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Learning symbols from permanent and transient visual presentations: Don't overplay the hand

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ABSTRACT

Instructional dynamic pictures (animations and videos) contain transient visual information. Consequently, when learning from dynamic pictures, students must process in working memory the current images while trying to remember the images that left the screen. This additional activity in working memory may lead dynamic pictures to be less suitable instructional materials than comparable static pictures, which are more permanent. In order to directly show the influence of transient visual information on dynamic learning environments, we designed a well-matched comparison between a permanent and a transient presentation of an abstract-symbol memory task on the computer. In the task, 104 university students (50% females) had to memorize the type, color, and position of the symbols in a rectangular configuration. In addition, an embodied cognition factor was included where the symbols in the task were either shown with a precision grasping static hand or not. We also assessed how individual characteristics (spatial ability, spatial memory span, and gender) influenced performance. Results showed that (a) permanent outperformed transient presentations, (b) observing hands hindered learning, and (c) high spatial ability and high spatial memory span were beneficial, but gender did not affect performance.

1. Introduction

In this paper, we focus on instructional visualizations that are shown on computer screens, rather than other media outputs such as television screens. As described below (see Section 2.1), an influential bias in animation research has been to compare different media; hence, we use only computer-based presentations to avoid such a bias and also to embed our research into computer-based environments, which are most frequently researched. A major issue associated with computer instructional animation is that they are often no more effective than static pictures (Ayres & Paas, 2007). One possible reason, which is investigated further in this study, is that animations are subject to the transient information effect.

The *transient information effect* as described by cognitive load theory (see Sweller, Ayres, & Kalyuga, 2011), predicts that transient forms of information, such as dynamic images (e.g., animations and videos), are more difficult to understand than

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permanent forms, such as static images (e.g., A. Wong, Leahy, Marcus, & Sweller, 2012). Lowe (1999) observed that a challenge of learning from animations, as compared to statics, was the need to hold and integrate the images in working memory before they disappeared from the screen. In line with this observation, the main explanation for the transient information effect is that dynamic images disappear from view before being adequately processed in a limited working memory, while static images can be restudied and processed more easily because they do not disappear (see Ayres & Paas, 2007). Moreover, the detrimental effect of transitory information is accumulative, and the more learning elements to be managed in working memory, the more this problem should emerge (cf. element interactivity, see Sweller, 2010).

Nevertheless, it is often argued that there are constructive uses for instructional animations and videos, especially when presenting the complex systems of science, technology, engineering, and mathematics (STEM) disciplines (cf. Lowe & Schnotz, 2014). For example, Hegarty (1992) observed that learning mechanical systems from static images involves the difficult process of *mental animation*, which is not required when learning from dynamic visualizations (cf. Sánchez & Wiley, 2014). In support of this observation by Hegarty, the recent meta-analysis by Berney and Bétrancourt (2016), which included 140 pair-wise comparisons, found an overall advantage for dynamic and transient images over permanent depictions for many STEM computer visualizations. Hence, this evidence suggests that when learning the complex systems of STEM topics, animations and videos can be more effective than statics.

Comparing the arguments of Hegarty (1992) to those of the transient information effect (Sweller et al., 2011), instructional static pictures can have a negative mental animation effect and a positive permanent effect. In contrast, instructional dynamic pictures can have a positive direct animation effect and a negative transient effect. There have also been a number of other theoretical approaches suggesting different advantages and disadvantages for the two formats. For example, Wagner and Schnotz (2017) argued that static images could lead to higher *cognitive learning* (to answer *why* questions), whereas animations and videos would lead to higher *perceptual learning* (to answer *what* questions). Based on the *more-is-more* category by Mayer (2014), transient and moving images could result in more learning because movement might be more appealing. Mirroring these different perspectives, there is evidence that support static or dynamic presentations as instructional tools, dependent upon a number of differing factors (see Section 2). These theoretical perspectives are summarized in Table 1.

In the current study, we focused on the permanent versus transient dichotomy of visualizations, thus investigating further the problematic learning from animations and videos because of transient visual information. Specifically, we designed a well-matched comparison between a permanent and a transient presentation of an abstract-symbol memory task that involved visuospatial memory. As such, the transient display was not an *animation* according to most contemporary definitions (e.g., it is a *static-sequential visualization* in Imhof, Scheiter, & Gerjets, 2011), but a more fundamental example of transient information in a dynamic environment. The task was chosen specifically to include a high degree of transient information, in order to test the transient information effect more comprehensively than in previous studies. Consequently, in the experimental design, we controlled many of the comparisons' biases found in previous static versus animation studies, and also compared the computer visualizations within participants. In addition, we included an embodied factor that could impact on the effectiveness of permanent or transient visualizations: the presence of static hands in a precision posture, which appeared to be grasping the visual elements. We also considered three participants' characteristics that can influence learning from these tasks, namely: spatial ability, spatial memory span, and gender.

