the small sample size leading to non-generalizable findings. The small number of participants may be attributable to three factors: First, the recruitment period took place during the Covid-19 pandemic in 2020, thus students may be less motivated to participate in studies. Second, for the same reason, the researcher could not adopt several recruitment methods, especially those involving physical presence. And third, combined with the reasons before, the length of this two-hour study may be demotivating to students despite the compensation via an online-shopping voucher. Any follow-up research should try physical and online recruiting methods and provide more compensation for participation to gain a bigger sample size. Further, two students dropped out of the study because the program sent to students was not compatible with their computer's operating system. Future studies should identify this problem before data collection and either make the program compatible with every operating system or mention this in the requirements to participate in the study.

The reason why a program had to be adopted and was sent to participants online in the first place is only due to security measures during the Covid-19 pandemic. Individual variability may be higher due to the uncontrollability of the environment where the study is conducted. Related, the incubation phase during the NRT has intentionally been set in an environment with minimal sensory interference during mind-wandering (Craig et al., 2018). Since this has probably affected the study most, together with the small sample size, it may be worthwhile to re-do the entire study in a more controlled lab-setting with physical attendance of a researcher during all tasks.

Next, in the current study, the conceptualization of gifted students as creative, intelligent and motivated was employed and used to categorize students (Sriraman, 2005; Subotnik et al., 2011; Zhang et al., 2017). However, there is no uniform definition of giftedness and certain definitions always have been at risk to misidentify potentially gifted children as non-gifted (Subotnik et al., 2011). The current study tried to counteract this by adopting a multidimensional approach for identification of gifted students, however this method has not been tested for sensitivity and is merely derived from conceptual implications of what giftedness entails. Future studies could aim to identify a clearer picture of math-giftedness and test specific methodologies for identification of MG students.

Also, since a ceiling effect is observed for the normal math-ability test, it may be possible that there is a difference level between both groups of students on math-intelligence, but the measurement was unable to identify them since questions were too easy. SAT tests, where the questions in the current study were derived from, have usually been used to assess pre-college level in the USA. Because all students in the current study are already in the University, this test may have indeed been too easy. On the other hand, some of the students did not obtain full points, which might indicate that the difficulty level is appropriate and no real differences are observed. More students in the MI and MG group have received full points on the test than not full points which means that it is not attributable to an exceptional performance of the MG student either. To examine this point, future studies could include average-ability students as a separate group too and see whether they also score full points.

Even when no difference in intelligence is observed, the difference in measures used in the current study may not be (solely) attributable to creativity, but also to motivation since MG students have displayed higher levels of both than MI students (Zhang et al., 2017). It may even be reflected in the grouping criterion that MG students often participate in more extracurricular programmes related to mathematics since this indicates a strong motivation to engage in math activities. A further problem with this point is that such a grouping criterion may overlook mathematically gifted students with high creativity, but low motivation to engage in extracurricular programmes, autodidactic and more generally "unofficial" learning. Future studies may try to implement specific measures for creativity and motivation to account for these faults. In the current study, such measures were not employed since they were inaccessible and would also have stretched the length of the study too much.

Further, no reliability analyses could be conducted for the normal math ability test due to too little variance. This may be due to the test being employed to find out whether there is no difference, as well as the small sample size. However, in a future study, the test could be employed to find a difference between normal-intelligence and high-intelligence math students. If the test can then reliably obtain valid differences, it would also be able to detect an equal level of math-intelligence reliably. Also, the participants were instructed not to use internet help or a calculator, but since the study was not conducted in a controlled lab environment, it could not be checked.

Another methodological flaw may be the adoption of the finger tapping paradigm to measure interhemispheric communication. As mentioned earlier, in the current study results on this measure support a claim that language is lateralized in the right hemisphere. This is in direct opposition to many different studies which have confirmed the dominant view that verbal processing occurs in the left hemisphere (Baldo & Dronkers, 2007; Szaflarski et al., 2002). This gives rise to two lines of future research. First, the finger tapping paradigm could be investigated further in terms of validity to measure interhemispheric communication. And second, if the current study is repeated or a similar study is developed, researchers should rely on other means of measuring interhemispheric communication like brain-imaging devices or the dichotic listening test (Cowell & Hugdahl, 2000; Doron & Gazzaniga, 2008).

And lastly, a problem occurring in the current study was that both the creative math problem as well as the NRT were unsuccessful at measuring incubation effects and insight at the same time. As a result, the findings are detached from the process of incubation resulting in insight and examine both phases of creative problem-solving individually. On the creative math-test, students were encouraged to use the incubation period. Apart from that students may not know how to cope with an impasse and thus do not want to take an incubation period, it could also be improved by integrating the incubation period into the task. In the original study, when students did not solve the creative math-problem after twenty minutes, they had to take an incubation period (Segal, 2004). For the NRT, this problem may have occurred because the amount of maximum trials has been reduced by one third of the trials from the original study (Craig et al., 2018). This may have deprived participants of valuable time to arrive at the insight about the hidden rule. However, in the original study, only this task was assessed while in the current study multiple assessments are involved. Using the original amount of trials would result in too much participation time and possibly affect the results due to concentration loss. Follow-up research could thus use the original amount of trials or other means of measuring incubation resulting in insight and split the measures up into multiple studies each with a shorter total timespan needed.

Further research based on conceptual implications

Future research could also try to identify the SIP model proposed here by other, more precise means like brain-imaging of the corpus callosum and cingulate cortex during incubation and insight. Alternatively, different study designs investigating different cognitive processes in relation to incubation and insights could be conducted. It is just important to gain clarification about underlying processes to train students accordingly within RME curricula and give them the rewarding experience of insight more often which has not only increased their motivation, but has also resulted in more innovative ideas (Liljedahl, 2013; Mann, 2006; Sitorus, 2016; Sriraman, 2005; Yuan & Sriraman, 2011).

Furthermore, the main observation of the current study is the differentiation between intuitive and analytical type in gaining insight. The intuitive insight-type is reflected by either a lower time and proportion of correct responses on the conflict solving task. This type is associated with faster correct solutions on the creative math task. On the other hand, the analytical type may take longer to respond to conflict solving tasks with a higher rate of correct answers, ultimately resulting in slower correct performance on the creative math test. A future study could identify whether these insight-types really exist, since it may help in structuring RME curricula regarding both types, and whether the intuitive insight-type is attributable to math-giftedness while the analytical insight-type is related to math-intelligence as suggested.

Moreover, it could be assessed whether the insight-type can be evoked in analytical MI students and be trained by e.g. meditation which has increased connectivity of the cingulate cortex and corpus callosum (Fox et al., 2014). Other means of training could also be examined.

Lastly, once the cognitive mechanisms of creativity in mathematics are further explored and have improved RME curricula, the long-term effects of this should be examined in a longitudinal stury by measuring whether creative capabilities in math really result in better job opportunities, or innovative ideas over time.

