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Embodied Mental Imagery Improves Memory

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Abstract

According to embodied cognition theory, cognitive processes are grounded in sensory, motor and emotional systems. This theory supports the idea that language comprehension and access to memory are based on sensorimotor mental simulations, which does indeed explain experimental results for visual imagery. These results show that word memorization is improved when the individual actively simulates the visual characteristics of the object to be learned. Very few studies, however, have investigated the effectiveness of more embodied mental simulations, that is, simulating both the sensory and motor aspects of the object (i.e., motor imagery) from a first-person perspective. The recall performances of 83 adults were analysed in four different conditions: mental rehearsal, visual imagery, third-person motor imagery, and first-person motor imagery. Results revealed a memory efficiency gradient running from low-embodiment strategies (i.e., involving poor perceptual and/or motor simulation) to high-embodiment strategies (i.e., rich simulation in the sensory and motor systems involved in interactions with the object). However, the benefit of engaging in motor imagery, as opposed to purely visual imagery, was only observed when participants adopted the first-person perspective. Surprisingly, visual and motor imagery vividness seemed to play a negligible role in this effect of the sensorimotor grounding of mental imagery on memory efficiency.

Keywords: simulation; memory strategies; word retention; embodied cognition

Embodied Mental Imagery Improves Memory

Mental imagery can be defined as a “quasi-perceptual experience” that “resembles perceptual experience, but occurs in the absence of appropriate external stimuli” (Thomas, 2014, p. 1). It occurs constantly in everyday life, be it when remembering past events, projecting ourselves into the future, or representing the route someone is describing to us. It should be noted that the term *imagery* does not only concern images. *Visual imagery* can be either *object imagery*, which consists in visualizing the details of individual objects and scenes in terms of shape, color, brightness and texture or *spatial imagery* when this visualization concerns spatial relations, movements of objects and their parts, and spatial transformations such as mental rotation (Blazhenkova, 2016). Visual imagery relies on the manipulation of representations that share the same attributes as percepts (Borst & Kosslyn, 2008; Kosslyn, Ball, & Reiser, 1978; Shepard & Metzler, 1971), and requires the activation of the same brain systems that are involved in visual perception (Albers, Kok, Toni, Dijkerman, & de Lange, 2013; Kosslyn & Thompson, 2003). Shepard and Metzler (1971), for example, showed that the time taken to resolve visuo-spatial tasks correlates linearly with the difference between the angle of the starting figure and the target figure, which suggests that there is an actual rotation of the image that is operated mentally. Kosslyn highlighted the properties of mental scanning, showing that it takes more time for participants to mentally move between two nearby elements than between two distant ones (Kosslyn, Ball & Reiter, 1978).

Imagery may involve not only other sensory modalities, like olfaction and audition, but also the motor modality. In this case, *motor imagery* is defined as a mental reproduction of physical activity without any actual movement (Driskell, Copper, & Moran, 1994). The visual sense is involved: actions can be imagined either from an internal/first-person perspective, such as being inside one’s body or having a camera on one’s head, or from an

