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Recalling Ideas: Mnemonic and Attentional Inhibition in Creativity

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ABSTRACT

Executive functions (updating, shifting, and inhibition) play an important role in creativity. Until now, only attentional inhibition (the Stroop effect) but not mnemonic inhibition (Thinking-Induced Forgetting, TIF) have been studied. Additionally, the temporal dynamics of the influence of the executive functions on creativity remains unknown. Using structural equation modelling and multilevel models, the relationships between both types of inhibition with creative thinking, as well as their temporal dynamics, were tested on a sample of 300 individuals. Mnemonic and attentional inhibition were shown to be independently associated with originality of thinking. Mnemonic inhibition was found to be more important in the later phases of generating ideas, while attentional inhibition was equally important throughout the idea-generation process, consistent with the predictions of the controlled attention theory of creativity. An interaction between both types of inhibition was also observed, indicating that attentional inhibition may be a prerequisite for mnemonic inhibition.

KEYWORDS:

creativity, executive functions, inhibition, Thinking-Induced Forgetting, Stroop effect

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Creative thinking is one of the basic human activities. It enables us to generate new ideas, discover innovative solutions to problems, or transform ideas into concrete products (Kaufman & Sternberg, 2019). As such, it is intensively researched within the behavioural sciences. It requires both bottom-up and top-down cognitive processes (Benedek et al., 2023), mainly creating associations and deliberately using strategies. The role of top-down attentional mechanisms and memory in creative thinking has been investigated in recent years (e.g., Beaty & Silvia, 2012, Benedek et al., 2023). There has been a rapid increase in knowledge of the cognitive mechanisms that allow the creation of novel and valuable products, but the details of these mechanisms and their processes still remain unrecognised.

One such mechanism is inhibition, a process of suppressing undesired internal or external stimuli that interfere with current activity (for a more detailed discussion of the definition see Friedman & Miyake, 2004). The broad construct can be further divided into independent attentional inhibition and mnemonic inhibition (Friedman & Miyake, 2004; Miyake & Friedman, 2012). Attentional inhibition refers to the suppression of dominating reaction and ignoring distracting stimuli (Friedman & Miyake, 2004; Miyake & Friedman, 2012). It allows me to write this article despite local children having a screaming contest just outside my window. It is often measured using the Stroop test (Stroop, 1935). Mnemonic inhibition can be understood as deliberate forgetting of precluding memory contents (Friedman & Miyake, 2004; Miyake & Friedman, 2012). Put simply, if a memory hinders my thinking, I can forcefully separate myself from that memory. It makes recalling harder but thinking simultaneously becomes easier and more effective (e.g., Storm, Angello & Bjork, 2011). This distinction is rarely taken into account in creativity research, where mnemonic inhibition is often equated with attentional inhibition (e.g., Beaty & Silvia, 2012). Given the increasing role of memory in theories describing creative thinking (Benedek, Beaty, Schacter, & Kenett, 2023), it seems valuable to identify the role of mnemonic inhibition in creativity.

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General Models of Creativity

Creative thinking can be understood as a cognitive activity (Ward & Kolomyts, 2019). Thus, psychology of creativity includes within its framework the study and description of the fundamental cognitive processes involved in divergent thinking, i.e. the process and ability to find solutions to open problems. It can be considered an indicator of creative potential (Runco & Acar, 2012). These have led to the development of two different general theories of divergent thinking—the associative theory of the activation spread in the semantic network (Collins & Loftus, 1975) and the controlled-attention theory of creativity (Beaty & Silvia, 2012).

Despite frequently juxtaposing these two theories (e.g., Beaty & Silvia, 2012), they are not necessarily contradictory. Indeed, as contemporary research shows, the interaction of automatic associative processes (bottom-up) and executive processes (top-down) have a completing rather than competing character (Beaty et al., 2014). Two-fold line of thinking might better reflect the nature of creativity than single theories propose (Benedek et al., 2023). It should be noted that there are multiple models of creativity that can be considered dual-process which try to incorporate both associative and executive thinking (see Sowden, Pringle & Gabora, 2015 for a summary).

Associative Theory of Creativity

The first theory draws on Sarnoff Mednick's (1962) views on creativity and can be understood in the context of the network model of semantic memory (Collins & Loftus, 1975). In this view, the creative process is a process of making associations. A person confronted with a task requiring creative thinking, such as the Alternative Uses Test (Torrance, 1966), generates associations with a key stimulus (e.g., a brick) to find unusual ways to use the object. Close associations lead to generating ideas with low originality (e.g., building a house), while distant associations produce creative ideas (e.g., butter for trolls).

The theory predicts that associations become increasingly distant from the original stimulus as thinking continues, and so the ideas generated will become more creative. This phenomenon, known as the serial order effect, was first described by Paul Christensen and colleagues (1957) and has been frequently replicated since (e.g., Beaty & Silvia, 2012). This process can also be understood as memory search (Benedek et al., 2023).

The associative theory also proposes a way to explain individual differences in creativity using a concept of semantic web's steepness. Some semantic networks are said to be steep, that is to say only close associations can be made. Flat networks allow for creating both close and distant associations. It is much harder to walk a kilometre in the mountains than in a city. The same applies to the semantic activation wave—it can travel longer distances in more flat networks.

The Controlled-Attention Theory of Creativity

The latter theory describes divergent thinking as a controlled process in which executive functions play a key role. The theory was not authored by a single person but is a stream of thinking visible in contemporary research (Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014; Forthmann et al., 2016). The main executive functions studied within this strand include updating, shifting, and inhibition (Benedek et al., 2014; Miyake et al., 2000; Palmiero, Fusi, Crepaldi, Borsa, & Rusconi, 2022).

In this perspective, divergent thinking is not a passive process, like the wave of semantic activation, but an active and controlled action. As for the previous example, the person inventing alternative uses for a brick can use different strategies, such as determining the object's properties, transformations, etc. (Gilhooly, Fioratou, Anthony, & Wynn, 2007). From inferring that a brick is hard, one can move on to specifying uses for a hard object (e.g., a cheap bulletproof vest).

As shown by Benedek and colleagues (2014), when including intelligence in the model, of the three executive processes, updating and inhibition are associated with creativity, while the effect of shifting remains statistically insignificant. It should be noted that the study's conclusions were drawn at the level of individual differences in the effectiveness of executive processes rather than at the processual level. Similar conclusions are also drawn from the literature review by Palmiero and colleagues (2022).

