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Inhibition, friend or foe? Cognitive inhibition as a moderator between mathematical ability and mathematical creativity in primary school students

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ABSTRACT

It is still unclear which cognitive factors stand at the base of mathematical creativity. One factor could be inhibition, but results are inconsistent. A possible explanation is that this relation is more complex than the direct relations tested, until now. In the current study, the hypothesis was tested that cognitive inhibition moderated the relationship between mathematical ability and mathematical creativity. The sample included 82 primary school students between 8 and 12 years of age. Mathematical creativity was measured with a multiple solution task and scored on fluency, flexibility, and originality. While there was a direct relation between mathematical ability and mathematical creativity, inhibition did not have a direct effect on mathematical creativity, but it positively moderated this relationship for flexibility and originality. These results indicate that reduced inhibition strengthens the relationship between mathematical ability and mathematical flexibility and between mathematical ability and mathematical originality, but not the relation between mathematical ability and mathematical fluency. These findings are discussed in relation to children with high and low mathematical abilities, measurement of inhibition, and the domain-general/domain-specific discussion of creativity.

1. Introduction

Creativity has been identified as necessary to thrive in the 21st century (Bell, 2010), however, creativity is least promoted during primary school in the domain of mathematics (Bolden, Harries, & Newton, 2010; UNESCO, 2012). Since creativity is deemed important in reaching excellence in mathematics and in extending the domain (Sriraman, 2004; Sternberg & Lubart, 1999), mathematical creativity should be an important aspect of the mathematical curriculum. However, in contrast to mathematical abilities, it is less clear which cognitive factors play a role in mathematical creativity. Therefore, the current study investigated whether the executive function inhibition (i.e. suppressing irrelevant, prepotent, and bottom-up thoughts or stimuli in favour of other, more fitting information; Miyake et al., 2000) plays a role in mathematical creativity. Specifically, we tested the hypothesis that inhibition moderates the relationship between mathematical ability and mathematical creativity in primary school children.

1.1. Mathematical creativity

Mathematical creativity is commonly operationalized as divergent thinking in mathematical tasks and is often measured with a multiple solution task (Kattou, Kontoyianni, Pitta-Pantazi, & Christou, 2013; Leikin, 2009). In the current study, mathematical creativity thus refers to mathematical divergent thinking. However, for readability and adherence to related literature, it is described as mathematical creativity. Leikin and Lev (2013), for example, developed a mathematical creativity task and scored each answer on fluency (i.e. the number of answers), flexibility (i.e. the amount of strategies with different properties, representations, or mathematical domains), and originality (i.e. the answers of a participants compared to a reference group). Multiple solution tasks make it possible to look at the originality of an idea, which is a qualitative way of measuring creativity, and to examine the different ways in which mathematical assignments were solved, even when solutions are less original (i.e. flexibility; Silver, 1997), which is an important aspect of creativity, as well.

1.2. Mathematical ability

Mathematical ability (i.e. quantitative properties such as number sense and pre-algebraic reasoning, causal abilities which include cause and effect, spatial abilities such as perspective and spatial rotation,

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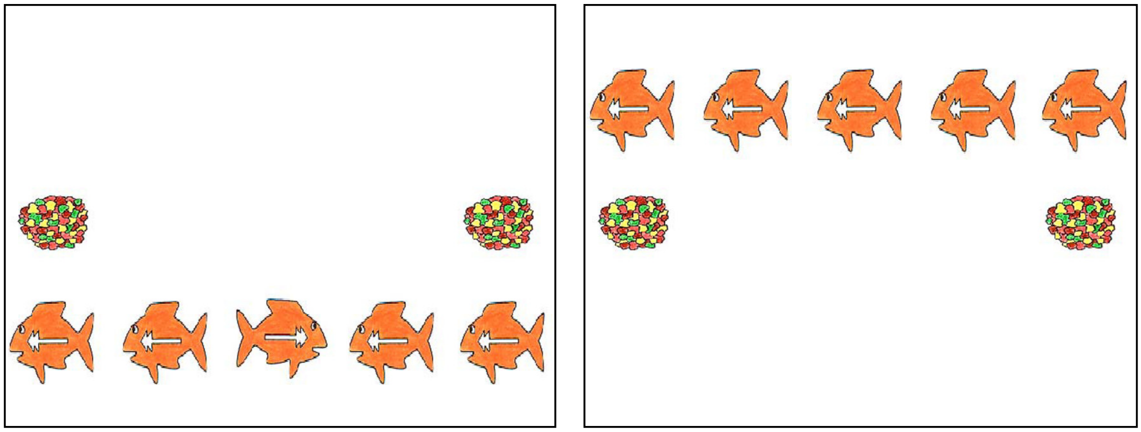