external perspective, either observing oneself performing an action or observing someone else perform an action (Guillot et al., 2009; Roberts, Callow, Hardy, Markland, & Bringer, 2008). In motor imagery, the kinaesthetic sense is generally involved, that is, the sensation of executing a movement, feeling the contraction and stretching of the muscles and the position of the limbs relative to others (Cumming & Williams, 2012; Guillot et al., 2009). This kinaesthetic imagery can be performed in either external or internal motor imagery (Glisky, Williams, & Kihlstrom, 1996; Robert et al., 2008). Just as visual imagery shares attributes with visual perception, motor imagery involves the same neural networks (e.g., primary motor cortex, premotor cortex, cerebellum or somatosensory cortex) as the actual physical actions (Cumming & Williams, 2012). This explains several features of motor imagery such as the activation of the limb muscles affected by the action in question (Lebon, Rouffet, Guillot, & Collet, 2008). There are also identical temporal characteristics between the duration of the imagery and the duration of the movement, suggesting an actual motor simulation during imagery (Guillot & Collet, 2005). Motor imagery is grounded in the body of the individual with all its specificities. In a task where left-handers and right-handers had to imagine actions designated by verbs, some manual others not, a difference in the lateralization of the motor cortex was found between right-handers and left-handers for the imagery of manual action verbs (Willems, Toni, Hagoort, & Casasanto, 2009). Similarly, Schwoebel, Friedman, Duda and Coslett (2001) showed that for patients with chronic pain in one of their arms, the duration of motor imagery involving the painful arm was longer than when they imagined doing the movement with their unaffected arm, once again indicating that motor imagery is a simulation grounded in the body of the individual. Motor imagery can also be influenced by the perspective that is taken (Lorey et al., 2009; Sigiru & Duhamel, 2001). For example, Lorey and her colleagues (2009) found that imagining a hand movement was influenced by the current position of the participant's hand, in that it was facilitated if the

actual position of the hand was the same as that of the imagined hand. This facilitation was observed if participants imagined the movement from a first-person perspective (i.e., imagining it from their own point of view), but not if they imagined it from a third-person perspective (i.e., imagining it from the outside, out of their body).

One interesting property of mental imagery is its positive impact on memory performances when people processing stimuli are compared according to whether they have been given a mental imagery instruction or not. Participants who have been given a visual imagery instruction remember verbal material better, especially words of high *imageability* (e.g., Bower, 1972; Gupton & Frincke, 1970; McCauley, Eskes, & Moscovitch, 1996; Mueller & Jablonski, 1970; Paivio, 1971; Pressley & Brewster, 1990). In Bower (1972), for instance, participants were instructed to memorize 20 concrete-noun pairs either by imagining a visual scene in which the two objects of the pair interacted, or by just memorizing the relation between the two words. In this typical example, participants in the imagery group performed about 30% better than controls on both immediate and delayed cued recall tests. Recent studies have yielded similar patterns of results, with participants who were given an imagery instruction (compared with others who were told not to use imagery) correctly recalling or recognizing more items (Oliver, Bays, & Zabucki, 2016) and producing fewer false memories (Foley, 2012; Foley, Hughes, Librot, & Paysnick, 2009; Foley, Wozniak, & Gillum, 2006; Robin & Mahé, 2015).

Furthermore, motor imagery can facilitate motor learning. A meta-analysis by Driskell (1997) measured the effect of mental practice on performance against a 100 scientifically tested hypotheses, and found a significant effect of mental practice on performance (albeit weaker than actual practice). A literature review focusing mainly on athletes in laboratory studies and follow-up of athletes by Weinberg (2008) also went in this direction, its results seemingly attesting to the effectiveness of motor imagery. Holmes and Collins (2001)

developed the Physical, Environment, Task, Timing, Learning, Emotion and Perspective (PETTTLEP) model to condense the important variables for effective motor imagery. These authors advise maximizing resemblance to the actual physical performance (e.g., posture, sports clothes), physical environment, content of the pictorial task, timing, emotions felt, and perspective (i.e. first-person).

The scientific literature has frequently provided theoretical frameworks for explaining the nature and properties of mental imagery. However, few of these have given a coherent explanation that integrates neuroscience observations and allows the positive effects of mental imagery on memorization to be easily described. The embodied cognition paradigm takes up this challenge by offering a framework that fits well with the features of mental imagery described above. It states that cognitive processes are grounded in our bodily experiences and that high-level cognitive processes cannot be detached from the peripheral brain systems that process input from the outside world. There are several embodied approaches. Simulation theory states that the brain captures modal states during perception, action and introspection and later simulate these states to represent knowledge. Cognition therefore corresponds to the activation of modal states, be they perceptual, motor or emotional, and more particularly to the simulation or partial re-enactment of lived experiences (Barsalou, 1999; Barsalou, Simmons, Barbey, & Wilson, 2003). It is supported by neuroscience data which suggest that memory retrieval involves multimodal simulation. For example, word retrieval requires the reactivation of the sensory cortex regions activated at encoding (see Buckner & Wheeler, 2001, for a review), or put another way, the simulation of the modal operations performed at encoding. This happens to be in line with the encoding specificity principle which states that “specific encoding operations performed on what is perceived determine what is stored, and what is stored determines what retrieval cues are effective in providing access to what is stored” (Tulving & Thomson, 1973, p.369).