An important element in considering the creative process in terms of strategies used is the distinction between mnemonic and executive strategies. The original study by Gilhooly and colleagues (2007) has already shown that people completing a creativity task use strategies based on searching their memory in the first phases of thinking, while later on, they start to use more active strategies. This distinction and its temporal dynamics are used to explain phenomena such as the serial order effect (Beaty & Silvia, 2012; Silvia & Beaty, 2012) or the be-creative effect (Forthmann et al., 2016).

Executive Functions and Creativity

Executive functions are a set of cognitive functions by which an individual exercises active control over behaviour (Beaty & Silvia, 2012; Miyake et al., 2000; Friedman et al., 2006) and performs mental work with ideas (Diamond, 2013). Initially, executive function was considered a single, homogeneous construct (Denckla, 1996), but over time independent executive processes began to be distinguished (Friedman & Miyake, 2004; Friedman et al., 2006; Miyake et al., 2000). There are different classifications of executive functions, but updating, shifting, and inhibition are often mentioned as the key ones (Benedek & Jauk, 2019; Benedek et al., 2014; Friedman et al., 2006; Miyake et al., 2000; Miyake & Friedman, 2012). In other studies, updating is sometimes referred to as working memory and shifting cognitive flexibility (Diamond, 2013; Palmiero et al., 2022). Executive functions are often linked to intelligence (Beaty & Silvia, 2012; Benedek & Jauk, 2019; Benedek et al., 2014; Chen & Li, 2007; Silvia & Beaty, 2012; Troche et al., 2024), although Friedman and colleagues (2006) show that not all executive functions exhibit such connection.

The classical classification was first proposed by Miyake et al. (2000). In this view, updating can be understood as an ability or process that leads to a change in cognitive representation. It can manifest itself, for example, by incorporating new information into the cognitive representation of a problem. Shifting is the ability to redirect attention from one cognitive representation to another, for example, focusing on a different aspect of a task. Finally, inhibition is actively suppressing or removing cognitive representations from working memory. As was later added by Friedman and Miyake (2004) it can involve ignoring some aspect of a cognitive representation (attentional inhibition, e.g., ignoring the colour of a writing and focusing on the content) or deliberate, periodic forgetting of specific information (mnemonic inhibition).

The controlled-attention theory of creativity discussed above allows for inclusion of executive functions into the description of the creative process. Classical associative theory of creativity considers automatic processes to be the mechanism of divergent thinking and thus does not allow for the inclusion of top-down cognitive activity. Yet, the relationship of individual executive functions to creativity has been intensively studied. A review of 57 research papers on this topic was conducted by Palmiero and colleagues (2022). The results were mixed. The literature suggests a positive relationship between creativity and inhibition and updating, while the association of cognitive flexibility with creativity is less clear (Palmiero et al., 2022).

Attentional Inhibition

Attentional inhibition consists of prepotent response inhibition (inhibition of automatic reactions) and resistance to distractor interference (ability to ignore external distractors, see Friedman & Miyake, 2004). Put simply, it allows us to focus our attention and behave appropriately despite distractors (noises, flashes of light, etc.) and impulses. When an optometrist measures the blood pressure in my eye, they use a light blow of air oriented towards my eyeball. In such cases, I always violently move away from the machine despite strongly trying not to. That is to say, I lack the ability to inhibit my automatic reaction, which interests me, a psychologist, and irritates the optometrist.

Inhibition is usually measured using the Stroop test (11 out of 28 studies in Palmiero et al., 2022). It includes showing the participant a set of conflicting stimuli in the form of a name of a colour written in a different colour (e.g., the word "RED" written in blue). The participant must inhibit the automatic reaction of reading the word and name the colour in which the word is written (Stroop, 1935). The Stroop effect is so fundamental that it was used to detect Russian spies during the cold war—if a person exhibited interference, they apparently could read and understand Russian (Chen & Zou, 2021).

Other classical attentional inhibition tests include the Flanker task (Eriksen & Eriksen, 1974) and the Simon task (Simon & Wolf, 1963). The first one requires that the participant reacts to some central stimulus (e.g., a letter) surrounded by either distractors (e.g., other letters) or neutral signs (e.g., squares). Thus, the distractors must be inhibited. The Simon task includes reacting to a stimulus with properties conflicting or corresponding to the desired reaction. For example, a participant might be instructed to click the right arrow when they see a red dot. The reaction is faster when the red dot appears on the right side of the screen and slower when the dot appears on the left side of the screen.

There appears to be a linear relationship between attentional inhibition and divergent thinking (Palmiero et al., 2022). In Benedek et al.'s (2014) latent model including intelligence and the three main executive functions, the relationship of attentional inhibition with divergent thinking was .20. The cognitive mechanisms of this relationship were not fully discovered.

Goal-Directed Forgetting

Outside the psychology of creativity, there is research on the Retrieval-Induced Forgetting (Anderson, Bjork, & Bjork, 1994) and related phenomena such as Problem-Solving-Induced Forgetting (Storm, Angello, & Bjork, 2011) or Thinking-Induced Forgetting (Storm & Patel, 2014). Their common properties allow them to be subsumed under the common term "goal-directed forgetting" (Bjork, Bjork, & Anderson, 1998). Goal-directed forgetting is usually understood as the removal of memory contents in such a way that expedites the main task. Goal-directed forgetting could potentially be considered a metacognitive process (but see Koriat & Levy-Sadot, 2000 for an opposing view), an element of metacognitive control (Lebuda & Benedek, 2023).

The relationship between mnemonic inhibition and divergent thinking can be viewed in the context of MemiC (Benedek et al., 2023), a contemporary theoretical framework defining the role of memory in creativity. The authors provide four key assumptions on which MemiC is based:

1. Creative thinking is based on the interplay of automatic bottom-up processes and active top-down processes.
2. Not only semantic memory but also episodic memory, which is much less studied, plays an important role in creative thinking.
3. Creative thinking is similar to active, constructive memory processes (also at the neuronal level). The active nature of memory can be used to explain creative thinking processes.
4. The two types of memory contribute differently to various stages of creative thinking.

The authors propose dividing the creative thinking process into two phases: Generation and Evaluation. Generation consists of deliberate memory search and construction or cognitive transformation of patterns, while the evaluation phase consists of assessing the novelty of the idea and its effectiveness.