Fig. 1. Example of an incongruent (right) and congruent (left) trial of the Fish Game.

qualitative abilities such as examining differences and similarities, and inductive/deductive abilities which focus on reasoning problems; Kattou, Kontoyianni, Pitta-Pantazi, and Christou, 2013) is an essential prerequisite for mathematical creativity (Haavold, 2013) because as peoples' knowledge about a subject increases, they are able to connect more and different types of information, which will lead to more, different, and more original answers (Schoevers, Kattou, & Kroesbergen, 2018; Sheffield, 2009). In other words, previously learned mathematical knowledge is the scaffolding on which novel mathematical solutions are formed (Nakakoji, Yamamoto, & Ohira, 1999) and will also determine how new mathematical knowledge and assignments will be approached (Sheffield, 2009).

1.3. Inhibition

Although it is clear that executive functions (i.e. higher cognitive functions that regulate thoughts and behaviours) are important during mathematics (as found by Friso-Van Den Bos, Van der Ven, Kroesbergen, and Van Luit, 2013 in a meta-analysis on elementary education children), it is not clear what role they play in mathematical creativity. Executive functions are especially useful during unfamiliar, novel situations which possibly make them an important aspect of creativity, as well.

In the current study, we focus on the executive function inhibition. At face value, it seems as if (mathematical) creativity relies upon adequate inhibition, by inhibiting common answers and increasing the fluent generation of ideas (Benedek, Franz, Heene, & Neubauer, 2012; Golden, 1975; Groborz & Nęcka, 2003; sample ages 14–25). However, evidence that reduced inhibition leads to increased creative performance or that inhibition and creativity are unrelated has been found in adult studies (Burch, Hemsley, Pavelis, & Corr, 2006; Stavridou & Furnham, 1996). Reduced inhibition may facilitate creativity by broadening a person's attentional range and increasing the amount of unfiltered stimuli that gain access to working memory. However, since the age range of the reported studies is very heterogeneous and mostly focuses on adolescents and adults, it is difficult to generalize these findings to a child sample.

In addition, the predictive value of inhibition on mathematics is also still under debate. For example, it has been found that for 3–18 year-olds, inhibition has a unique contribution to mathematical abilities (Harvey & Miller, 2017; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Sikora, Haley, Edwards, & Butler, 2002). However, another study, with 5–8 year olds, reported that mathematical ability and inhibition are only partially related (Toll, Van der Ven, Kroesbergen, & Van Luit, 2010). Moreover, there are even results that indicate the two are unrelated in 6–10 year olds (Censabelle & Noël, 2007; Lee et al., 2012).

To excel in mathematics, flexible thinking and the ability to examine a mathematical situation from different angles are necessary (Dreyfus & Eisenberg, 1996), which are common characteristic of creativity (Batey & Furnham, 2006). However, despite these claims and inconsistent results, the relationship between mathematical abilities, mathematical creativity, and cognitive inhibition has not been studied before (to our knowledge), especially not in children. Furthermore, the inconsistency of previous results makes it difficult to formulate a clear hypothesis. Therefore, we hypothesized that better mathematical abilities lead to better performance on a mathematical creativity task and that inhibition influences this relationship.