Conclusion

In conclusion, the study has stressed the need to further examine the cognitive mechanisms involved in incubation and insight since a lot of uncertainty surrounds these creative processes. Also, more generally there is a need for more research about mathematical creativity to increase the efficacy of RME. These needs have somewhat been fulfilled by the current study since insights were gained into the role of the corpus callosum and cingulate cortex in relation to creativity in math, specifically the incubation and insight processes. Due to methods of questionable validity and a small sample size, interpretation of the results is difficult. The main finding which is worthwhile to be investigated further, is the proposed differentiation of analytical and intuitive insight-gaining strategies and their relation to math-giftedness and math-intelligence.

It is important to investigate these and other issues further to improve RME by increasing student's capacities for creativity in mathematics. Ultimately, the venture of improving RME will result in more students being motivated for mathematics, who will bring innovation by applying math to real-world problems.

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References

Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., ... & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *Journal of Neuroscience, 32*(44), 15601-15610. https://doi.org/10.1523/JNEUROSCI.2957-12.2012

Baldo, J. V., & Dronkers, N. F. (2007). Neural correlates of arithmetic and language comprehension: A common substrate?. *Neuropsychologia*, *45*(2), 229-235. https://doi.org/10.1016/j.neuropsychologia.2006.07.014

Beaty, R. E., Benedek, M., Wilkins, R. W., Jauk, E., Fink, A., Silvia, P. J., ... & Neubauer, A. C. (2014). Creativity and the default network: A functional connectivity analysis of the creative brain at rest. *Neuropsychologia*, *64*, 92-98. https://doi.org/10.1016/j.neuropsychologia.2014.09.019

Beckmann, M., Johansen-Berg, H., & Rushworth, M. F. (2009). Connectivity-based parcellation of human cingulate cortex and its relation to functional specialization. *Journal of Neuroscience, 29*(4), 1175-1190. https://doi.org/10.1523/JNEUROSCI.3328-08.20

Bennet, A., & Bennet, D. (2008). The human knowledge system: Music and brain coherence. *Vine*.

Bray, A., Oldham, E., & Tangney, B. (2015, February). Technology-mediated realistic mathematics education and the bridge21 model: A teaching experiment. https://hal.archives-ouvertes.fr/hal-01289351

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*(6), 215-222. https://doi.org/10.1016/s1364-6613(00)01483-2

Collegeboard, (n.d.). *Sample questions*. Collegeboard. https://collegereadiness.collegeboard.org/sample-questions/math

Cowell, P., & Hugdahl, K. (2000). Individual differences in neurobehavioral measures of laterality and interhemispheric function as measured by dichotic listening. *Developmental Neuropsychology*, *18*(1), 95-112. https://doi.org/10.1207/S15326942DN1801_6

Craig, M., Ottaway, G., & Dewar, M. (2018). Rest on it: Awake quiescence facilitates insight. *Cortex, 109*, 205-214. https://doi.org/10.1016/j.cortex.2018.09.009

DeAzevedo, L. C., Hedin-Pereira, C., & Lent, R. (1997). Callosal neurons in the cingulate cortical plate and subplate of human fetuses. *Journal of Comparative Neurology*, *386*(1), 60-70. https://doi.org/10.1002/(SICI)1096-9861(19970915)386:1<60::AID-CNE7>3.0.CO;2-B

Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin*, *136*(5), 822. https://doi.org/10.1037/a0019749

Ding, X., Tang, Y. Y., Tang, R., & Posner, M. I. (2014). Improving creativity performance by short-term meditation. *Behavioral and Brain Functions*, *10*(1), 1-8. https://doi.org/10.1186/1744-9081-10-9

Doron, K. W., & Gazzaniga, M. S. (2008). Neuroimaging techniques offer new perspectives on callosal transfer and interhemispheric communication. *Cortex*, *44*(8), 1023-1029. https://doi.org/10.1016/j.cortex.2008.03.007

Doyle, M., & McCoy, L. P. (2012). Creative expression in the math classroom: How incorporating performance arts affects student engagement and motivation. *Studies in Teaching 2012 Research Digest*, 37-41.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics, 16*(1), 143-149. https://doi.org/10.3758/BF03203267

Evans, J. S. B. (1984). Heuristic and analytic processes in reasoning. *British Journal of Psychology*, *75*(4), 451-468. https://doi.org/10.1111/j.2044-8295.1984.tb01915.x

Fox, K. C., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., ... & Christoff, K. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience & Biobehavioral Reviews*, *43*, 48-73. https://doi.org/10.1016/j.neubiorev.2014.03.016

Gravemeijer, K., Bruin-Muurling, G., Kraemer, J. M., & van Stiphout, I. (2016). Shortcomings of mathematics education reform in the Netherlands: a paradigm case?. *Mathematical Thinking and Learning*, *18*(1), 25-44. https://doi.org/10.1080/10986065.2016.1107821

Gravemeijer, K., & Doorman, M. (1999). Context problems in realistic mathematics education: A calculus course as an example. *Educational Studies in Mathematics*, *39*(1-3), 111-129. https://doi.org/10.1023/A:1003749919816

Hoppe, K. D. (1988). Hemispheric specialization and creativity. *Psychiatric Clinics of North America*, *11*(3), 303-315. https://doi.org/10.1016/S0193-953X(18)30482-9

Hoppe, C., Fliessbach, K., Stausberg, S., Stojanovic, J., Trautner, P., Elger, C. E., & Weber, B. (2012). A key role for experimental task performance: effects of math talent, gender and performance on the neural correlates of mental rotation. *Brain and Cognition, 78*(1), 14-27. https://doi.org/10.1016/j.bandc.2011.10.008

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research: Neuroimaging*, *191*(1), 36-43. https://doi.org/10.1016/j.pscychresns.2010.08.006

Iwabuchi, S. J., & Kirk, I. J. (2009). Atypical interhemispheric communication in left-handed individuals. *Neuroreport*, *20*(2), 166-169. https://doi.org/10.1097/WNR.0b013e32831f1cbb

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences, 9*(11), 512-518. https://doi.org/10.1016/j.tics.2005.09.009

Jung, R. E., & Vartanian, O. (Eds.). (2018). *The Cambridge Handbook of the Neuroscience of Creativity*. Cambridge University Press. https://doi.org/10.1017/9781316556238

Kalbfleisch, M. L. (2004). Functional neural anatomy of talent. *The Anatomical Record Part B: The New Anatomist: An Official Publication of the American Association of Anatomists, 277*(1), 21-36. https://doi.org/10.1002/ar.b.20010

Khedr, E. M., Hamed, E., Said, A., & Basahi, J. (2002). Handedness and language cerebral lateralization. *European Journal of Applied Physiology*, *87*(4-5), 469-473. https://doi.org/10.1007/s00421-002-0652-y

Kounios, J., & Beeman, M. (2014). The cognitive neuroscience of insight. *Annual Review of Psychology*, *65*. https://doi.org/10.1146/annurev-psych-010213-115154

Laurens, T., Batlolona, F. A., Batlolona, J. R., & Leasa, M. (2017). How does realistic mathematics education (RME) improve students' mathematics cognitive achievement?. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(2), 569-578. https://doi.org/10.12973/ejmste/76959

Leikin, R., Leikin, M., Paz-Baruch, N., Waisman, I., & Lev, M. (2017). On the four types of characteristics of super mathematically gifted students. *High Ability Studies*, *28*(1), 107-125. https://doi.org/10.1080/13598139.2017.1305330

Leikin, R., & Pitta-Pantazi, D. (2013). Creativity and mathematics education: The state of the art. *ZDM*, *45*(2), 159-166. https://doi.org/10.1007/s11858-012-0459-1

Leikin, M., Waisman, I., & Leikin, R. (2013). How brain research can contribute to the evaluation of mathematical giftedness. *Psychological Test and Assessment Modeling*, *55*(4), 415.