Based on the results obtained in a seminal study by Gilhooly and colleagues (2007) as well as later findings (Beaty & Silvia, 2012; Forthmann et al., 2016; Silvia & Beaty, 2012), it might be inferred that initially, the bottom-up processes dominate thinking. Memory searches are uncoordinated and random. Then, either naturally or through manipulation, top-down coordination of memory search occurs (e.g., by focusing on particular properties of a stimulus object in a task or deconstructing it in the imagination).

Retrieval-Induced Forgetting

In its most basic form, this phenomenon was first detected by Anderson, Bjork, and Bjork (1994) using a paradigm they called the Retrieval-Practice Paradigm (RPP). In a typical study, the participant is asked to learn words belonging to a series of different categories (e.g., fruit—orange, fruit—cherry, tools—screwdriver, tools—hammer). Firstly, each category-word pair is displayed one-by-one with the instruction to memorise as many as possible. In the second phase, some of the learned words are practised (repeated). Half of the categories are practised (Rp), while the other is not (Nrp; e.g., the fruits are practised, but the tools are not). The practice usually involves showing the name of the category with the first letters of the word (e.g., fruit—or____) with a request to recall which word is referred to (here: complete "orange"). However, not all words are practised. Only half of the words in the practised category are repeated (e.g., orange is repeated, but cherry is not, even though fruits are an Rp category). This divides the overall Rp set into sets Rp+ (practised words from practised categories) and Rp- (unpractised words from practised categories). The final result is therefore (1) unpractised categories (e.g., all tools), (2) practised words from practised categories (e.g., half of the fruits, including orange) and unpractised words from practised categories (e.g., the other half of the fruits, including cherry). See Figure 1 for reference. This is followed by a memory test covering all the words.

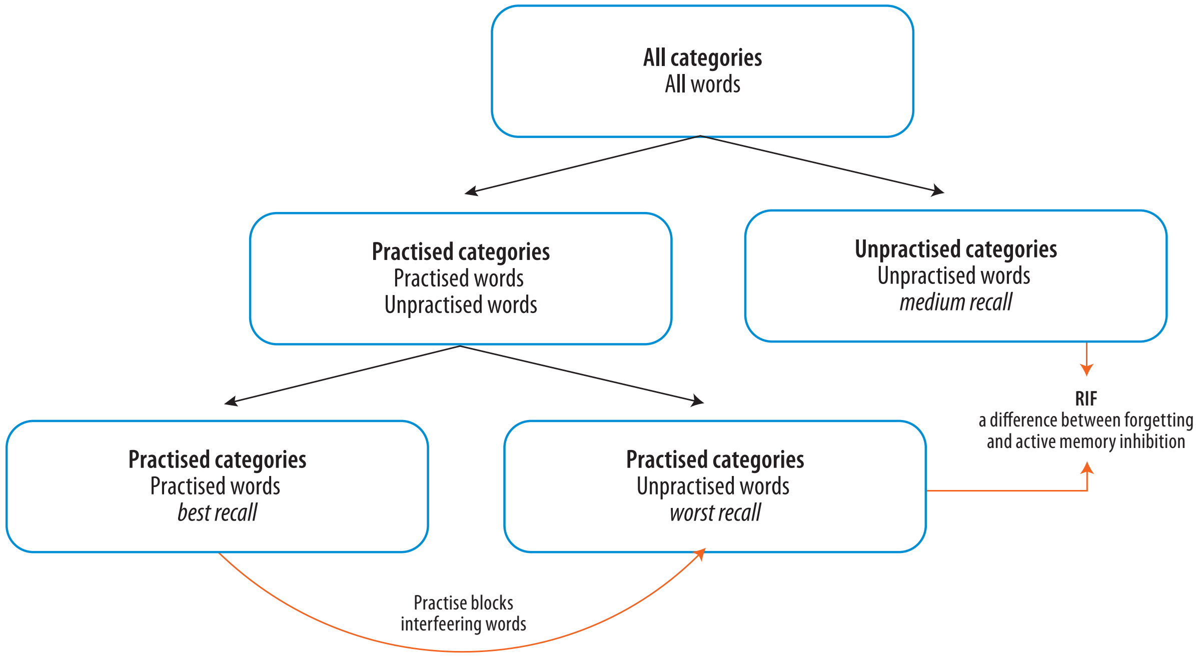

Figure 1. The scheme of the Retrieval-Practice Paradigm words and categories

The semantic network theory and intuitive predictions suggest that words that have been practised are remembered most effectively. This is, in fact, the case, but the RIF effect is revealed in the other two categories. The Rp- words can be expected to be less recalled than the Rp+ words, and it should be most difficult to remember the words from the categories that have not been repeated at all (Nrp). The semantic activation generated while recalling the Rp+ words should also automatically strengthen semantically close Rp- words (e.g., repeating orange and apple should also strengthen the recollection of cherry and pear by association), as the semantic network theory predicted. However, the results consistently show that training the Rp+ words actually significantly weakens the recall of the Rp- words. Ultimately, the Rp- words are recalled even worse than the Nrp words. A meta-analysis by Murayama and colleagues (2014) estimates the mean effect size (i.e., the difference between the level of recall of Rp- and Nrp words) of 8.7% and suggests that this may be an underestimation.

This effect can be interpreted in terms of the executive processes. During the practice phase, the Rp- words are a source of mental fixation (Storm & Angello, 2010) and, in order not to impede the practise of the Rp+ words, they are inhibited. The inhibition process thus blocks the memory access to the Rp- words, which remain blocked during the memory test. This kind of "a memory wall" naturally subsides after some time (Koppel & Storm, 2014). It is thus an adaptive phenomenon, as it facilitates the performance during the training phase (Storm & Stone, 2015)—the disruptive associations are forgotten. This type of inhibition can be referred to as Resistance to Proactive Interference (Friedman & Miyake, 2004), but I do not find this term accurate, as it suggests a passive trait (resistance), whereas inhibition is an active process (Lemire-Rodger et al., 2019; Palmiero et al., 2022). Whether the process of inhibition is necessary to explain the phenomenon of Retrieval-Induced Forgetting remains a contentious issue (Murayama et al., 2014; Verde, 2012).