Consequently, item retrieval is facilitated when the retrieval context matches the encoding context. This contextual element can be either the physical environment (Godden et Baddeley, 1975), posture (Dijkstra, Kaschak, & Zwaan, 2007) or a previously associated sensory stimulus (Brunel, Labeye, Lesourd, & Versace, 2009). Therefore, memory traces are composed of sensorimotor elements of the encoding context and remembering seems to reactivate sensorimotor cortices involved in encoding.

It is worth mentioning that other embodied approaches in the embodied cognition paradigm deny the existence of representations. According to the enactive approach, perception is a form of active interrogation of the environment that uses the sensory system to search for specific information needed for action at a particular moment (Thomas, 1999, 2014). Mental imagery is therefore a partial re-enactment, a mental rehearsal of the exploratory perceptual acts that are executed during actual perception. According to sensorimotor theory, there is no such mental rehearsal of perceptual acts. The experience of mental imagery would emerge from the activation or exercise of a practical sensorimotor knowledge of possibilities for action. This sensorimotor knowledge concerns how sensory inputs (e.g., visual stimulations) changes as a function of motor outputs (movements). Mental imagery is therefore simply the fact of holding implicit expectations regarding how sensory stimulation changes as a function of movement (Foglia & O'Regan, 2015). Whatever the theory, the embodied cognition paradigm defends the idea that processes like mental imagery, conceptual processing or memory, are based on the reactivation of sensorimotor brain patterns activated during the real experience to which the knowledge refers. In the present study, we adopted the perspective of simulation theory, and hypothesized that mental imagery corresponds to a mental simulation, emphasizing certain visual attributes during visual imagery, or certain motor attributes during motor imagery. Behavioural empirical data and

neural activations reported in the mental imagery literature are highly consistent with empirical data defending the simulation view.

The literature shows that memorization is enhanced when the individual actively simulates the visual characteristics of the object to be learned, that is to say when participants are explicitly instructed to perform visual imagery. However, few studies have investigated the effectiveness of more embodied imagery (i.e., instructions that promotes mental simulation of both sensory and motor aspects of the object) or else have failed to distinguish between the influence of motor versus visual components of imagery on memory performance. Motor imagery presumably promotes the re-enactment not only of visual experiences, but also of motor (and potentially kinaesthetic and tactile) ones, thus increasing the number of modalities by which the memory trace can be retrieved. Motor imagery may also induce a higher degree of self-involvement than a nondynamic mental image that does not involve any mental action on the part of the individual, and personal involvement is known to be a factor favouring retention (Rogers, 1977). In addition, first-person motor imagery may be more efficient than third-person motor imagery, as the degree of self-involvement is greater in the first person (Bagri & Jones, 2018) and the level of embodiment is higher, as third-person imagery preferentially recruits nonmotor structures (Lorey et al., 2009; Sigiru & Duhamel, 2001). We therefore postulated that memory strategies lie on a continuum running from low embodiment strategies (e.g., mental rehearsal) to high embodiment strategies involving first-person motor imagery. This continuum is based on the idea that sensorimotor elements are privileged cues for retrieval. The more the memorization consciously calls for a sensorimotor mental elaboration about an object, the more sensorimotor cues are available during retrieval, thus facilitating the retrieval of the memory trace.