Liljedahl, P. (2013). Illumination: an affective experience?. *ZDM*, *45*(2), 253-265. https://doi.org/10.1007/s11858-012-0473-3

Lin, C. L., Jung, M., Wu, Y. C., Lin, C. T., & She, H. C. (2012, August). Brain dynamics of mathematical problem solving. In *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (pp. 4768-4771). IEEE. https://doi.org/10.1109/EMBC.2012.6347033

Lin, J. W., & Mai, L. J. (2018). Impact of mindfulness meditation intervention on academic performance. *Innovations in Education and Teaching International*, *55*(3), 366-375. https://doi.org/10.1080/14703297.2016.1231617

Lövdén, M., Bodammer, N. C., Kühn, S., Kaufmann, J., Schütze, H., Tempelmann, C., ... & Lindenberger, U. (2010). Experience-dependent plasticity of white-matter microstructure extends into old age. *Neuropsychologia, 48*(13), 3878-3883. https://doi.org/10.1016/j.neuropsychologia.2010.08.026

Luders, E., Narr, K. L., Bilder, R. M., Thompson, P. M., Szeszko, P. R., Hamilton, L., & Toga, A. W. (2007). Positive correlations between corpus callosum thickness and intelligence. *Neuroimage, 37*(4), 1457-1464. https://doi.org/10.1016/j.neuroimage.2007.06.028

Luders, E., Thompson, P. M., & Toga, A. W. (2010). The development of the corpus callosum in the healthy human brain. *Journal of Neuroscience*, *30*(33), 10985-10990. https://doi.org/10.1523/JNEUROSCI.5122-09.2010

Luo, C., Tu, S., Peng, Y., Gao, S., Li, J., Dong, L., ... & Yao, D. (2014). Long-term effects of musical training and functional plasticity in salience system. *Neural Plasticity, 2014.* https://doi.org/10.1155/2014/180138

Mann, E. L. (2006). Creativity: The essence of mathematics. *Journal for the Education of the Gifted, 30*(2), 236-260. https://doi.org/10.4219/jeg-2006-264

O'Boyle, M. W., Gill, H. S., Benbow, C. P., & Alexander, J. E. (1994). Concurrent finger-tapping in mathematically gifted males: Evidence for enhanced right hemisphere involvement during linguistic processing. *Cortex, 30*(3), 519-526. https://doi.org/10.1016/S0010-9452(13)80347-4

Ohlsson, S. (1984). Restructuring revisited: II. An information processing theory of restructuring and insight. *Scandinavian Journal of Psychology, 25*(2), 117-129. https://doi.org/10.1111/j.1467-9450.1984.tb01005.x

Olszewski-Kubilius, P., & Lee, S. Y. (2004). The role of participation in in-school and outside-of-school activities in the talent development of gifted students. *Journal of Secondary Gifted Education, 15*(3), 107-123. https://doi.org/10.4219/jsge-2004-454

Owen, J. P., Li, Y. O., Ziv, E., Strominger, Z., Gold, J., Bukhpun, P., ... & Mukherjee, P. (2013). The structural connectome of the human brain in agenesis of the corpus callosum. *Neuroimage, 70*, 340-355. https://doi.org/10.1016/j.neuroimage.2012.12.031

Peña-López, I. (2016). PISA 2015 results (Volume I). Excellence and equity in education. https://doi.org/10.1787/19963777

Prescott, J., Gavrilescu, M., Cunnington, R., O'Boyle, M. W., & Egan, G. F. (2010). Enhanced brain connectivity in math-gifted adolescents: An fMRI study using mental rotation. *Cognitive Neuroscience, 1*(4), 277-288. https://doi.org/10.1080/17588928.2010.506951

Rash, B. G., & Richards, L. J. (2001). A role for cingulate pioneering axons in the development of the corpus callosum. *Journal of Comparative Neurology*, *434*(2), 147-157. https://doi.org/10.1002/cne.1170

Szaflarski, J. P., Binder, J. R., Possing, E. T., McKiernan, K. A., Ward, B. D., & Hammeke, T. A. (2002). Language lateralization in left-handed and ambidextrous people: fMRI data. *Neurology, 59*(2), 238-244. https://doi.org/10.1212/WNL.59.2.238

Savic, M. (2016). Mathematical problem-solving via Wallas' four stages of creativity: Implications for the undergraduate classroom. *The Mathematics Enthusiast*, *13*(3), 255-278. https://scholarworks.umt.edu/tme/vol13/iss3/6

Sawyer, K. (2011). The cognitive neuroscience of creativity: A critical review. *Creativity Research Journal*, *23*(2), 137-154. https://doi.org/10.1080/10400419.2011.571191

Segal, E. (2004). Incubation in insight problem solving. *Creativity Research Journal, 16*(1), 141-148. https://doi.org/10.1207/s15326934crj1601_13

Sharp, D. J., Beckmann, C. F., Greenwood, R., Kinnunen, K. M., Bonnelle, V., De Boissezon, X., ... & Leech, R. (2011). Default mode network functional and structural connectivity after traumatic brain injury. *Brain, 134*(8), 2233-2247. https://doi.org/10.1093/brain/awr175

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: an integrative theory of anterior cingulate cortex function. *Neuron*, *79*(2), 217-240. https://doi.org/10.1016/j.neuron.2013.07.007

Siffredi, V., Anderson, V. A., McIlroy, A., Wood, A., Leventer, R. J., & Spencer-Smith, M. (2018). A Neuropsychological Profile for Agenesis of the Corpus Callosum?: Cognitive, Academic, Executive, Social, and Behavioral Functioning in School-Age Children. *Journal of the International Neuropsychological Society*, 1-11. https://doi.org/10.1017/S1355617717001357

Sitorus, J. (2016). Students' creative thinking process stages: Implementation of realistic mathematics education. *Thinking Skills and Creativity*, *22*, 111-120. https://doi.org/10.1016/j.tsc.2016.09.007

Soffel, J. (2016, March). What are the 21st-century skills every student needs. In *World Economic Forum* (Vol. 10).

Sriraman, B. (2004). The characteristics of mathematical creativity. *Mathematics Educator*, *14*(1), 19-34.