RELATED PHENOMENA

Research into the phenomenon of Retrieval-Induced Forgetting has led to the discovery of related phenomena. The most important here will be Problem-Solving-Induced Forgetting (PSIF) and Thinking-Induced Forgetting (TIF). Both of these processes are studied using their own paradigms, which are modifications of the RPP. The difference occurs in the second phase of the paradigm, that is the practice of previously memorised information. In the original paradigm the practice takes the form of repetition, whereas in the modified versions of the method the form is different.

Problem-Solving-Induced Forgetting

The existence of Problem-Solving-Induced Forgetting was demonstrated by Storm, Angello and Bjork (2011). They modified the RPP in such a way that, instead of repeating previously memorised words, the subject tries to perform a Remote Associates Test (RAT, Mednick, 1968). The items of the tests are sets of three words (e.g., Bass, Complex, Sleep) to which the participant must add a fourth, related word (e.g., Deep).

Some of the learned words interfered with the RAT by introducing a false lead. For example, the subject might be required to remember a pair of Sleep-Mask while trying to find the answer to the Bass-Complex-Deep triad. These associations held in memory are a source of fixation, making it difficult to find a connection between words, and are actively inhibited. This results in a similar pattern to the original RIF study (Storm et al., 2011)—words that appear in the RAT items are remembered worse than the words that do not appear in RAT. Importantly, forgetting correlated positively with performance on the Remote Associates Test. Again, this suggests that goal-conditioned forgetting is an adaptive process.

Thinking-induced forgetting

Thinking-induced forgetting was discovered by Storm and Patel (2014). Here, word repetition was replaced by an Alternate Uses Test (AUT, Torrance, 1966), and the material to be learned was different uses for typical objects (e.g., brick—weight plate, give as a gift, crush into powder, stepping stones). After a memorisation session, the participant is asked to come up with some new uses for half of the objects. Uses held in memory were inhibited as sources of fixation, resulting in their increased forgetting. The results obtained allow us to conclude that the Alternative Uses Test produces similar memory effects as word repetition or problem solving (Storm et al., 2015).

Moreover, as in the case of Problem-Solving-Induced Forgetting, the level of performance (i.e., creativity of responses) correlated positively with forgetting. This seemingly paradoxical effect can be explained by viewing forgetting as blocking information causing fixation. The release of cognitive resources allows for more effective divergent thinking. This indicates the adaptive nature of the phenomenon of Thinking-Induced Forgetting.

Remembering the typical uses of an item in a Thinking-Induced Forgetting paradigm is a source of fixation in the first phases of thinking. The effectiveness of divergent thinking depends on the suppression of this fixation. However, if it is effectively suppressed at an early stage, the effect should later increase, nullifying the negative effects of fixation. This explains the positive correlation of the TIF effect with creativity (Storm & Patel, 2014). The initial bottom-up processes rely on memory alone, without engaging attention, which can be inferred from the automaticity of these processes (Benedek et al., 2023). If the participant is actively directed towards associative strategies, the previously learned uses are not a source of mental fixation, and inhibition does not take place (Storm & Patel, 2014). Thus, a person adept in mnemonic inhibition should find it easier to use executive strategies in the later stages of thinking as there is no mental fixation to interfere with the strategy. The temporal dynamics of the effect of mnemonic inhibition on creative thinking will be examined in this study. As George and Wiley (2019) suggest, one's own early ideas can also be a source of fixation and thus be an object of mnemonic inhibition.

THIS STUDY

The present study aims to explore the relationship between mnemonic inhibition and creativity in the context of the Controlled-Attention Theory of Creativity. The study was preregistered (osf.io/7mdgb), and received approval from the Research Ethics Committee at the University of Wrocław.

Firstly, this study attempts to replicate the relationship between the effect of Thinking-Induced Forgetting (Storm & Patel, 2014) using measures adopted in this branch of research. The multidimensional way of assessing creativity used by Storm and Patel (2014) captures the phenomenon of creativity perhaps more holistically but makes it difficult to compare the effects with other creativity research. It also does not allow for interpretation in the context of the dimensions of divergent thinking (fluency, flexibility, originality, and, less frequently studied, elaboration; see Guilford, 1957).

Secondly, the effect will be tested when controlling for attentional inhibition. If mnemonic and attentional inhibition are independent processes (Friedman & Miyake, 2004; Miyake & Friedman, 2012), their effect on divergent thinking should also be independent. This will call into question their inclusion in creativity research under the single category of inhibition and will point the way forward for research into the role of executive processes in divergent thinking.

Thirdly, the TIF effect will be confronted with the assumptions of the attentional theory of creativity already flowing from Gilhooly and colleagues' (2007) classic research, stipulating that memory strategies are used in the initial phase of divergent thinking and executive strategies in the later phase. On this basis, the Controlled-Attention Theory of Creativity attempts to explain the serial-order effect (Beaty & Silvia, 2012; Silvia & Beaty, 2012) or the be-creative effect (Forthmann et al., 2016). A similar conclusion comes from the MemiC model (Benedek et al., 2023). As the association is an automatic process that does not require attentional engagement, both types of inhibition should gain importance as the participant shifts from mnemonic to executive strategies.

- H1: Mnemonic inhibition (Thinking-Induced Forgetting) positively correlates with originality of divergent thinking.
- H2: Attentional and mnemonic inhibition have independent positive relationships with originality of divergent thinking.
- H3: The associations of both types of inhibition with the originality of divergent thinking are moderated by time, where both gain importance.

METHODS

Participants

A power analysis performed with G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) assuming parameter values of $\alpha = .05$ and $\beta = .95$ and an effect size for the H1 hypothesis of $r = .19$ (based on Storm & Patel, 2014). The analysis was based on a one-tailed correlation test. It showed a minimum sample size of 295 individuals.

Study subjects were recruited using the Prolific survey panel. Participants were paid £1.98 (£6.00/hour) for completing the survey. The sample consisted of 330 observations, of which 30 were excluded due to admitting to cheating on the memory test (16 subjects), less than two ideas on at least one of the Alternative Use Tests (7 subjects), missing a score on at least one of the tests (2 subjects), or completion time exceeding 3 standard deviations from the mean (6 subjects). These exclusions were preregistered. Finally, 300 observations (172 women, 127 men, and 1 non-binary person) were analysed. The mean age was $M = 43.5$ years ($SD = 14.5$).