Overview of the Present Study

The present study was design to distinguish between the influence of visual imagery and the influence of motor imagery and compare the two, in order to test the idea of an embodiment continuum in imagery that results in varying efficiency depending on the memorization strategy adopted. In our study, participants were asked to memorize a 30-word list using either mental rehearsal, visual imagery, third-person motor imagery, or first-person motor imagery. For each group, we analysed the numbers of correct and incorrect responses at immediate and delayed (48 hours later) recall. We expected the continuum of memory embodiment strategies to be reflected in memory performances. In other words, the recall rate would improve as the embodiment level of memory strategies increased. More specifically, recall performance would be better when learning was based on first-person motor imagery rather than on third-person motor imagery. These performances would also be better than those resulting from learning with visual imagery, which in turn would be better than memorization based on mental rehearsal. According to several authors, the level of imagery skills influences the cognitive benefits of imagery. Thus, visual imagery can decrease false memories, but only for individuals with high visual imagery abilities (Marmurek & Hamilton, 2000). In addition, vividness plays a key role in the retrieval of sensory traces (Palmiero et al., 2019) as individuals who are able to create vivid images activate their brain more selectively than low-vividness imagers (Fulford et al., 2018). We therefore predicted that visual and motor imagery vividness would moderate the effect of memory strategy on recall performance.

Method

Participants

Participants were 85 adults (59 women and 26 men), who were randomly divided into four groups corresponding to the encoding conditions: mental rehearsal group (MR), visual imagery group (VI), third-person motor imagery group (TPI), and first-person motor imagery group (FPI). Persons under 18 and over 50 years were excluded, as were individuals who did not speak French fluently. The participants were mostly psychology students recruited on the campus of Toulouse Jean Jaurès University. Their mean age was 23 years ($SD = 5.27$, range = 18-45). They all volunteered to take part in the research, and gave their written informed consent.

To know if the number of participants was sufficient for the desired statistical power, we ran a G*Power (Faul, Erdfelder, Buchner & Lang, 2009; Faul, Erdfelder, Lang & Buchner, 2007; Version 3.1.9.6) analysis. The effect size was often not available in the literature so we were forced to base our expected effect size on the most recent researches on memory and imagery (Foley, 2012; Foley et al., 2006; Foley et al., 2009, Oliver et al., 2016). We took the smallest effect size we found in these articles ($\eta^2=.24$, Cohen's $f=.56$). The G*Power analysis yielded a total sample size of 40 (for $\alpha = .05$, power = .80, number of groups = 4). As we recruited more participants (85) than the minimum sample size required according to the G*Power analysis, our sample size was not a problem in terms of statistical power.

Materials

Participants in all four groups heard the same list of 30 nouns to memorize in the form of a recording (one word every 7 s). We only used referents that were nonliving and lent

themselves to manual motor imagery. Based on these two criteria, we selected words with the highest sensory experience scores in Bonin, Méot, Ferrand, and Bugaiska (2015)'s study. A *sensory experience score* refers to the degree to which a word generates sensory and perceptual experiences (Juhasz & Yap, 2013). A list of 10 words was created in the same way for the training phase. Words used in the experiment are available in the Supplemental Material, together with their associated sensory experience score and other psycholinguistic variables: concreteness, context availability, emotional valence, arousal, and imagery value, based on the norms established by Bonin, Meot, and Bugaiska (2018) and Bonin et al. (2003). Frequency was measured with the GlàffOLI web interface using the FrWAc indicator (Sajous, Hathout, & Calderone, n.d.).

For the immediate free recall test, participants were each given a sheet with 30 spaces in which to write the remembered words. There were also two 6-point scales, one to rate the ease of performing the memorization task, the other to indicate how far retrieval was based on the memory strategy indicated in the instruction. There was also a question about any other strategies that were used.