2. Methods

2.1. Participants

We investigated a convenience sample of 92 Dutch primary school students from grade 3 to 5. After exclusions, based on missing and extreme values, the final sample was composed of 80 participants for measures of fluency (38 boys, $M_{age} = 9.95$ $SD_{age} = 0.84$, post-hoc power = 0.77); 82 participants for flexibility (41 boys, $M_{age} = 9.93$ $SD_{age} = 0.82$, post-hoc power = 0.93); and 81 participants for originality (41 boys, $M_{age} = 9.96$ $SD_{age} = 0.82$, post-hoc power = 0.95).

2.2. Measures

2.2.1. Inhibition

Inhibition was measured with an adapted version of the Flanker task, the Fish Game, in which the direction of the middle target has to be identified (Eriksen & Eriksen, 1974). This target is flanked by four identical targets that cause distraction when they are in the opposite direction (i.e. incongruent trials) or facilitate identification when they are in the same direction (i.e. congruent trials), as can be seen in Fig. 1. The task consisted of 5 practice trials, in which the participant received feedback on their responses, followed by 12 congruent trials, 12 incongruent trials, and 12 neutral trials (i.e. in which only one fish was presented and there were no flanking fishes). Stimuli were randomly selected and presented at the top or the bottom of the screen. Inhibition was measured by subtracting the reaction time of the neutral trials from the incongruent trials, thereby subtracting general processing speed. The Fish Game has medium to good internal consistency (in this study: Cronbach's α is between 0.56 and 0.79).

2.2.2. Mathematical ability

The Cito test is the standard test battery used by most Dutch primary schools to monitor spelling, vocabulary, reading comprehension, and mathematical development (Janssen, Scheltens, & Kraemer, 2007). The mathematical part of the Cito consists of several mathematical categories (e.g. arithmetic, measuring, fractions, percentages, and proportions), adjusted for the level of mathematical ability in each grade. An example question in the category percentages is: '*With a 50% discount the new price is €1.95. What was the old price?*' For the current study, only the ability sumscores on the Cito math-test were relevant, which have a good reliability (between 0.91 and 0.94 for grades 3 and 5; Janssen, Verhelst, Engelen, & Scheltens, 2010).

2.2.3. Mathematical creativity

To measure mathematical creativity, we used an adapted version of the Mathematical Creativity Test (Kattou et al., 2013; Dutch translation: Schoevers et al., 2018) with five multiple-solution mathematical questions. This test has good internal consistency (Cronbach's α 0.78). Participants have to construct as many solutions as they can that are distinct from each other. We used three mathematical tasks from the original task and added one additional task from Hershikovitz, Peled, and Littler (2009) about dividing a pie in such a way that four people would get the same amount. This task had the following instruction: '*Four children [names given] have to share a square cake fairly. How will they cut the cake?*'. Answers were scored on fluency, flexibility (maximum score = 22), and originality (maximum score = 1 for each questions).

2.3. Procedure

The students were tested during two 1-hour sessions in 2 days. Prior to the study, we received ethical approval from the Faculty Ethics Review Board of Social and Behavioural Sciences (FERB16-112), and active informed consent from at least one parent of the participating child. On the first day, individual paper-and-pencil tasks were administered in a classroom setting, amongst which was the mathematical creativity task. On the second day, computer tasks to measure executive functioning were administered in groups of six participants under the supervision of a researcher, alongside a paper-and-pencil task.

2.4. Data analysis

We utilized hierarchical multiple regression analysis to assess the relationship between mathematical creativity, mathematical ability, and cognitive inhibition, with age in block one, mathematical ability and inhibition in block two, and the moderator variable mathematical ability × inhibition in block three. This process was repeated three times to investigate this relationship for outcomes of fluency, flexibility, and originality. The significance alpha level was set at $p < .05$ (two-tailed) and the t-statistic was used to test if predictors were significant contributors. Standardized scores ($M = 0$, $SD = 1$) were used in the analyses to avoid multicollinearity and ease interpreting the magnitude of effects.