Procedure

The study was conducted using the online platform PsyToolkit (Stoet, 2010, 2017). The subjects were presented with the purpose of the study ("exploring the relationship between memory and creative thinking"), after which they had agreed to participate. The participants were then informed that participation in the study required correct colour discrimination (for the Stroop test). The ability to discriminate colours was then tested by showing the test person pictures with the letters "XXXXX" written in red, green, blue and yellow (one at a time, in random order). The participant was given 10 seconds to choose from the given answers the name of the colour in which the characters were written. If the subject answered all four questions correctly, they moved on to demographic questions about age and gender.

Later, the participant completed an attentional inhibition test followed by the mnemonic inhibition test. The Alternative Uses Tasks were conducted as a part of the mnemonic inhibition test (see below). After that, the participant was asked two control questions: “Did you carry out the task as instructed?” and “We are not interested in getting the assignment as correct as possible, but in having the data tell us something about the human psyche, so we ask you to answer honestly. You will be paid regardless of your answer to this question. Did you write down the applications you were supposed to remember on a piece of paper or take screenshots?” The answers were used to exclude cheaters. The procedure ended with a memory test.

Attentional Inhibition

The first test performed by the subjects was the classic Stroop test (1935). The test subject was shown the name of a colour written in a coloured font. The colour name and colour could be congruent (e.g., the word “red” written in red), incongruent (e.g., the word “red” written in blue) or neutral (“XXXXX” written in a given colour). The subject was asked to ignore the word’s meaning and name the colour with which the word was written, which they did by clicking the corresponding button on the keyboard. The difference between the mean response time in the incongruent and neutral condition for correct responses was used as an index of attentional inhibition, following Benedek et al. (2014). The test was repeated 3 times. A single repetition consisted of 32 trials, of which 16 were neutral stimuli, 12 were congruent stimuli, and 4 were incongruent stimuli in random order. Each trial was followed by brief feedback (“good” or “bad”). Before the actual test, the subject underwent 2 practice sessions, 10 trials each. Between the test repetitions, the subject was shown a brief thank-you note and was reminded which key was associated with which colour. The interval between repetitions lasted 20 seconds. The total score for each test subject was modelled at the latent level using all three repetitions of the test. The reliability of the latent measurement was $\omega = .61$ which is the same as in Benedek et al. (2014).

Mnemonic Inhibition

The subject then took a test in a modified RPP paradigm examining Thinking-Induced Forgetting (Storm & Patel, 2014). In a random order, they were shown the name of an item with its 4 typical uses with the instruction to remember as many of them as possible. The uses were taken from Storm and Patel’s (2014) study. A total of 6 objects were used (balloon, spoon, newspaper, bucket, paperclip, and screwdriver). The 2nd, 4th, and 6th items were followed by an Alternative Uses Test (AUT, cf. below). After all 6 items, this part of the test was followed by a memory test. The items were displayed in the same order in which they appeared during the previous test phase, one at a time. The subject was asked to recall all the 4 uses they had initially learned by heart. The time limit was 30 seconds per item. The effect size was calculated as the difference between the average recall performance of the uses of the items followed by AUT and those not followed by AUT. Assessment of recall accuracy was done manually by the researcher.

Originality of Divergent Thinking

The mnemonic inhibition test was punctuated by three Alternative Uses Tests (AUT, Torrance, 1966). This task involves coming up with unusual, original, creative uses for typical objects (enumerated above). Which items were followed by an AUT was randomised and depended on the order in which the items were presented. Ultimately, each subject came up with unusual uses for 3 of the 6 items used in the study. The time limit for a single AUT was 2 minutes. Each response was scored for originality using the Oscai system, daVinci model 2 (Organisciak & Dumas, 2020). The individual scores modeled an overall creativity index for each subject using the Multidimensional Top Scoring method (Forthmann, Karwowski, & Beaty, 2023; Jędrusiak, Forthmann, Beaty, & Karwowski, 2023). This method of modelling creativity can combine the validity of the top-scoring method (using only some number of best ideas rather than all the ideas) with the reliability of basing the overall score on more information. The time of each response was recorded.

DATA ANALYSIS

The data analysis was performed using the R environment (R Core Team, 2022) and packages, especially *tidyverse* (Wickham et al., 2019), *rstatix* (Kassambara, 2021), *lavaan* (Rosseel, 2012) and *lme4* (Bates, Mächler, Bolker, & Walker, 2015). The *mtscr* package (Jędrusiak et al., 2023) was used to model the creativity of the subjects. The data and the analytic code are available in open access (osf.io/7mdgb).

RESULTS

The descriptive statistics are presented in Table 1. Each participant's creativity was estimated using the Multidimensional Top Scoring model (Forthmann et al., 2023; Jędrusiak et al., 2023). A model based on the top 3 ideas was used. The empirical reliability of the model was high ($R = .93$). The mean number of correctly recalled item uses in the condition with and without AUT was compared to test the Thinking-Induced Forgetting effect. The mean number of recalled object uses in the condition with AUT was $M = 4.06$ ($SD = 2.36$), and in the condition without AUT, $M = 4.76$ ($SD = 2.1$). A t-test for dependent samples was performed. The difference was statistically significant ($t(313) = -5.37$, $p < .001$, $d_z = -0.30$).

Table 1. Descriptive statistics

	M	*SD*	*Min*	*Max*	*Me*
Creativity score	.02	.35	–1.19	.98	.04
TIF 1	.27	1.17	–3	3	0
TIF 2	.19	1.21	–4	3	0
TIF 3	.26	1.26	–4	3	0
TIF sum	.72	2.29	–6	7	1
Stroop 1	–200.15	142.46	–862.11	150.99	–177.01
Stroop 2	–178	129.4	–626.82	241.69	–164.13
Stroop 3	–175.9	140.76	–750.97	154.5	–164.23
Stroop mean	–184.68	103.15	–474.47	99.91	–175.36

Hypothesis 1.

To test hypothesis 1, we examined the correlation between scores on the mnemonic inhibition test and originality of divergent thinking. These variables were significantly, positively, yet weakly associated ($r = .12$, $p = .031$).

Hypothesis 2.

Initially, we fitted a confirmatory factor analysis measurement model to examine the fit of latent mnemonic inhibition factors. Given that the model showed some signs of overfitting ($CFI = 1.0$, $TLI = 1.05$, $RMSEA = .00$, $SRMR = .03$), we proceeded with the difference between the recall performance of object uses followed by AUT and those not followed by AUT as an indicator of mnemonic inhibition.