The delayed free recall test was the same as the immediate one, except that it was sent as an online questionnaire (via Qualtrics) to participants 48 hours later.

We used the French Vividness of Visual Imagery Questionnaire (VVIQ; Santarpia et al., 2008) to measure the level of vividness the participants were able to reach in visual imagery. This questionnaire contains 32 items, each rated on a 5-point vividness scale ranging from 1 (*No image is visible*) to 5 (*The image is perfectly clear, as sharp and precise as a real-life perception*). The Vividness of Movement Imagery Questionnaire Version 2 (VMIQ-2; Roberts, Callow, Hardy, Markland, & Bringer, 2008) was used to measure their ability to do vivid motor imagery. This questionnaire contains 36 items, each rated on a 5-

point vividness scale ranging from 1 (*Perfectly clear and as vivid as normal vision or feel of movement*) to 5 (*No image at all, you only know that you are thinking of the skill*).

Procedure

The experiment began with a training phase, where the experimenter explained that the participants would hear a list of 10 words, each separated by a 7-second interval, and would have to respect one of the following instructions for each word: either mentally rehearse the word (MR); create a mental image of the word's referent (VI); imagine taking and throwing the object from an external point of view, in the third person (TPI); or imagine taking and throwing the object from one's own point of view, in the first person (FPI). The action to be imagined was standardized, in order to control for interindividual variability in the imaginary interaction with the object as much as possible. Instructions are available in the Supplemental Material. During the listening phase, participants were asked to close their eyes and lay their hands flat on their knees (to control for the influence of posture on the motor imagery). We also asked them to chunk the information as little as possible and to perform the task for each word independently of the other words. After listening to the list, participants had to fill in the free recall sheet and the two rating scales for each word. The instruction for the experimental phase was exactly the same as for the training phase, but with a 30-word list. After the immediate recall test, participants were asked to complete the VVIQ and then the VMIQ-2. They were contacted 48 hours later to perform the delayed recall test.

Results

Two participants were excluded because they did not follow the instructions. We therefore analysed the data of 83 participants (20 for MR, 21 for VI, 21 for TPI, and 21 for

FPI). These analyses were performed using R software. Tests based on comparisons of means were performed when assumptions were met. Otherwise, nonparametric tests were used.

Immediate Recall

We ran a one-way analysis of variance (ANOVA) for independent samples on the number of correctly recalled words. This revealed a significant effect of type of instruction on the number of correct responses, $F(3, 79) = 12.7, p < .001, \eta^2_p = .325$. A unilateral post hoc test with Bonferroni correction showed that this effect was due to the fact that participants in the FPI group correctly recalled significantly more words ($M = 19.6, SD = 4.26$) than those in either the TPI ($M = 16.2, SD = 3.46, p = .01$), VI ($M = 16.1, SD = 3.79, p < .01$), or MR ($M = 12.6, SD = 2.89, p < .001$) groups. Participants in the TPI group correctly recalled significantly more words than those in the MR group ($p < .01$), and there were significantly more correct responses in the VI group than in the MR group ($p < .01$). However, recall performances did not differ significantly between the VI and TPI groups ($p = 1.00$). These results are reflected in the sizes of the confidence intervals in Figure 1.

[insert Figure 1]

Regarding the numbers of incorrectly recalled words, the mean was 0.70 ($SD = 1.26$) for MR, 0.29 ($SD = 0.72$) for VI, 0.38 ($SD = 0.80$) for TPI, and 0.24 ($SD = 0.54$) for FPI. A Kruskal-Wallis test failed to reveal a significant effect of instruction type on the number of incorrectly recalled words, $\chi^2(3) = 3.14, p = .37$.