3. Results

Table 1 shows the descriptive statistics and Table 2 shows the correlations per mathematical creativity outcome, which show that mathematical ability was significantly correlated with flexibility, fluency ($p < .001$), and originality ($p < .01$) and that flexibility ($p < .02$) and originality ($p < .05$) were significantly correlated with the interaction-term between inhibition and mathematical ability. The multiple regression results are depicted in Table 3.

Note. The variable Mathematical Ability consists of standardized scores. RT = reaction time.

Mathematical ability, but not inhibition, accounted for a significant amount of variance in flexibility ($R^2 = 0.276$, $F(3, 78) = 9.894$, $p < .001$) and in fluency ($R^2 = 0.182$, $F(3, 76) = 5.623$, $p < .001$). Similarly, for originality, mathematical ability, but not inhibition, accounted for a significant amount of the variance ($R^2 = 0.374$, $F(3, 77) = 4.117$, $p < .01$).

Table 1
Descriptive statistics for Mathematical Ability, Flexibility, Fluency, Originality, and Inhibition.

	Variable	*M*	*SD*	*Min*	*Max*
Flexibility (*n* = 82)	Age	9.93	0.83	8.38	11.39
	Mathematical Ability	0.06	0.90	−2.55	2.47
	Inhibition RT (ms)	244.49	401.44	−824.00	2573.67
	Flexibility	6.94	1.74	1	10
Fluency (*n* = 80)	Age	9.92	0.85	8.38	11.39
	Mathematical Ability	−0.01	0.90	−2.55	2.47
	Inhibition RT (ms)	238.63	404.50	−824.00	2573.67
	Fluency	18.14	13.08	5	90
Originality (*n* = 81)	Age	9.93	0.84	8.38	11.39
	Mathematical Ability	0.15	0.89	−2.55	2.47
	Inhibition RT (ms)	244.38	404.16	−824.00	2573.67
	Originality	1.81	0.54	0.2	2.8

Table 2
Correlations of Flexibility, Fluency and Originality with Age, Mathematical Ability, Inhibition and Mathematical Ability × Inhibition.

	Age	Mathematical Ability	Inhibition RT (ms)	Mathematical Ability × Inhibition
Flexibility	−0.085	0.522***	−0.018	0.261*
Fluency	0.147	0.391***	−0.023	0.019
Originality	0.026	0.372**	−0.050	0.255*

Note. Scores are standardized. RT = mean reaction time.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

The interaction term accounted for a significant proportion of the variance in flexibility ($\Delta R^2 = 0.055$, $\Delta F(1, 77) = 6.307$, $p < .02$, b = 0.252, $t(77) = 2.51$, $p < .02$) and originality ($\Delta R^2 = 0.049$, $\Delta F(1, 76) = 4.374$, $p = .04$, $b = 0.219$, t(76) = 2.09, $p < .05$), but not in fluency ($\Delta R^2 = 0.00$, $\Delta F(1, 75) = 0.037$, $p = .847$, $b = -0.016$, $t(75) = -0.193$, $p = .847$).

Lastly, to further examine the direction of the moderation effect for groups with good and reduced inhibition, we examined the simple slopes, which can be viewed in Fig. 2, by subtracting the standard deviation (i.e. 1) from the centred inhibition and mathematical scores to create the high inhibition group and high mathematical group, and adding the standard deviation (i.e. 1) to the centred inhibition and mathematical scores to create the low inhibition group and low mathematical group.

For flexibility, results indicated that with good inhibition, mathematical flexibility only marginally increased as mathematical ability increased ($t(77) = 1.98$, $p = .052$). However, when inhibition was average (i.e. as in the original regression analysis), mathematical flexibility increased as mathematical ability increased ($t(77) = 5.38$, $p < .001$), and this effect was even larger for reduced inhibition ($t(77) = 5.77$, $p < .001$).