Sriraman, B. (2005). Are giftedness and creativity synonyms in mathematics?. *Journal of Secondary Gifted Education*, *17*(1), 20-36. https://doi.org/10.4219/jsge-2005-389

Subotnik, R. F., Olszewski-Kubilius, P., & Worrell, F. C. (2011). Rethinking giftedness and gifted education: A proposed direction forward based on psychological science. *Psychological Science in the Public Interest, 12*(1), 3-54. https://doi.org/10.1177/1529100611418056

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. (2010). White matter structures associated with creativity: evidence from diffusion tensor imaging. *Neuroimage, 51*(1), 11-18. https://doi.org/10.1016/j.neuroimage.2010.02.035

Tan, T., Zou, H., Chen, C., & Luo, J. (2015). Mind wandering and the incubation effect in insight problem solving. *Creativity Research Journal*, *27*(4), 375-382. https://doi.org/10.1080/10400419.2015.1088290

University of Twente. (2020a, June). *Mathematics.* University of Twente. https://www.utwente.nl/en/honours/bachelor/tracks/

University of Twente. (2020b, January). *Requirements.* University of Twente. https://www.utwente.nl/en/honours/bachelor/application/

Veale, J. F. (2014). Edinburgh handedness inventory–short form: a revised version based on confirmatory factor analysis. *Laterality: Asymmetries of Body, Brain and Cognition, 19*(2), 164-177. https://doi.org/10.1080/1357650X.2013.783045

Van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology & Behavior, 77*(4-5), 477-482. https://doi.org/10.1016/S0031-9384(02)00930-7

Yuan, X., & Sriraman, B. (2011). An exploratory study of relationships between students' creativity and mathematical problem-posing abilities: Comparing Chinese and US students. In *The Elements of Creativity and Giftedness in Mathematics* (pp. 5-28). Brill Sense. https://doi.org/10.1007/978-94-6091-439-3_2

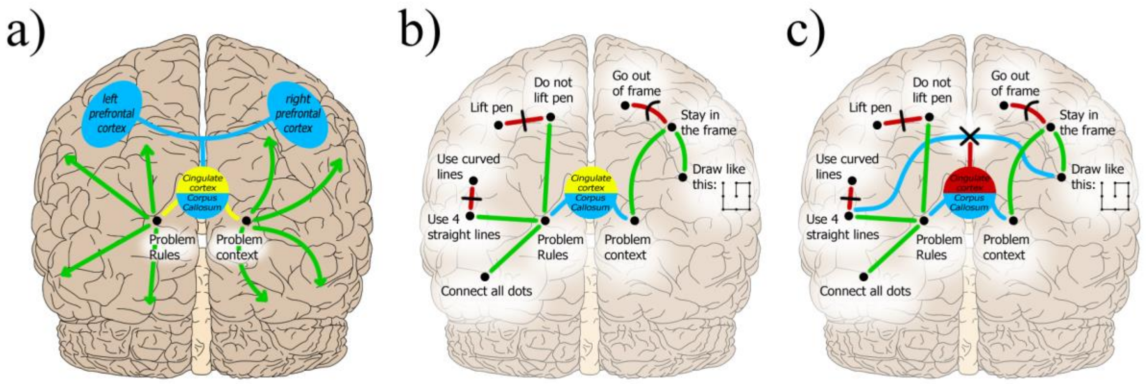
Zhang, L., Gan, J. Q., & Wang, H. (2017). Neurocognitive mechanisms of mathematical giftedness: A literature review. *Applied Neuropsychology: Child, 6*(1), 79-94. https://doi.org/10.1080/21622965.2015.1119692

Appendix

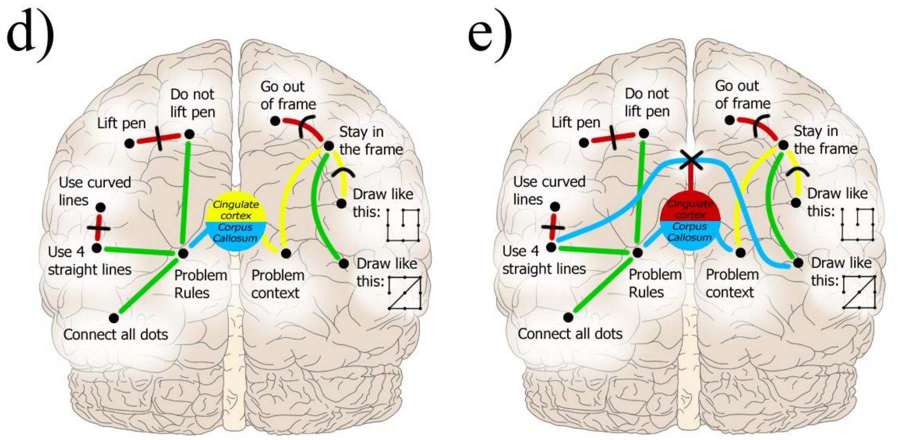
Appendix A – Example of the SIP model

Note: Legend: Color encoding: Yellow = active cingulate cortex related processes like inhibition, Blue = corpus callosum (and in the first picture also prefrontal cortex) related passive processes often for bilateral processing, Green = Established natural associations, Red = Established natural contradictory/inhibitory associations; Symbols: Node point = piece of information, Line/Curve = association (distinction between curves and lines based on aesthetic reasons), crossed out line/curve = dissociation/inhibition.

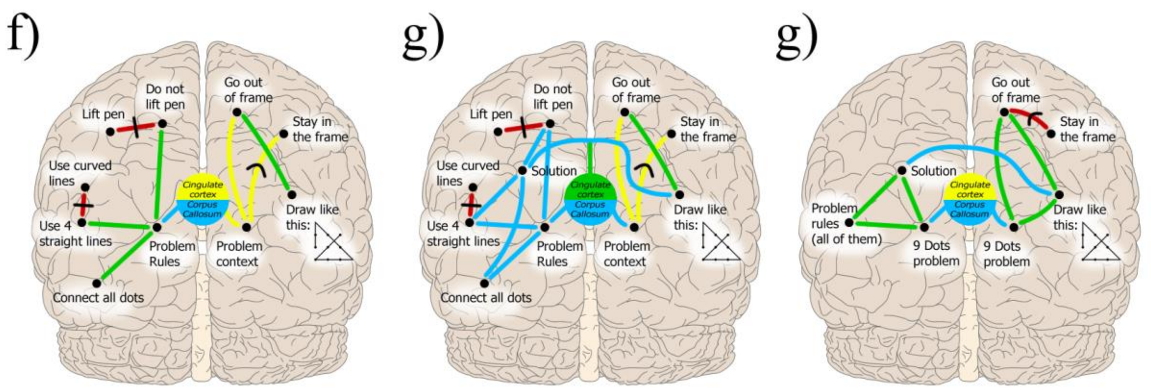
Note: These models are a simplification of reality. Therefore, some processes like learning may be incomplete since they also involve other brain areas such as the hippocampus. Also, which information is encoded in which hemisphere might not correspond to reality.