2. Literature review

2.1. Instructional static versus dynamic pictures

Because many STEM concepts are inherently visuospatial, most studies about computer visualizations have been conducted in the STEM disciplines (see, e.g., Ploetzner & Lowe, 2012). Consequently, many comparisons of the instructional effectiveness of static versus dynamic visualizations have been conducted for these scientific and technological topics (cf. Höffler & Leutner, 2007). Besides inconclusive results with no significant differences (e.g., Höffler & Schwartz, 2011; Kühl, Scheiter, Gerjets, & Gemballa, 2011), there are studies supporting either the static or the dynamic visualizations as instructional resources for these disciplines. To mention three examples showing advantages to static pictures, the diversity in participants and concepts includes (a) eighth graders solving physics problems about force (Chanlin, 2001), (b) high school participants studying the biological concepts of mitosis and meiosis (Koroghlanian & Klein, 2004), and (c) university students learning from multimedia examples of mathematical probability (Scheiter, Gerjets, & Catrambone, 2006). In contrast, studies supporting dynamic images over statics have been reported for (a) seventh graders learning biological energy

Table 1
Theoretical Perspectives that Endorse either Permanent or Transient Visualizations for Instruction.

Perspective	Endorsement	Reference
Transient information effect	Permanent	Ayres & Paas, 2007
Mental animation	Transient	Hegarty, 1992
Cognitive learning	Permanent	Wagner & Schnotz, 2017
Perceptual learning	Transient	Wagner & Schnotz, 2017
More-is-more	Transient	Mayer, 2014

transformations in photosynthesis (Ryoo & Linn, 2012), (b) university participants studying a multimedia lesson about the rock cycle (Lin & Atkinson, 2011), and (c) seventh and eighth graders studying chemical processes of laundry washing (Stebner, Kühl, Höffler, Wirth, & Ayres, 2017). In addition, two meta-analyses have shown a relative advantage of the dynamic format: (a) Höffler and Leutner (2007) reported that the tasks more positively influenced by dynamic visualizations were procedural, whereas (b) Berney and Bétrancourt (2016) showed that the effect was greatest for factual and conceptual (rather than procedural) tasks. Thus, although these meta-analyses support dynamic over statics, it is not clear under what learning scenarios the effects may be larger.

In general, the studies that have compared static versus dynamic instructional images have not been concerned with the transient factor that differentiate these two formats. However, one exception was the study by Castro-Alonso, Ayres, and Paas (2014) that directly examined the role of transitory information. In this study, static pictures were found to be superior to animation on an abstract symbol memory task. The task was chosen as it contained a high degree of transient information that disappeared from the screen after a short period of time. Rather than using a domain specific learning task, this more abstract task was highly dependent upon short-term memory and could test the transient information effect directly. This study directly confirmed the negative influence of transient information. Hence this type of symbol task was used in the current study.

Another of the reasons why the evidence is not conclusive in animation research is the presence of many variables moderating the effects of static and dynamic computer visualizations (see Lowe & Schnotz, 2014). Tversky, Morrison, and Betrancourt (2002) noted that some of the studies that perform these static versus dynamic comparisons do not control appropriately all the variables involved. In other words, many of the published comparisons between permanent and transient visualizations include more variables than the degree of transitory information presented. Failing to control these confounding variables may produce a bias toward either instructional format (for a recent review, see Castro-Alonso, Ayres, & Paas, 2016). For example, there are biases when comparing (a) *colored* animations versus *monochromatic* static images (e.g., Yang, Andre, Greenbowe, & Tibell, 2003), (b) statics *on-paper* versus dynamic pictures on other media, such as *on-screen* (e.g., Mayer, Hegarty, Mayer, & Campbell, 2005), (c) *many* statics versus *one* dynamic format (e.g., Castro-Alonso, Ayres, & Paas, 2015a), or (d) *interactive* versus *non-interactive* presentations (e.g., Akinlofa, Holt, & Elyan, 2014). Notably, some of these biases can be accumulative and sometimes they are deliberately included by researchers. However, in the present study, we wanted to control these confounding variables as much as possible. Consequently, we designed a controlled comparison between a permanent and a transient visualization. We also examined the effects of another potential moderator: an embodied hand moderator. This was investigated by showing precision static hands on both the permanent and the transient images, as described next.