For originality, results indicated that with reduced inhibition scores, mathematical originality did not increase when mathematical ability increased ($t(76) = 0.91$, $p = .368$). However, for average inhibition scores, mathematical ability did have a positive effect on mathematical originality ($t(76) = 3.36$, $p < .001$), and this effect was even stronger for good inhibition scores ($t(76) = 4.07$, $p < .001$).

4. Discussion

The current study investigated whether cognitive inhibition moderated the relationship between mathematical ability and mathematical creativity. As hypothesized, results indicate that mathematical

Table 3
Hierarchical Regression Models for Flexibility, Fluency, and Originality Predicted from Mathematical Ability, Inhibition, and Mathematical Ability × Inhibition, Corrected for Age.

		Predictor	B	SE B	β	*t*	*p*
Flexibility	Model 1	Constant	0.951	1.297		0.733	0.466
		Age	−0.099	0.130	−0.085	−0.759	0.450
	Model 2	Constant	0.605	1.124		0.538	0.592
		Age	−0.067	0.113	−0.058	−0.597	0.552
		Mathematical Ability	0.557	0.104	0.520	5.373	< 0.001
		Inhibition	0.016	0.105	0.015	0.153	0.879
	Model 3	Constant	0.730	1.089		0.670	0.505
		Age	−0.078	0.109	−0.067	−0.716	0.476
		Mathematical Ability	0.541	0.101	0.505	5.382	< 0.001
		Inhibition	0.071	0.104	0.065	0.680	0.499
		Mathematical Ability × Inhibition	0.252	0.100	0.240	2.511	0.014
Fluency	Model 1	Constant	−1.386	0.944		−1.468	0.146
		Age	0.124	0.095	0.147	1.309	0.194
	Model 2	Constant	−1.585	0.877		−1.808	0.075
		Age	0.143	0.088	0.170	1.631	0.107
		Mathematical Ability	0.319	0.083	0.401	3.853	< 0.001
		Inhibition	0.006	0.083	0.008	0.075	0.941
	Model 3	Constant	−1.593	0.883		−1.803	0.075
		Age	0.144	0.088	0.170	1.627	0.108
		Mathematical Ability	0.320	0.083	0.403	3.832	< 0.001
		Inhibition	0.003	0.085	0.003	0.031	0.976
		Mathematical Ability × Inhibition	−0.016	0.082	−0.021	−0.193	0.847
Originality	Model 1	Constant	−0.387	1.238		−0.313	0.755
		Age	0.029	0.124	0.026	0.233	0.817
	Model 2	Constant	−0.420	1.164		−0.361	0.719
		Age	0.030	0.117	0.027	0.259	0.796
		Mathematical Ability	0.382	0.109	0.371	3.501	0.001
		Inhibition	−0.028	0.108	−0.027	−0.258	0.797
	Model 3	Constant	−0.376	1.140		−0.330	0.742
		Age	0.027	0.114	0.024	0.237	0.814
		Mathematical Ability	0.361	0.107	0.350	3.363	0.001
		Inhibition	0.021	0.108	0.021	0.197	0.845
		Mathematical Ability × Inhibition	0.219	0.105	0.223	2.091	0.040