a) the prefrontal cortex makes sense of the problem and establishes the goal by learning the problem rules and context and the cingulate cortex establishing these associations in the head through the corpus callosum; b) the established problem brain architecture is an association with the rules and the context of the problem. If a dominant association is triggered, a contradictory association is naturally inhibited. The context node “stay in the frame” is related to the (subconscious) Gestalt principle assumption to stay within the perceived borders of the problem. The process of finding a dominant association is usually fast, so-to-say a fast-insight-incubation, in this case resulting in the attempt to draw the right-hemisphere response; c) the right hemisphere proposed solution for the problem is judged against the rules of the problem from the left hemisphere and in this case contradict since the response would have needed 5 lines instead of the allowed 4 lines. And this contradiction is detected by the cingulate cortex and coupled with negative emotions since it is diverging with the task.



d) as a response on the contradiction, the specific dominantly associated solution which contradicted the rules is now inhibited. But the overarching, even more dominant principle association ("stay in the frame") is not yet inhibited during incubation. As a result, a different solution association acting on the same principle is triggered (the second-most dominant); e) just like the first dominant solution association, this one also contradicts the rule to only use four lines and thus triggers the error detection of the cingulate cortex.



f) after some time of incubation and insight cycles, since the solution associations based on the principle association "stay in the frame" have contradicted the rules, the cingulate cortex might inhibit the principle association itself. Now, the less dominant node which has been inhibited (in this case the opposite principle "go out of frame") is free for association and is selected (if it is the second-dominant association) to provide for a result; g) the association has resulted in an insight that fits all of the rules of the problem and solves it. Therefore, the cingulate cortex responds with positive emotions and a strengthening of this problem-solution architecture. As a result, a new "solution" node incorporating these associations is established in the left (or right?) hemisphere; h) when now the same 9-dot problem (or a similar problem) is posed, the new dominant association acquired through insight-based learning is the correct solution to "go out of the frame" and in this particular case, the previously dominant solution is now naturally inhibited by the learned now-dominant association.

Appendix B – Background questionnaire

Appendix B.1 – Instructions for mental rotation task

“Please read carefully: In the following part, you will get a link to a website about a 3D mental rotation task. To do this task, you need a Computer with a working internet connection and Flash Player installed. The website is safe and developed by UT employees to help researchers administering certain types of cognitive experiments.

In the 3D mental rotation task, you will be presented with 2 figures viewed in various angles and have to indicate whether they are identical to each other, or mirrored. If they are ***identical***, press the "***m***" button on your keyboard and if they are ***mirrored***, please press "***c***".
At the beginning, you will get a few practice trials.
For all trials, please ***respond as fast and correct as possible***.
Since you have read the instructions here, you can skip the instructions on the website.
However, if you are interested in the background of the task, or did not understand something, feel free to read the text on the website.

After the last trial of each task, you will get insight into your data. If you are on this screen, please click on "***raw data***" below the data window and ***copy everything***, meaning all the data. Then paste it into a text-box you will be given in this questionnaire below the link for the 3D mental rotation task.“

Appendix B.2 – Background questionnaire

Question	**Answer Options**
What is your age, in years and months?	Open-ended
What is your gender?	Male / Female / Other
What nationality are you?	Dutch / German / Other (open-ended)
Which Bachelor programme do/did you take at the University of Twente?	Applied Mathematics / Other (open-ended)
Which year of study are you currently in?	Bachelor year 1 / Bachelor year 2 / Bachelor year 3 / Master year 4 / Master year 5
Are you participating in the "Mathematics" track of the honours programme?	Yes / No
Are you participating in any other giftedness/excellence programmes (if yes, please indicate the name)?	Yes (open-ended indication) / No
Are you participating/did you participate in any math competitions in the last 2 years?	Yes, more than 5 / Yes, 4-5 / Yes, 2-3 / Yes, 1 / No

Are you participating in any other extracurricular activities (if yes, please indicate the name)?	Yes (open-ended) / No

Appendix B.3 – Edinburgh Handedness Inventory – Short-form (EHI-SF)

Questionnaire derived from the article: "Edinburgh handedness inventory – short form: A revised version based on confirmatory factor analysis" written by Veale (2014)

Instruction: "Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
Writing	☐	☐	☐	☐	☐
Throwing	☐	☐	☐	☐	☐
Toothbrush	☐	☐	☐	☐	☐
Spoon	☐	☐	☐	☐	☐

Scoring:

For each item: Always right = 100; Usually right = 50; Both equally = 0; Usually left = -50; Always left = -100. To calculate the Laterality Quotient add the scores for the four items in the scale and divide this by four: Writing + Throwing + Toothbrush + Spoon = Total; Total / 4 (Laterality Quotient).

Classification	Laterality Quotient score
Left-hander	-100 to -61
Mixed-hander	-60 to 60
Right-hander	61 to 100

Appendix C – Normal math test (SAT example questions)

All items derived from "https://collegereadiness.collegeboard.org/sample-questions/math" in the "Calculator: Not permitted" section. Pictures are also taken from the website and the current study has only altered some text if anything, but the meaning of each problem and solution remains the same.

The items used in the current study include original items 3, 7, 10, 6, 4, 14 and 16 in that order.

Before administration of the items, following text is displayed:

"The following 7 items include math operations of varying difficulty levels, originally for pre-college students in America. The test will take about 10-20 minutes. All questions are multiple choice. Use of calculator is not allowed. However, you can of course use paper and pencil, but be sure to prepare it beforehand. Try to solve the problems as fast and good as you can. Once you are ready, click on question 1, from then until finishing question 7, time will be measured. The questions are not related to each other, but you can always go back and forth between the questions. And please fill out every question. At the end of the study, you will get an answer sheet. Good luck!"

Following, the 7 questions in order of presentation will be described together with the solution options with the correct one for each question being marked in green.

Question 1

If $a^2 + 14a = 51$ and $a > 0$, then what is the value of $a + 7$?

A) 3	B) 7	C) 10	D) 9

Question 2

The graph of $y = (2x - 4)(x - 4)$ is a parabola in the *xy*-plane. In which of the following equivalent equations do the *x*- and *y*-coordinates of the vertex of the parabola appears as constants of coefficients?

A) $y = 2x^2 - 12x + 16$	B) $y = 2x(x - 6) + 16$	C) $y = 2(x-3)^2 + (-2)$	D) $y = (x - 2)(2x - 8)$

Question 3

$4x - y = 3y + 7$

$X + 8y = 4$

Based on the system of equations above, what is the value of the product *xy*?

A) $-\frac{3}{2}$	B) $\frac{1}{4}$	C) $\frac{1}{2}$	D) $\frac{11}{9}$

Question 4

If $a^{-\frac{1}{2}} = x$, where $a > 0$ and $x > 0$, which of the following equations gives a in terms of x?

A) $a = \frac{1}{\sqrt{x}}$	B) $a = \frac{1}{x^2}$	C) $a = \sqrt{x}$	D) $a = -x^2$

Question 5

If $\frac{2}{a-1} = \frac{4}{y}$ where *y ≠ 0* and *a ≠ 1*, what is *y* in terms of *a*?

A) y = 2a – 2	B) y = 2a – 4	C) y = 2a – $\frac{1}{2}$	D) y = $\frac{1}{2}$a + 1

Question 6

$\frac{1}{x} + \frac{2}{x} = \frac{1}{5}$

Anise needs to complete a printing job using both of the printers in her office. One of the printers is twice as fast as the other, and together the printers can complete the job in 5 hours. The equation above represents the situation described. Which of the following describes what the expression $\frac{1}{x}$ represents in this equation?