For the VVIQ results, the mean was 119.9 ($SD = 14.2$) for MR, 121 ($SD = 19.3$) for VI, 125 ($SD = 18.0$) for TPI, and 131 ($SD = 16.4$) for FPI. For the VMIQ-2 results, the scale was reversed, such that the minimum degree of vividness was 1, and the maximum 5. The mean

was 134 ($SD = 20.7$) for MR, 136 ($SD = 19.5$) for VI, 145 ($SD = 23.5$) for TPI, and 140 ($SD = 18.9$) for FPI. We had expected to observe a moderating effect of visual imagery and motor imagery vividness on the relation between instruction and memory performances. However, these scores failed to predict immediate recall performance. The regression coefficients for VVIQ scores ($b = .011$, $t(76) = .322$, $p = .748$) and VMIQ scores ($b = .017$, $t(76) = .569$, $p = .571$) were not significant. This regression model did not account for a significant portion of the variance in memory performance, $R^2_{adj} = -.013$, $F(2,76) = .497$, $p = .611$. Since no link could be found between imagery vividness and memory performance, no moderation effect of vividness could be revealed on the effect of instructions on immediate memory performances.

Delayed Recall

Of the initial sample of 83 participants, only 79 responded to the delayed recall test (19 for MR, 21 for VI, 20 for TPI, and 19 for FPI).

A one-way ANOVA for independent samples showed that the effect of instructions on the number of correctly recalled words was still present after 48 hours, $F(3, 75) = 8.77$, $p < .001$, $\eta^2p = .260$. When we investigated this effect more closely, a unilateral post hoc test with Bonferroni correction showed that more words were correctly recalled by participants in the FPI ($M = 14.0$, $SD = 5.89$, $p < .001$), TPI ($M = 10.1$, $SD = 4.49$, $p < .05$) and VI ($M = 10.9$, $SD = 4.99$, $p < .05$) groups than in the MR ($M = 5.79$, $SD = 3.95$) group. However, there were no significant differences between the three imagery groups. This is in agreement with the overlapping confidence intervals in the diagram in Figure 2.

[insert Figure 2]

After 48 hours, the mean number of incorrectly recalled words was 2.00 ($SD = 2.21$) for MR, 1.19 ($SD = 1.54$) for VI, 1.95 ($SD = 2.35$) for TPI, and 2.42 ($SD = 2.01$) for FPI. Once again, a Kruskal-Wallis test failed to reveal a significant effect of instruction type on the number of incorrectly recalled words, $\chi^2(3) = 4.32, p = .23$. We had expected to observe a moderating effect of visual imagery and motor imagery vividness on the relation between instruction and delayed correct recalls. The regression coefficients for VVIQ scores ($b = .031, t(72) = .653, p = .516$) and VMIQ scores ($b = .030, t(72) = .739, p = .462$) were not significant. This regression model did not account for a significant portion of the variance in memory performance, $R^2_{adj} = .003, F(2, 72) = 1.13, p = .329$. Even after 48 hours, no link could be found between imagery vividness and memory performance, therefore no moderation effect of vividness could be revealed on the effect of instructions on delayed memory performances.

Ease of Performing the Memorization Task and Use of Instructed Strategy

Mean ratings for the ease of performing the task in the MR ($M = 5.07$), VI ($M = 5.11$), TPI ($M = 4.41$) and FPI ($M = 5.1$) groups were all between 4 (*Fairly easy*) and 6 (*Very easy*). A one-way ANOVA for independent samples showed no significant difference between the groups, $F(3, 77) = 2.20, p = .095$. Participants therefore generally complied with the instructions with relative ease in each experimental condition.

Mean ratings for the extent to which participants used the instructed strategy in the MR ($M = 4.58$), VI ($M = 3.84$), TPI ($M = 4.24$) and FPI ($M = 4.39$) groups were all between 3 (*Medium*) and 5 (*High*). A one-way ANOVA for independent samples failed to reveal any significant difference between groups, $F(3, 77) = 1.27, p = .292$. Therefore, most of the participants remembered the words using the strategy indicated in the instructions.