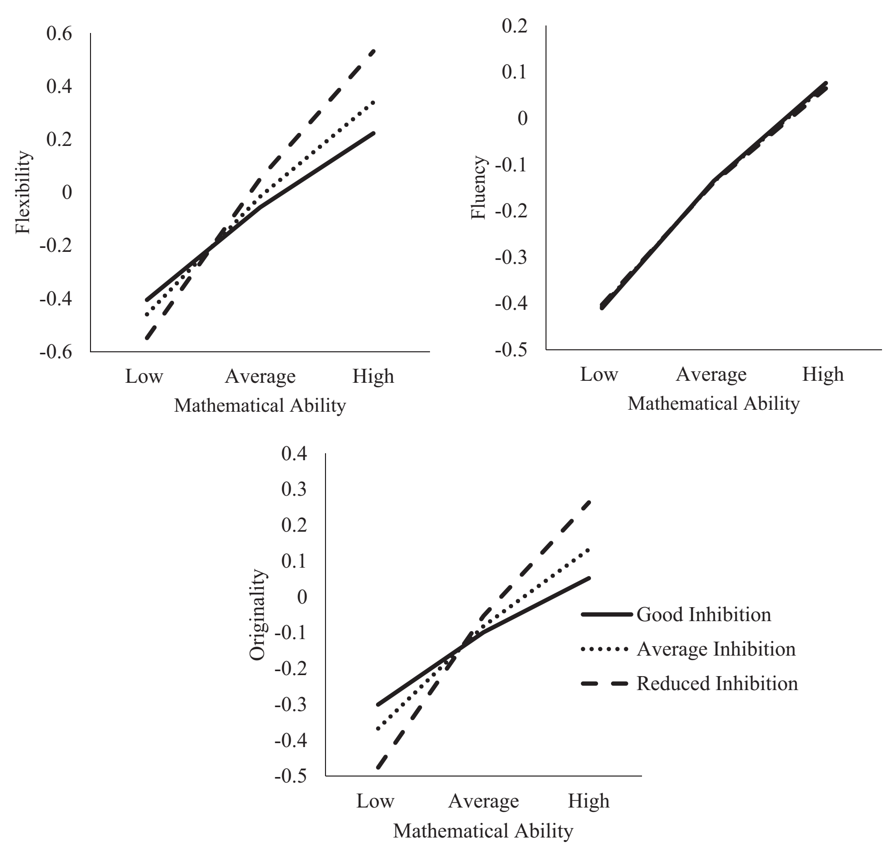

Fig. 2. The influence of mathematical ability on measures of mathematical creativity for participants with good, average, and reduced inhibition.

creativity depends on mathematical abilities and that reduced inhibition led to a stronger relationship between mathematical ability and mathematical creativity for the originality and flexibility of students' answers. The current results offer a new perspective on inhibition as a moderator, which is a valuable addition to previous creativity research that reported either positive or negative direct relationships between cognitive inhibition and creativity (Burch et al., 2006; Edl, Benedek, Papousek, Weiss, & Fink, 2014; Groborz & Nęcka, 2003).

It appears that children with low mathematical abilities and reduced inhibition have a double impairment in the sense that they do not possess enough mathematical abilities to imagine original, flexible, and creative solutions, which makes the task-demands higher for this group. In addition, they may experience more issues with the (increased) task-demands because of their reduced inhibition (Gilhooly, Fioratou, Anthony, & Wynn, 2007). These children probably show a limited range and persistency of solution-categories because of their limited mathematical abilities. Additionally, they may have difficulty inhibiting the most obvious answer, previous answers, and incorrect answers (Gilhooly et al., 2007). Similarly, inhibition has previously been linked to general mathematical (dis)ability as well (Harvey & Miller, 2017; Kroesbergen et al., 2009; Sikora et al., 2002). Thus, for children with low mathematical abilities, reduced inhibition does not seem to facilitate creativity.

On the other hand, reduced inhibition does have a positive influence on mathematical creativity for children with high mathematical ability. These children have an extensive repertoire of mathematical abilities, which probably lowers task-demands during mathematical multiple-solution tasks. Furthermore, it has been proposed that creative people attend to, at first sight, irrelevant stimuli (i.e. over-inclusive thinking because of reduced inhibition), which they can use to generate more original answers (Howard-Jones & Murray, 2003). In combination with increased mathematical ability, this may lead to the availability of different strategies, knowledge, and other stimuli in working memory that can be combined in such a way that solutions are more original and creative. Thus, reduced inhibition strengthens the relationship between knowledge and creativity in children with high mathematical abilities by letting them be more flexible and original. This is in line with Silver (1997), who emphasized the importance of deep, flexible knowledge during creative acts. In contrast, high fluency might be more related to intelligence (Lee & Therriault, 2013). Thus, it is perhaps better to focus on originality and flexibility when examining creativity because of their qualitative nature, whereas fluency is quantitative (Stavridou & Furnham, 1996).