A) The time, in hours, it takes the slower printer to complete the printing job alone	B) The portion of the job that the slower printer would complete in one hour	C) The portion of the job that the faster printer would complete in two hours	D) The time, in hours, that it takes the slower printer to complete $\frac{1}{5}$ of the printing job

Question 7

It is given that *sin x = a*, where *x* is the radian measure of an angle and $\frac{\pi}{2}$ < x < π.

If *sin w = -a*, which of the following could be the value of *w*?

A) π – x	B) x – π	C) 2π + x	D) x – 2π

Scoring criteria:
If a question is correct, the participant receives full points for the question. If not, no points are given.

Question	Points
1	10 (Easy)
2	20 (Medium)
3	20 (Medium)
4	20 (Medium)
5	20 (Medium)
6	30 (Difficult)
7	30 (Difficult)
Total:	X / 150

Appendix D – Finger tapping text sample

Text 1: Every afternoon, as they were coming from school, the children used to go and play in the Giant's garden. It was a large lovely garden, with soft green grass. Here and there over the grass stood beautiful flowers like stars, and there were twelve peach-trees that in the spring-time broke out into delicate blossoms of pink and pearl, and in the autumn bore rich fruit.

Text 2: High above the city, on a tall column, stood the statue of the Happy Prince. He was gilded all over with thin leaves of fine gold, for eyes he had two bright sapphires, and a large red ruby glowed on his sword-hilt. He was very much admired indeed. "He is as beautiful as a weathercock," remarked one of the Town Councillors who wished to gain a reputation for having artistic tastes.

Text 3: In the forest, high up on the steep shore, and not far from the open seacoast, stood a very old oak-tree. It was just three hundred and sixty-five years old, but that long time was to the tree as the same number of days might be to us; we wake by day and sleep by night, and then we have our dreams. It is different with the tree.

Text 4: Outside a woman walked along the wet street-lamp lit sidewalk through the sleet and snow. Inside in the Fine Arts Institute on the sixth floor of the Y.W.C.A. Building, 1020 McGee Street, a merry crowd of soldiers from Camp Funston and Fort Leavenworth fox trotted and one-stepped with girls from the Fine Arts School while a sober faced young man pounded out the latest jazz music as he watched the moving figures.

Text 5: Two very shabby looking young men stood at the corner of Prairie Avenue and Eightieth Street, looking despondently at the carriages that whirled by. It was Christmas Eve, and the streets were full of vehicles; florists' wagons, grocers' carts and carriages. The streets were in that half-liquid, half-congealed condition peculiar to the streets of Chicago at that season of the year.

Text 6: In the fifth century, just as now, the sun rose every morning and every evening retired to rest. In the morning, when the first rays kissed the dew, the earth revived, the air was filled with the sounds of rapture and hope; while in the evening the same earth subsided into silence and plunged into gloomy darkness. One day was like another, one night like another.

Text 7: Once upon a time, a good many years ago, there was a traveller, and he set out upon a journey. It was a magic journey, and was to seem very long when he began it, and very short when he got half way through. He travelled along a rather dark path for some little time, without meeting anything, until at last he came to a beautiful child.

Text 8: With the first day of spring, when the awakening earth puts on its garment of green, and the warm, fragrant air fans our faces and fills our lungs and appears even to penetrate to our hearts, we experience a vague, undefined longing for freedom, for happiness, a desire to run, to wander aimlessly, to breathe in the spring. The previous winter having been unusually severe, this spring feeling was like a form of intoxication in May, as if there were an overabundant supply of sap.

Text 9: You must know, gentlemen, that there lived some years ago, in the city of Périgueux, an honest notary public, the descendant of a very ancient and broken-down family, and the occupant of one of those old weather-beaten tenements which remind you of the times of your great-grandfather. He was a man of an unoffending, quiet disposition.

Text 10: From the oval-shaped flower-bed there rose perhaps a hundred stalks spreading into heart-shaped or tongue-shaped leaves half way up and unfurling at the tip red or blue or yellow petals marked with spots of colour raised upon the surface; and from the red, blue or yellow gloom of the throat emerged a straight bar, rough with gold dust and slightly clubbed at the end.

Appendix E – Newspaper articles for incubation

"Now, please read the following newspaper articles for 5 minutes. After 5 minutes, you will abruptly go back to solving the problem. But please read the newspaper mindfully. If any article sparked your interest but you could not read it fully, you can contact the researcher afterwards. You can scroll through the articles below."

Biggest cosmic mystery 'step closer' to solution

By BBC News

Stars, galaxies, planets, pretty much everything that makes up our everyday lives owes its existence to a cosmic quirk. The nature of this quirk, which allowed matter to dominate the Universe at the expense of antimatter, remains a mystery. Now, results from an experiment in Japan could help researchers solve the puzzle - one of the biggest in science. It hinges on a difference in the way matter and antimatter particles behave. The world that's familiar to us - including all the everyday objects we can touch - is made up of matter. The fundamental building blocks of matter are sub-atomic particles, such as electrons, quarks and neutrinos. But matter has a shadowy counterpart called antimatter. Each sub-atomic particle of ordinary matter has a corresponding "antiparticle". Today, there is far more matter than antimatter in the Universe. But it wasn't always this way. The Big Bang should have created matter and antimatter in equal amounts. "When particle physicists make new particles in accelerators, they always find that they produce particle-antiparticle pairs: for every negative electron, a positively charged positron (the electron's antimatter counterpart)," said Prof Lee Thompson from the University of Sheffield, a member of the 350-strong T2K collaboration, which includes a relatively large number of scientists from UK universities. "So why isn't the universe 50% antimatter? This is a long-standing problem in cosmology - what happened to the antimatter?" However, when a matter particle meets its antiparticle, they "annihilate" - disappear in a flash of energy. During the first fractions of a second of the Big Bang, the hot, dense Universe was fizzing with particle-antiparticle pairs popping in and out of existence. Without some other, unknown mechanism at play, the Universe should contain nothing but leftover energy. "It would be pretty boring and we wouldn't be here," Prof Stefan Söldner-Rembold, head of the particle physics group at the University of Manchester, told BBC News. So what happened to tip the balance? That's where the T2K experiment comes in. T2K is based at the Super-Kamiokande neutrino observatory, based underground in the Kamioka area of Hida, Japan. Researchers used the facility's detector to observe neutrinos and their antimatter counterparts, antineutrinos, generated 295km away at the Japanese Proton Accelerator Research Complex (J-Parc) in Tokai. T2K stands for Tokai to Kamioka. As they travel through the Earth, the particles and antiparticles oscillate between different physical properties known as flavours. Physicists think that finding a difference - or asymmetry - in the physical properties of neutrinos and antineutrinos might help us understand why matter is so prevalent compared with antimatter. This asymmetry is known as charge-conjugation and parity reversal (CP) violation. It is one of three necessary conditions, proposed by the Russian physicist Andrei Sakharov in 1967, that must be satisfied to produce matter and antimatter at different rates. After analysing nine years' worth of data, the researchers found a mismatch in the way neutrinos and antineutrinos oscillate by recording the numbers that reached Super Kamiokande with a flavour different from the one they had been created with. The result has also reached a level of statistical significance - called three-sigma - that's high enough to indicate that CP violation occurs in these particles. The results have been published in the journal Nature. "While CP violation involving quarks is experimentally well established, CP violation has never been observed for neutrinos," said Stefan Söldner-Rembold. "The violation of CP symmetry is one of the (Sakharov) conditions for a matter-dominated Universe to exist, but the quark-driven effect is unfortunately much too small to explain why our Universe is mainly filled with matter. "Discovering CP violation with neutrinos would be a great leap forward in understanding how the Universe was formed." He said a theory called leptogenesis links the dominance of matter to CP violation involving neutrinos. "These leptogenesis models predict that the matter domination is actually due to the neutrino sector. If you were to observe neutrino CP violation, that would give us a strong indication that the leptogenesis model is the way forward," said Prof Söldner-Rembold. The results from T2K "give strong hints" that the CP violation effect could be large for neutrinos. This would mean that the next-generation neutrino experiment DUNE, which is currently being constructed in a mine in South Dakota, might detect the effect faster than expected. The international project is being hosted by the US Fermi National Accelerator Laboratory (Fermilab). Prof Söldner-Rembold is a member of the DUNE scientific team and the collaboration's spokesperson. The experiment's detector will contain 70,000 tons of liquid argon buried one mile underground. It will be used to discover and measure CP violation with high precision. He added that the T2K result "brings us a step closer to having a model that explains how the Universe evolved from the beginning to the matter-dominated Universe today".