Other Memory Strategies

A total of 49 participants (57%) stated that they used another complementary strategy. They were mainly in the MR group, where 80% of participants declared that they had semantically chunked the words in order to remember them. In the imagery groups, participants mainly used semantic chunking and mental rehearsal: 57% in VI, 38% in TPI, and 52% in FPI.

Controlling the gender effect

Gender differences may be observed in mental imagery (e.g., Campos, 2014; Richardson, 1995) and in the memory benefit of imagery mnemonic instructions (e.g. Lenhart & Schwartz, 1983; Metzger & Antes, 1976). In order to ensure that gender has no influence on the link between instructions and memory performance, we ran an ANOVA with gender and instructions as independent variables and found that there is no main effect of gender on the number of immediate correct recalls, $F(1,75) = .248, p = .620$, and no interaction between gender and instructions, $F(3,75) = .295, p = .829$. The same pattern was observed on delayed correct recalls where no main effect, $F(1,71) = .107, p = .745$, or interaction effect, $F(3,71) = .103, p = .958$, was significant. The imager could be a man or a woman, the effect of instructions on memory performance was the same.

Discussion

Our first hypothesis concerned the effect of type of memory strategy (induced by the instructions in the experiment) on recall performance. More specifically, we postulated that

memory efficiency increases with the strategies' level of sensorimotor simulation. This hypothesis was generally corroborated.

First, as expected, participants in the VI condition correctly recalled more words than those in the MR condition, which involved little multimodal simulation. This is in agreement with the results of classic studies such as those of Paivio (1971), as well as more recent ones (e.g., Oliver et al., 2016).

Second, as expected, FPI proved to be the most effective strategy of all. Adding the simulation of motor characteristics to purely visual imagery improved its memory benefits. This echoes the embodied cognition literature, which has repeatedly highlighted the fundamental role of action and motor skills in cognition, whether in word recall (Engelkamp, Seiler, & Zimmer, 2004; Senkfor, Van Petten, & Kutas, 2002) or in conceptual processing (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008).

Regarding TPI, results showed that it did not differ significantly from VI, contrary to predictions. We had expected the performances of participants in the TPI group to lie between those of the VI group and those of the FPI group, but this was not the case. It may be that in the third person, motor imagery is not sufficiently embodied to recruit brain structures that are not directly involved in motor skills (Sigiru & Duhamel, 2001).

Over the longer term, strategies based on imagery (i.e. VI, TPI and FPI) remained more effective than MR. The benefits of motor simulation, however, appeared to fade over time, as the recall performance of participants in the FPI group no longer differed from that of participants in the VI group after 48 hours. This means that the motor memory trace had no consolidation advantages over the other conditions.

No particularly salient result pattern was detected for incorrect recall, in contrast to the results of Foley (2012) and her colleagues (2006; 2009) for imagery instructions. These results are most certainly due to the fact that our experimental protocol was not conducive to the emergence of false memories, unlike the Deese-Roediger-McDermott (DRM) paradigm used by these researchers.

Our second hypothesis concerned the moderation of the association between strategy and recall by visual or motor imagery vividness. Surprisingly, both types of vividness seemed to play only a negligible role. This went against not only our hypothesis, but also what the literature (i.e., Fulford et al., 2018; Marmurek & Hamilton, 2000; Palmiero et al., 2019) suggests. It may be that the questionnaires we used were not sensitive enough to capture the variability of the vividness level among the participants, thus preventing us from detecting an effect. However, a more likely explanation is that we treated the vividness variables differently. Most researchers studying the role of imagery vividness divide their participants into vividness level groups (high vs. low vividness). In the present study, however, we preferred to leave the vividness variables as continuous variables and not to arbitrarily dichotomize them.