2.2. Embodied hand effects

Producing our own body movement and observing others doing similar human movements can be cognitively beneficial. Increasing *embodied cognition* evidence shows that memory and cognition are favorably enhanced by producing bodily motion (e.g., Allen & Waterman, 2015; Jang, Vitale, Jyung, & Black, 2017; Mavilidi, Okely, Chandler, Cliff, & Paas, 2015; Toumpaniari, Loyens, Mavilidi, & Paas, 2015). In addition, our cognitive systems are wired to observe human movement of others (see *the mirror neuron system* in Rizzolatti & Craighero, 2004; see also the *animacy effect*, e.g., Bonin, Gelin, & Bugaiska, 2014). Hence, there is a positive *embodied* effect that is triggered when producing or observing human movement (e.g., Feyereisen, 2009; see also; de Koning & Tabbers, 2011). These beneficial effects have been coined by cognitive load theorists as *the human movement effect* (see Paas & Sweller, 2012), where these motions have been shown to improve learning from difficult materials. As such, the embodied effects of producing and observing human motion can be applied, for example, to teach STEM concepts (see Castro-Alonso, Ayres, & Paas, 2015b) or as part of many effective *generative learning* strategies (see Fiorella & Mayer, 2016b).

As well as whole body effects, watching solely the hands moving is also beneficial for learning (e.g., Brucker, Ehlis, Häußinger, Fallgatter, & Gerjets, 2015; Fiorella & Mayer, 2016a; see also; Novack & Goldin-Meadow, 2015). Moreover, the hands do not need to be moving to show embodied effects on cognition, which also applies to static images of another individual's hands (e.g., Fischer, Prinz, & Lotz, 2008; Vainio & Mustonen, 2011).

Recent evidence suggests that not all tasks equally benefit from the vision of static hands near the stimuli, and Goodhew, Edwards, Ferber, and Pratt (2015) note that this difference can be best explained by the *modulated visual pathways* account originally proposed by Gozli, West, and Pratt (2012), which involves the *magnocellular* and the *parvocellular* systems. Magnocellular neurons are more sensitive to temporal than to spatial changes, and are more implicated in *vision for action*; whereas parvocellular cells are more sensitive to spatial than to temporal changes, and are more involved in *vision for recognition* (Goodhew et al., 2015; Gozli et al., 2012). As reported by Gozli et al. (2012), when the participants placed both hands in a still position near the stimuli, they showed higher temporal accuracy (recruitment of the magnocellular visual pathway); in contrast, when their hands were still and away from the display, they showed higher spatial performance (more activation of the parvocellular system; see also Davoli, Brockmole, & Goujon, 2012). In addition, the number of hands (Bush & Vecera, 2014) and their posture (Thomas, 2015) can affect the degree of activation of the magnocellular versus the parvocellular pathways. Tasks requiring a finer spatial resolution, such as those employing only one hand or a precision posture, tend to trigger more the parvocellular system for visual recognition (Goodhew et al., 2015).

In the current study, we investigated the embodied effect of the parvocellular (recognition) pathway by showing or not showing the static image of one hand in a precision posture near the presentation elements. Besides the moderating effects of a hand picture on permanent versus transitory visual information, there are three other individual characteristics that can influence visual memory and learning performance, which are included as factors in this study.

2.3. *Individual characteristics*

Finally, we also investigated three individual characteristics known to affect memorization of visualizations: spatial ability, spatial memory span, and gender. The review of Höffler (2010) found that students with higher spatial ability tend to outperform their low counterparts in tasks with computer visualizations (e.g., Imhof et al., 2011). Moreover, there is some evidence that spatial ability is more important when learning from static rather than dynamic images (see Höffler, 2010). The spatial span characteristic also positively affects the memorizing of elements from visualizations (e.g., So, Shum, & Wong, 2015). In addition, there is a strong relationship between spatial ability and spatial span (e.g., Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; So et al., 2015; see also; Liesefeld & Zimmer, 2013). Although both variables are dependent on visuospatial memory, in general spatial ability requires additional resources than spatial span, in order to rotate or transform the visual elements (cf. Uttal et al., 2013).

Considering gender, males tend to outperform females in spatial ability (e.g., Masters, 1998; see; Uttal et al., 2013; Voyer, Voyer, & Bryden, 1995) and spatial memory span tests (e.g., Orsini et al., 1986; but see; Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). There are also studies showing gender effects for dynamic visualizations, although the results are somewhat mixed, sometimes showing that these presentations can be more helpful to females (e.g., Sánchez & Wiley, 2010; M. Wong, Castro-Alonso, Ayres, & Paas, 2015), and sometimes to males (e.g., Griffin, MacEachren, Hardisty, Steiner, & Li, 2006).

In conclusion, spatial ability, spatial memory span, and gender influence visual memory tasks. However, to our knowledge, the effects of these three variables have not been investigated in studies contrasting permanent versus transitory or dynamic formats of visual presentations.