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Coronavirus: Could gaming be good for you during lockdown?

By BBC news

For gamers around the country, lockdown might appear to be an ideal opportunity to hone your skills in pretty much every waking moment. But how much should we be playing online? And could it offer some benefits at a time of social isolation? According to Dr Dayna Galloway, who heads of the division of games and arts at Abertay University, the main message - as in all things - is not to overdo it. "Screentime guidance varies for age groups - but the key is to ensure a healthy balance across activities," he said. "It's important for individuals to ensure a mix of physical activity, sedentary behaviour such as reading and screen time, and, of course, a good night's sleep. Isolation and lockdown in different circumstances will of course skew this, but it's important for people to try to maintain as much balance as possible." There are a range of activities aimed at trying to persuade young people in particular to take a screen break. In Dumfries and Galloway, the council's youth work team has sent out isolation packs which include old-school games like dominoes and playing cards. The Wigtown Book Festival recently launched a writing competition for children from eight to 18. The Scottish Book Trust is also encouraging us to get our pens out and contribute stories to a publication planned on the theme of "future". In addition, fitness classes have gone online and are proving particularly successful. A recent festival in Dumfries highlighted the positive aspects of gaming and these could be particularly relevant while confined to your home for large parts of the day. Dr Galloway said online gameplay allowed for "communication and collaboration" to achieve goals or compete with others. "It easily replaces some of the activities that are no longer feasible due to social distancing and isolation," he said. "It's very important for mental well-being to maintain relationships and contact with friends and family, and online games are an excellent method for facilitating this. "The games themselves also create emergent outcomes and scenarios that create positive shared experiences, and memories for those engaged with them." He said that meant they could have more impact than a video call and were "a good replacement in the current circumstances" for other forms of social interaction. "Entertainment such as games and streaming services also help us pass the time and, more importantly, stay indoors - so this aspect is particularly helpful in the situation we are in," he added. There are different potential benefits attached, according to the type of game being played. Minecraft, Sea of Thieves or Fortnite can help maintain social activity and encourage contact with your peer-group. Dr Galloway said they boosted "communication, creativity and collaboration". Other games encourage physical activity, which is something we are being encouraged to maintain. "It may be a good opportunity to dust off the Nintendo Wii for some Wii Sports," suggested Dr Galloway. Pokemon Go, with social distancing, could be used on a daily exercise walk. But it might also be time to go retro - but using technology to give it a twist. "Raid the cupboard or pick up some traditional board games to have some fun with whoever you are under lockdown with," suggested Dr Galloway. "Some games can also be played over video chats - if you are creative and promise not to cheat." But above all, the recommendation is moderation for however long lockdown may continue.

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Music can boost your productivity while working from home – here's how

By the guardian

Music has been shown to improve both productivity and cognitive performance, especially in adults. If you're attempting to work from home, a conundrum has probably presented itself: how can you get anything done in a distracting environment amid unsettled times? Your streaming service or record collection may hold the answer. Beyond providing background noise, music has been shown to improve both productivity and cognitive performance, especially in adults. Listening to music can help people manage anxiety, become motivated and stay productive. You just need to know how to make the right playlist.

Start off slow

Kick off the day with a trick from music therapy. The concept is known as the iso principle, which is a technique therapists use to alter the mood of a patient. The therapist will match music to how the patient is feeling, and then gradually alter the songs to achieve the desired mood state. The songs at the beginning of the playlist shouldn't force you into a state of productivity, but they should gradually bring you there. While song choice will vary by person, Kirsten Nelson, a music therapist at the University of Iowa Stead family children's hospital, suggests tracks like Here Comes the Sun by the Beatles and Ooh Child, by the Five Stairsteps as places to start. "If you're feeling really down in the morning, then find something peaceful to start with," Nelson says. "From there, you can bring yourself into a more motivating song to achieve the state you want."

Transition into a 'power song'

Researchers have found that a faster track speed can result in increased performance. In one study that examined the relationship between music tempo and productivity, most test subjects performed best while listening to songs paced at around 121bpm. This is about as fast as tracks like Carly Rae Jepsen's Call Me Maybe, Whitney Houston's I Wanna Dance with Somebody, and I Will Survive, by Diana Ross. Nelson refers to this phenomenon as finding the "power song", which can used to motivate the listener to be productive. "I think that music can activate people in a way that other things cannot," she says. "If we're looking to get into a place where we might have some more energy and motivation, a power song can be very helpful." Nelson says that adding power songs at strategic points in a work playlist, such as right when the day starts, while transitioning between tasks, and as the day ends, can help maintain motivation.

Rethink your lyrics

Nelson says that the choice to include lyrical tracks in a playlist should depend on individual preference. While research suggests that listening to upbeat, complex music can help workers stay alert and motivated while performing repetitive tasks, narrative lyrics can be distracting to those trying to do cognitive work. The bulk of a work playlist should include songs with innocuous or subtlely performed lyrics, such as those by artists like Grouper, Brian Eno and Jenny Hval. For those who prefer non-lyrical music, music by Dawn of Midi, Steve Reich and John Adams are great places to start. And, while lyrics can be a powerful motivator, don't automatically reach for your favorite tracks. One study found a decrease in performance while listening to songs characterized as "familiar vocal music". The research suggests that, while it is important to listen to enjoyable music, songs that are very familiar can be distracting.