4.1. Strengths and limitations

To our knowledge, the current study is the first to investigate inhibition as a moderator, within the domain of mathematics, in a primary school setting. Often, studies about the relation between creativity and inhibition only report correlational effects or analysis of variances, and the exact influence of the variables remains unknown (e.g. Burch et al., 2006; Stavridou & Furnham, 1996; Vartanian, Martindale, & Kwiatkowski, 2007). By using hierarchical multiple regression analyses, we provide more detail by adding multiple predictors to the model.

However, the current study also has some limitations. For example, originality was calculated based on all answers of the sample, which may differ greatly from sample to sample, and the originality score is dependent on sample size (Silva, 2008). Thus, investigating a broad range of creativity measures is advised in the future.

Additionally, accuracy of inhibition responses was not investigated because there was no response deadline during the task, which led to a ceiling effect of accuracy of nearly one. According to other studies, we thus only used the mean reaction time (e.g. Burch et al., 2006; Stavridou & Funham, 1996; Toll et al., 2010). Although it does not seem as if omitting accuracy is a cause for concern, examining both accuracy and reaction time in future studies would increase the reliability of results and provide additional knowledge.

4.2. Future directions and implications

It appears that reduced cognitive inhibition (i.e. more distributed attention) is beneficial for the original and flexible use of mathematical abilities during multiple-solution tasks if there is a solid mathematical knowledge base to build on. However, if children have lower mathematical abilities and reduced inhibition, these two factors amplify each other, standing in the way of mathematical creativity.

By further examining the effect of inhibition in combination with low and high mathematical ability, we made it possible to take a closer look at the effect that cognitive inhibition has on mathematical creativity, providing a more detailed image and greater clarity concerning the inconsistent results thus far. Therefore, our results may not be as contradictory to previous findings as they seem. For instance, previous research regarding inhibition and creativity investigated different domains or domain-general creativity (e.g. Benedek et al., 2012; Burch et al., 2006). Since we investigated domain-specific creativity in the domain of mathematics, our results form an addition instead of a contradiction to existing literature and may further encourage researchers to investigate the relation between domain-specific creativity and other measures. Perhaps the effect inhibition has on creativity is as highly domain-specific as it is task-dependent (Wöstmann et al., 2013). For example, it has been suggested that task-demands in inhibition tasks can cause large differences in results and even reverse correlational effects (Vartanian et al., 2007). Another explanation may be found in the developmental path of inhibition. That is, inhibition plateaus around the age of 11 (Huizinga & Van der Molen, 2007). This may mean that there are (individual) differences in how well children can implement their inhibition during a creativity task before this age.

Often, reduced inhibition and higher distractibility are frowned upon, and focused attention and good inhibitory skills are seen as crucial for successful learning (Espy et al., 2004). However, our results suggest that these skills can lend a helping hand in tasks that demand flexibility and originality if children possess enough domain-specific knowledge and skills that they can creatively apply. Since the current study investigated a specific age range, future studies should investigate this further with different age ranges, as well as investigate the involvement of other executive functions and examine if these results are transferable to other domains of creativity, as well.

5. Conclusion

To conclude, in the pursuit of (mathematical) creativity, good inhibition seems more of a foe than a friend in regards to the flexibility and originality of imagined ideas from pre-existing mathematical abilities for children with high mathematical ability. However, inhibition seems to be a friend for children with low mathematical abilities. This is the first time this has been researched in children, and it may lead to an encouragement of distributed attention and creativity during development and differentiated education.

Declarations of interest

None.

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