These results point to the existence of a memory efficiency gradient running from low-embodiment (i.e., poor perceptual and/or motor simulation) to high-embodiment (i.e., rich simulation in sensory and motor systems engaged in interactions with the object) strategies. This is a logical follow-on from previous studies (e.g., Engelkamp et al., 2004; Senkfor, Van Petten, & Kutas, 2002) suggesting that there is a gradient of effectiveness in recalling action verbs running from the reading of the verb and then the observation of the action designated by the verb to the actual personal action. More generally, this continuum is in line with embodied and grounded theories (e.g., Barsalou, 1999; Barsalou et al., 2003). The recall of

concepts related to words requires the simulation of sensorimotor experiences that have contributed to the creation of the meaning of these concepts. In our experiment, mental rehearsal did not favour this type of simulation during encoding. In this case, because there was no explicit perceptual and/or motor simulation instruction, individuals did not intentionally implement this cognitive strategy. The resulting memory trace had few sensory and motor components. By contrast, active visual imagery favoured the emergence of visual experiences, and motor imagery promoted the re-enactment not only of visual experiences, but also of motor (and potentially tactile and kinaesthetic) ones. The intentional cognitive activity of sensorimotor simulation seemed to increase the memory effects of mental imagery compared with other types of imagery.

Through the experimental conditions tested in the present study, we were able to elicit an increasingly rich multimodal simulation with greater probability of word retrieval. The positive effects of the FPI condition could be predicted by the more radical embodied theories. From the sensorimotor perspective (Foglia & O'Regan, 2015) practical sensorimotor knowledge was more accessible in the FPI condition than it was in other the conditions, presumably making it easier to exercise knowledge about how the object should look as a function of movement. During retrieval, this knowledge about the object was presumably more accessible (having been more explicitly exercised during encoding), thus facilitating recall. From the enactive perspective (Thomas, 1999, 2014), because it was potentially easier to perceptually explore an object in FPI, it may also have been easier to recreate that exploration when recalling the word associated with the object.

In brief, the embodied cognition paradigm allowed us to shed new light on the links between mental imagery and memory. This study also had the merit of providing original data on different types of imagery and their relative efficiency in terms of memorization.

These results could thus be used to optimize memory strategies, especially in the school context, although the effect on abstract concepts has yet to be ascertained. In our experiment, the word list contained quite concrete words. Although the sensorimotor grounding of mental imagery was found to have an effect on the memorization of these concrete words, results might have been different for more abstract ones. According to the language-and-situated-simulation theory (Barsalou, Santos, Simmons, & Wilson, 2008), the implication of modal systems is not exactly the same for abstract concepts, although in categorization tasks, access to these abstract concepts is facilitated by the level of sensory experiences they produce (Zdrzilova & Pexman, 2013).

Finally, it should be noted that several experimental modifications will have to be made in order to reproduce and confirm our results. First, many of our participants reported verbally that third-person motor imagery was particularly hard to master. Thus, even if there were motor activations, this difficulty may have reduced the memory benefits of the motor simulation-benefits that could be fully manifested in the first person. It is difficult to determine whether the difference between third- and first-person imagery arose because the former is harder to achieve or because it is less embodied. Second, a number of participants, most of them in the mental rehearsal condition, said that they used other strategies to memorize the words. It is possible that this type of memorization spontaneously encourages people to adopt other, more effective strategies. However, the results of our study show that the chunking strategy they favoured did not actually result in higher scores than those resulting from mental imagery strategies. Finally, some of the objects named in the word list may have been linked to one or more prototypical actions (e.g. reading a book, eating an apple) that conflicted to a greater or lesser degree with the action indicated in the motor imagery instructions. Thus, in the case where the action intuitively related to the object was close to the action indicated in the instruction, the recall of certain words may have been

facilitated. It would be advisable to consider complementing the questionnaires with different metrics of visual and motor imagery skills, such as response times or neurophysiological markers, which would provide information on the nature of the participants' subjective experience. These same neurophysiological measures could also prove useful for verifying the correct execution of the imagery tasks.

Declaration of Competing Interests

The authors declare that there are no conflicts of interest.

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