Structural Equation modelling was then carried out. We fitted a model in which attentional inhibition was the latent variable based on three repetitions of the Stroop test, and the other variables were the measured variables. This model fit was satisfactory ($CFI = 1.0$, $TLI = 1.04$, $RMSEA = .00$ (90% CI .00-.07), $SRMR = .019$). The relationships between the variables are presented in Figure 2.

As it is difficult to compare effect sizes between latent and measured variables, a linear regression model was also fitted in which attentional inhibition was expressed as the mean of three repetitions of the Stroop test. The model was statistically significant ($F(2, 297) = 5.95$, $p = .003$). The adjusted coefficient of determination was $R^2 = .032$. The standardised regression coefficient for attentional inhibition in this model was $\beta_1 = .152$ ($p = .008$), and for mnemonic inhibition it was $\beta_2 = .130$ ($p = .023$).

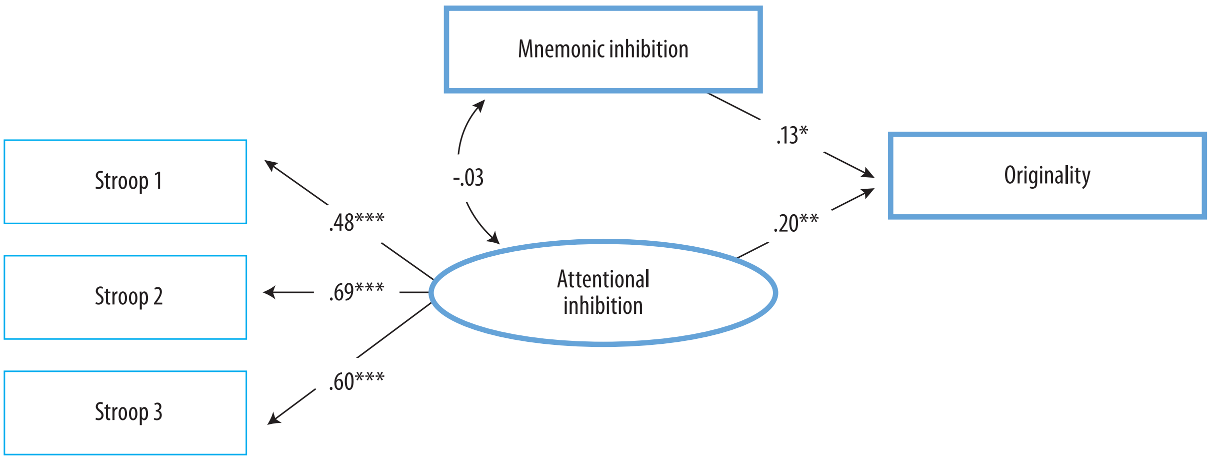

Figure 2. SEM model of both types of inhibition and originality

Hypothesis 3.

Before fitting the models, time was transformed using the natural logarithm to obtain a near-normal distribution. Each value was standardised at the person level to account for individual differences in task speed. In addition, individuals answering at a time farther than 3 SD from the mean were excluded ($n = 90$), according to preregistration. The values of the remaining variables were standardised at the level of the whole sample. Finally, 4,902 ideas grouped by 230 individuals were included in model 1 and 5,178 ideas grouped by 231 individuals were included in model 2.

In order to test hypothesis 3, two two-level models were fitted, where ideas (level 1 variable) were nested within individuals (level 2 variable). The dependent variable in each model was the originality of divergent thinking, which was assessed at the level of ideas. The predictors were mnemonic inhibition (Model 1, Table 2.) and attentional inhibition measured at the person level (Model 2, Table 3.), the time elapsed between starting the task and approving the answer, and the interaction between the two, respectively. The significant interaction between time and mnemonic inhibition from model 1 is shown in Figure 3. Subsequently, we fitted a model including both types of inhibition and their interaction with time (Model 3, Table 4.), and a model including all predictors from model 3, an interaction between both types of inhibition, and a triple interaction of both types of inhibition with time (Model 4). Models 3 and 4 were not significantly different ($\chi^2(2) = .385$, $p = .825$).

Table 2. Regression coefficients for Model 1. in H3 (`originality ~ TIF * time + (1|ID)`)

	β	*SE*	*t*	*df*	*p*
(Intercept)	.011	.029	.369	229.74	.713
TIF	–.004	.03	–.124	223.24	.901
Time	.093	.013	6.969	4676.24	< .001***
TIF : Time	.035	.014	2.568	4676.24	.01*

Table 3. Regression coefficients for Model 2. in H3 (`originality ~ stroop * time + (1|ID)`)

	β	*SE*	*t*	*df*	*p*
(Intercept)	0	.028	–.007	242.11	.995
Stroop	.054	.028	1.929	239.01	.055
Time	.09	.013	6.869	4942.94	< .001***
Stroop : Time	.003	.013	.263	4942.94	.793

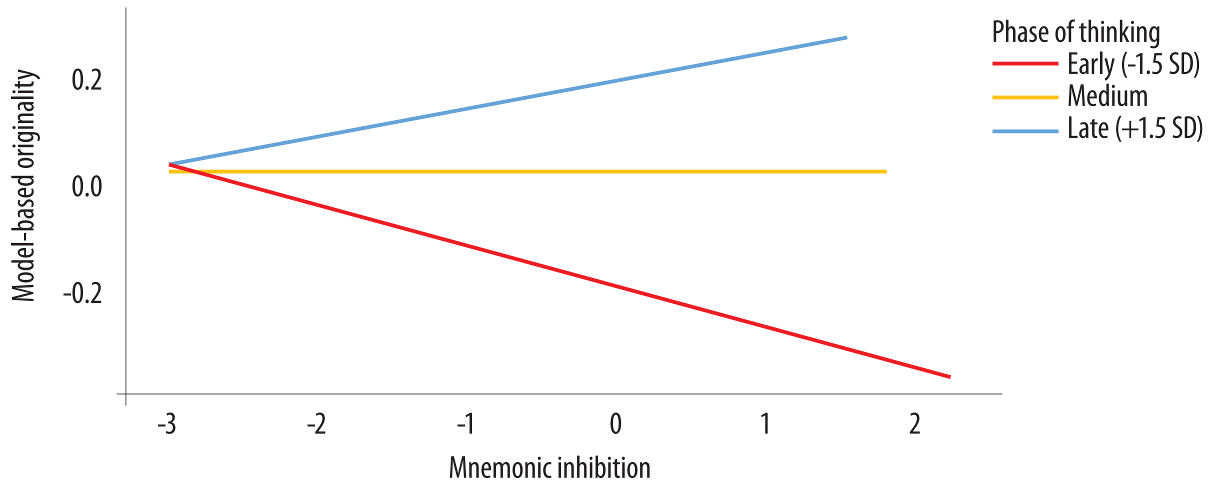

Figure 3. Moderation of relationship between mnemonic inhibition and originality by time