Be flexible with yourself

Creating a work-from-home playlist should never feel like a chore. Rather, it can be something that accretes over time. "If you hear a song and know that it makes you feel good, pop it into a playlist," says Nelson. As the playlist grows, arrange tracks in the order that makes sense for the way you work. "Allow yourself permission to listen to new music, try out new things, take things out, bring things in," Nelson says. "Allow yourself that flexibility." If you don't feel like listening to your playlist, you don't have to.

Suggested productivity playlist

Tracks 1-4 are for transitioning into work. Tracks 5-16 are good tracks for when you're in the flow. Tracks 17-20 are for transitioning back out.

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Scientists create mutant enzyme that recycles plastic bottles in hours

By the guardian

Bacterial enzyme originally found in compost can be used to make high-quality new bottles. A mutant bacterial enzyme that breaks down plastic bottles for recycling in hours has been created by scientists. The enzyme, originally discovered in a compost heap of leaves, reduced the bottles to chemical building blocks that were then used to make high-quality new bottles. Existing recycling technologies usually produce plastic only good enough for clothing and carpets. The company behind the breakthrough, Carbios, said it was aiming for industrial-scale recycling within five years. It has partnered with major companies including Pepsi and L'Oréal to accelerate development. Independent experts called the new enzyme a major advance. Billions of tonnes of plastic waste have polluted the planet, from the Arctic to the deepest ocean trench, and pose a particular risk to sea life. Campaigners say reducing the use of plastic is key, but the company said the strong, lightweight material was very useful and that true recycling was part of the solution. The new enzyme was revealed in research published on Wednesday in the journal Nature. The work began with the screening of 100,000 micro-organisms for promising candidates, including the leaf compost bug, which was first discovered in 2012. "It had been completely forgotten, but it turned out to be the best," said Prof Alain Marty at the Université de Toulouse, France, the chief science officer at Carbios. The scientists analysed the enzyme and introduced mutations to improve its ability to break down the PET plastic from which drinks bottles are made. They also made it stable at 72C, close to the perfect temperature for fast degradation. The team used the optimised enzyme to break down a tonne of waste plastic bottles, which were 90% degraded within 10 hours. The scientists then used the material to create new food-grade plastic bottles. Carbios has a deal with the biotechnology company Novozymes to produce the new enzyme at scale using fungi. It said the cost of the enzyme was just 4% of the cost of virgin plastic made from oil. Waste bottles also have to be ground up and heated before the enzyme is added, so the recycled PET will be more expensive than virgin plastic. But Martin Stephan, the deputy chief executive at Carbios, said existing lower-quality recycled plastic sells at a premium due to a shortage of supply. "We are the first company to bring this technology on the market," said Stephan. "Our goal is to be up and running by 2024, 2025, at large industrial scale." He said a reduction in plastic use was one part of solving the waste problem. "But we all know that plastic brings a lot of value to society, in food, medical care, transportation. The problem is plastic waste." Increasing the collection of plastic waste was key, Stephan said, with about half of all plastic ending up in the environment or in landfill. Another team of scientists revealed in 2018 that they had accidentally created an enzyme that breaks down plastic drinks bottles. One of the team behind this advance, Prof John McGeehan, the director of the Centre for Enzyme Innovation at the University of Portsmouth, said Carbios was the leading company engineering enzymes to break down PET at large scale and that the new work was a major advance. “It makes the possibility of true industrial-scale biological recycling of PET a possibility. This is a very large advance in terms of speed, efficiency and heat tolerance,” McGeehan said. “It represents a significant step forward for true circular recycling of PET and has the potential to reduce our reliance on oil, cut carbon emissions and energy use, and incentivise the collection and recycling of waste plastic.” Scientists are also making progress in finding biological ways to break down other major types of plastic. In March, German researchers revealed a bug that feasts on toxic polyurethane, while earlier work has shown that wax moth larvae – usually bred as fish bait – can eat up polythene bags.

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Robots deliver food in Milton Keynes under coronavirus lockdown

By the guardian

Starship Technologies’ small vehicles navigate pavements with no human driver required. A robotic delivery service in Milton Keynes could prove to be the future of locked-down Britain, as miniature autonomous vehicles bring food deliveries to almost 200,000 residents of the town. Starship Technologies, an autonomous delivery startup created in 2014 by two Skype cofounders, has been testing its beer cooler-sized robots in public since 2015. The small, white, six-wheeled vehicles trundle along pavements to bring small deliveries to residents and workers of the neighbourhoods in which they operate, without the need for a human driver or delivery person. The Milton Keynes operation is the first commercial deployment in the UK, and started in mid-March, just as the country was implementing widespread social distancing in an effort to tackle the spread of coronavirus. Residents can download the Deliveroo-style Starship Deliveries app to buy cooked food and small orders from supermarkets, which gets loaded into the robots and driven to them. Sam Crooks, the mayor of Milton Keynes, said: “I’ve got a fairly young demographic in my ward, and they love it. There was obviously a burst of use at the beginning, because of the novelty, but already it’s just a part of people’s routines. “People are taking seriously the guidance about not going out, so something like the robot deliveries are absolutely ideal, because people can order and obtain something without going out. Particularly as their first relationship was with Tesco and the Co-op.” Andy Curtis, the head of UK operations at Starship, said: “We’ve seen huge surges in demand since we started operating in Milton Keynes two years ago. We’re excited that both residents and workers can now enjoy this low cost and convenient benefit in the centre of Milton Keynes, and we hope that it will make the town an even more attractive place to work in the future.” The launch of Starship’s Milton Keynes offering comes as conventional delivery services are under increasing strain. Royal Mail delivery workers have complained that they are being asked to risk their health for non-essential deliveries, and the service has had to deal with a growing number of workers taking sick leave. Gig economy delivery companies, such as Deliveroo, have come under pressure too, with their riders, who are not normal employees, worrying that they may have to continue deliveries if they get sick or lose their income entirely. The robotics firm says demand has been high in the last week, and that it plans to expand further across the UK and US. A spokesperson said: “We’ve had grocery stores, restaurants and other delivery companies get in touch to ask for assistance from our robots. To date the robots have completed over 100,000 autonomous deliveries, travelled over 500,000 miles and completed over 5m road crossings around the world. “We are doing everything we can to keep our customers and employees safe. All of the sanitisation processes around our service have been reviewed by experts and we’re following their guidance on operating procedures to ensure a safe and convenient service for everyone. Without robots, more humans are needed in the supply chain for delivery, and as humans are the key source of transmission – using robots decreases this risk.” Starship is just one of a number of startups hoping that lightweight, slow, pedestrian-friendly vehicles might be the solution to normalising autonomous driving. Bigger companies like Amazon have also got involved: the retail giant has been trialling its Scout robots in Washington state. But the robots have not been without controversy. Some competitors have been revealed to have less automation than it seemed: one, Kiwi Campus in Berkeley, California, was actually being driven by people based in Colombia. The spread of the robots has led to conflicts over who has the right to use the pavements, with critics describing their potential proliferation as “a privatisation of the public right of way”.

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