Table 4. Regression coefficients for Model 3. in H3 (`originality ~ stroop * time + TIF * time + (1|ID)`)

	β	*SE*	*t*	*df*	*p*
(Intercept)	.01	.029	.334	230.3	.739
Stroop	.056	.029	1.944	227.9	.053
TIF	–.005	.03	–.159	223.9	.874
Time	.093	.013	6.956	4677	< .001***
Stroop : Time	.003	.014	.26	4677	.795
TIF : Time	.035	.014	2.545	4677	.011*

To further explore the mechanism of mnemonic inhibition's contribution under hypothesis H3, the ideas were divided into those given in the first half of the task (the first 60 seconds) and those given in the second half. Participants' creativity was then estimated using a Multilevel Top Scoring model, separately for both halves. The model was based on the two best ideas, as it had the highest empirical reliability ($R=.878$, $FDI=.937$). A linear regression model was fitted to each half with mnemonic inhibition as the explanatory variable. The model for the first half was found to be statistically insignificant ($F(1, 226)=.011$, $p=.917$), while the model for the second half was statistically significant ($F(1, 220) = 8.1$, $p = .005$). Regression coefficients for the two models were compared using the Wald chi-squared test for fixed effects (Fox & Weisberg, 2019) based on a multilevel model with the half (first *vs.* second) and half-mnemonic inhibition interaction (`.originality ~ half + half:TIF_sum + (1|id)`). The regression coefficient in the second half was significantly higher than that in the first half ($\chi^2(1) = 4.31$, $p = .038$); for the TIF effect interaction with the first half it was $\beta_1 = -.033$ ($p = .603$) and with the second half $\beta_2 = .133$ ($p = .040$). That is to say, mnemonic inhibition has a statistically significant relationship with originality only in the second half of the thinking process.

Exploratory analysis

An exploratory analysis was conducted to test the significance of the interaction between mnemonic and attentional inhibition. The model was statistically significant ($F(3, 296) = 5.31$, $p = .001$). The adjusted coefficient of determination was $R^2 = .041$. The regression coefficients are presented in Table 5. A simple effects analysis was then conducted. For this purpose, the attentional inhibition variable was divided into 3 categories—low (over 1 SD below the mean), medium (within the range of 1 SD from the mean), and high (over 1 SD above the mean). The results are shown in Figure 4. Mnemonic inhibition did not predict the originality of divergent thinking for those with low ($F(1, 294) = .03$, $p = .088$) or medium ($F(1, 294) = 1.92$, $p = .167$) attentional inhibition, whereas for those with high attentional inhibition, the relationship was positive and statistically significant ($F(1, 294) = 6.25$, $p = .013$).

Table 5. Regression coefficients of interaction between both types of inhibition

	β	*SE*	*t*	*df*	*p*
(Intercept)	.004	.057	.074	296	.941
Stroop	.15	.057	2.649	296	.009**
TIF	.133	.057	2.343	296	.020*
Stroop : TIF	.11	.056	1.977	296	.049*

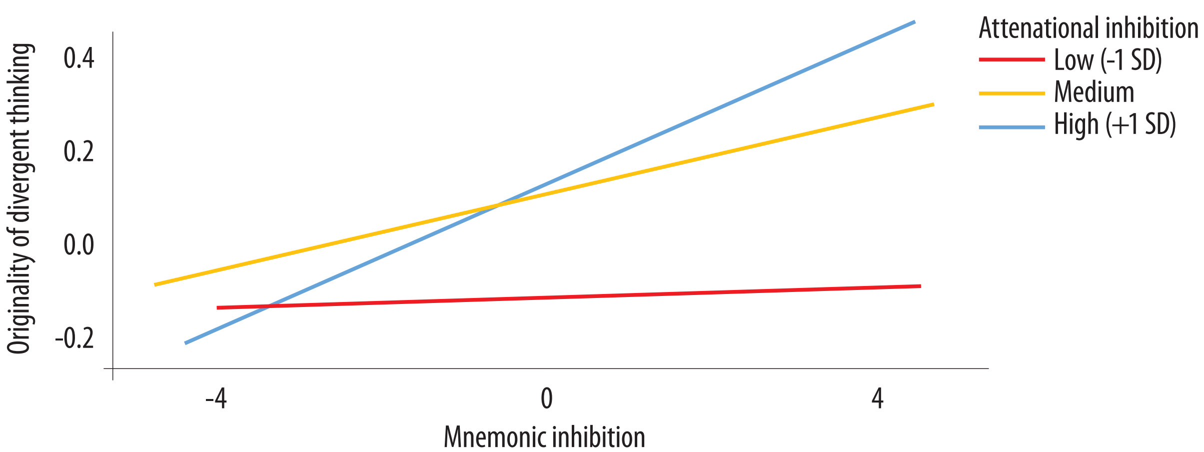

Figure 4. Interaction between both types of inhibition in their relationship with originality

In order to explore the mechanism of this interaction, the total number of memorised items was compared between groups of individuals with high ($M = 9.54$, $SD = 3.61$) and low ($M = 7.53$, $SD = 3.18$) attentional inhibition. The difference was found to be statistically significant ($t(90.2) = 2.9$, $p = .005$, $d = 0.592$).

DISCUSSION

The relationship between basic executive functions (updating, shifting and inhibition) and creativity has been a topic of research to date (Benedek et al., 2014), but the existence of two independent types of inhibition has not been considered until now. The present study tested whether mnemonic inhibition (i.e., the ability to inhibit disruptive memory content, is related to creativity). It was also tested whether the effect persists after accounting for attentional inhibition (i.e., the ability to ignore interfering stimuli).

Inhibition and Creativity

The effect of Thinking-Induced Forgetting, an indicator of mnemonic inhibition ability, was replicated. Mnemonic inhibition was also shown to predict the originality of divergent thinking, even after accounting for attentional inhibition, thus replicating the findings of Storm and Patel (2014) and setting them in the context of executive functions. Mnemonic inhibition was found to be an independent construct from attentional inhibition as conceptualised by Friedman and Miyake (2004; Miyake & Friedman, 2012), which was indicated by the lack of correlation between the two. For both indicators as measured by the observed variables, the effect sizes were similar. This suggests that mnemonic inhibition may be as important for creativity as attentional inhibition and thus may be worth including in research on the relationship between executive functions and creativity. This confirms the important role of executive functions in creative processes and provides a rationale in favour of the controlled-attention theory of creativity.

At the same time, the two types of inhibition explain only 3% of the variance in the originality of divergent thinking, although the correlations may actually be stronger when corrected for measurement error and modelled as a latent variable. Regardless, the results support the findings of Palmiero and colleagues (2022), suggesting a more important role of updating than inhibition in creativity, regardless of the type of inhibition.

The relationship between attentional inhibition and divergent thinking was not significant when a multilevel model with time was used. Yet it was close to the alpha value ($p = .055 > .05$). This raises the question about the temporal dynamics of attentional inhibition's contribution to divergent thinking. Further research is needed to determine whether this result is a statistical artefact.

The negative effect of mnemonic inhibition on divergent thinking in its early stages was unexpected. An explanation for this phenomenon may be the blocking of the propagation of the semantic activation wave. When mnemonic strategies are used, the participant starts with close associations and moves on to further associations. If close associations are actively removed from memory, access to them is impeded and they cannot be used to form further associations. Such a mechanism is suggested by the fact that when the subject is explicitly told to use remembered object uses to find original uses, mnemonic inhibition does not occur (Storm & Patel, 2014). Empirical verification of this explanation could involve testing fluency in coming up with typical item uses under conditions that force inhibition of previously learned uses. If mnemonic inhibition indeed impedes the propagation of the activation wave in the semantic network, the individual should also have fewer typical ideas under conditions forcing inhibition. Because this study used the be-creative instruction, inferences about fluency based on this study may not be accurate.

Temporal Dynamics of Inhibition

Multilevel models allowed us to determine the temporal dynamics of the influence of both types of inhibition in the process of divergent thinking. The results indicate that the relevance of mnemonic inhibition increases over time, while the relevance of attentional inhibition does not change. This is an additional indication towards contemporary executive conceptions of the mechanisms of creative thinking. They assume that executive processes are important for creativity but that their role only becomes apparent at later stages of the thinking process, when the person switches from memory strategies to executive strategies. The hypothesis that there is a strategy shift during thinking, which is used to explain effects such as the be-creative effect (Forthmann et al., 2016) for the serial order effect (Beaty & Silvia, 2012). This change has also been revealed in qualitative analysis (Gilhooly et al., 2007).

The interaction between mnemonic inhibition and time in predicting originality of divergent thinking can also be interpreted in the opposite direction—that the serial-order effect is moderated by mnemonic inhibition. Therefore, the relationship between mnemonic inhibition and originality of divergent thinking was tested separately for the first and second half of the task. The effect of mnemonic inhibition becomes apparent in the second half of thinking but not in the first half, thus strengthening the hypothesis of a change in thinking strategy over time.

Interaction between Two Types of Inhibition

Although attentional and mnemonic inhibition are uncorrelated, an interaction between them appears in their links with creative thinking. Mnemonic inhibition ability only predicts originality in divergent thinking for individuals with high attentional inhibition. The trend also suggests a correlation for those with medium attentional inhibition, but it is not statistically significant. For those with low attentional inhibition, mnemonic inhibition is unrelated to creativity.

In order to clarify this interaction, we can distinguish between two sources of forgetting—simple memory degradation and active mnemonic inhibition. Mnemonic inhibition is expressed as “excess” forgetting over that resulting from memory degradation (the difference between the number of remembered uses of items followed by AUT and those not followed by AUT). As LaRocque and colleagues (2015) point out, memory content in working memory, on which attention is not focused, is degraded. Attentional inhibitory capacity is also related to working memory capacity (Kiefer, Ahlegian, & Spitzer, 2005; Shilko, Dormashev, & Romanov, 2013; Stins, Polderman, Boomsma, & De Geus, 2005). This suggests that individuals with weaker attentional inhibitory abilities may have difficulty retaining content in working memory, leading to increased forgetting. Indeed, in this study, those in the low attentional inhibition group remembered fewer object uses than those in the high attentional inhibition group, regardless of whether AUT was present. This can be attributed to memory degradation. If interfering content was forgotten through memory degradation, it was not a source of fixation later and, therefore, did not require mnemonic inhibition. Consequently, mnemonic inhibition did not predict the originality of divergent thinking for people with low attentional inhibition because, as the present study found, they generally remember fewer applications. For individuals with high attentional inhibition, who remembered more object applications, the interfering content was a source of fixation and required mnemonic inhibition. Therefore, mnemonic inhibition predicts the originality of divergent thinking for individuals with high attentional inhibition. This is a hypothetical explanation that requires empirical verification.

LIMITATIONS AND FURTHER RESEARCH

The limitations of this study are related to the online procedure. Given that the study required a strong focus of attention, the results could be sensitive to environmental distractions that cannot be controlled over the Internet. Similarly, the mental involvement of the subjects may decrease when the study is not performed under supervision. The remote procedure may therefore underestimate effect sizes. The second limitation relates to the method of measuring mnemonic inhibition, which provides a generally low resolution of the index. The measure was an integer between –7 and 6, making the variance relatively low ($SD = 2.29$). Taken together, this expresses a strong need to develop a new method of measuring mnemonic inhibition with better psychometric properties.

Further research could test the temporal dynamics of the effect of the updating executive function on divergent thinking. In principle, the stronger effect of updating than inhibition on divergent thinking (Benedek et al., 2014) suggests that not only could the temporal effect replicate, but its strength could also be higher. There is also a need to discover a new method of measuring mnemonic inhibition, which (unlike the effect of forgetting by recalling) would allow measurement at the latent level and provide a better resolution of results. The current method is also highly taxing on the subject, which reduces the method's reliability in a remote study setting. Mechanisms of inhibiting one's own ideas (George & Wiley, 2019) could also be explored in the context of mnemonic inhibition. Finally, the present study must be replicated in a laboratory setting.

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