3. Research methodology

3.1. *Research questions and hypotheses*

Avoiding the confounding variables often found in the studies investigating the effectiveness of instructional static versus dynamic visualizations, we pursued a controlled design to compare permanent versus transient visual information (see Castro-Alonso et al., 2016). Hence, Research Question 1 was whether a permanent or transient visualization would lead to higher recall in a controlled within-subjects comparison. Research Question 2 was whether the recall would be lower at the end of the permanent or transient visualization, when memory should be more taxed than at the beginning. To answer these questions, both permanent and transient tasks involved memorizing the type, color, and position of 12 abstract symbols in a rectangular configuration on a computer screen. As described above (Section 2.1), such tasks directly examine transient information effects (see Castro-Alonso et al., 2014). Choosing a within-subjects approach meant that both tasks were attempted by the participants. To avoid possible practice effects due to these within-subjects design, the symbols were presented in different rectangle's positions in the permanent and transient versions. We also controlled for order effects, counterbalancing which presentation (permanent or transient) was shown first to the participants. To match these two research questions, we tested the following hypotheses:

- The permanent presentation would lead to higher recall than the transient presentation (Hypothesis 1a), and this effect will be greater at the end of the presentations (Hypothesis 1b).

Hypothesis 1a was based on the findings of negative effects of transitory presentations (e.g., Castro-Alonso et al., 2014). Hypothesis 1b was expected because the transitory effect is accumulative, so the more elements to be processed in working memory (end rather than beginning of the tasks), the more noticeable the effect (cf. Sweller, 2010).

Research Question 3 was whether adding static hands that appeared to be grasping the abstract symbols in a precision grip posture, to a permanent and transient visualization, would have a positive effect on the recall from these visualizations. We chose a between-subjects approach to investigate this hands factor, where a no-hands condition was compared to a with-hands group. To match this research question, we tested the following hypothesis:

- The with-hands condition would lead to higher recall than the no-hands condition (Hypothesis 2).

Hypothesis 2 was based on the findings showing the positive embodied effects of observing a static grasping hand (e.g., Fischer et al., 2008; Thomas, 2015).

In addition, Research Question 4 was whether three individual characteristics (spatial ability, spatial memory span, and gender) could moderate the recall of the visual elements. As detailed in Section 3.3.1, we measured spatial ability (mental rotation) with a standard pen-and-paper test. Spatial memory span was assessed with a computer test, and gender was self-reported in a written survey. We predicted the following hypotheses based on these three individual characteristics:

- Higher spatial ability participants would show higher recall (Hypothesis 3).
- Higher spatial span participants would show higher recall (Hypothesis 4).
- Males would show higher recall than females (Hypothesis 5).

Hypothesis 3 was based on studies that show that spatial ability can boost learning from visualizations (e.g., Höffler, 2010). Hypothesis 4, closely related to Hypothesis 3, was predicted by studies that show correlations between spatial memory span and spatial ability (e.g., So et al., 2015). Hypothesis 5 was predicted by reports of better performance of males on spatial and visual tasks (e.g., Uttal et al., 2013), such as those used in the current study.

3.2. *Participants*

The participants were 104 Australian university students (50% females) with an average age of 20.12 years ($SD = 2.26$, range 18–26), who were recruited via web advertising, email lists, and direct contact with other participants. As gender was expected to influence performance on a visual or a spatial task (cf. Reilly, Neumann, & Andrews, 2015), we kept a close to equal ratio for gender. Also, as discipline study could moderate these effects (see Wai, Lubinski, & Benbow, 2009), both STEM and non-STEM students were recruited in similar numbers. Thus, in the whole cohort there were 21 STEM males, 20 STEM females, 31 non-STEM males, and 32 non-STEM females. The volunteers were randomly allocated—while keeping an equal gender ratio—to one of the four conditions according to the 2 (Hands) x 2 (Order) factorial design. Hence, in each group there were 26 students, 13 males and 13 females. The participants were rewarded with a $20 gift card.

3.3. *Materials*

3.3.1. *Survey and pre-test instruments*

A written survey was used to obtain the participants' gender, age, handedness, and the university degree being studied. In addition to this survey, to assess spatial ability (mental rotation) we employed the pen-and-paper *Card Rotations Test*, a 6-min instrument with two-dimensional shapes developed by Ekstrom, French, Harman, and Dermen (1976), which ranges in potential score from −160 to 160. To assess spatial memory span, we devised a computerized two-dimensional version of the *Block Tapping Test* (Milner, 1971), programmed in Actionscript 3 with Adobe Flash CS4 Professional (Adobe, 2008). In this version of the test, the blocks (white squares) were activated in yellow color for 1 s, with a 0.5 s interval. The squares were oriented on the computer screen as in the examiner's view in Kessels et al. (2000). The test showed three five-square sequences (5-2-1-8-6; 4-2-7-3-1; 3-9-2-4-8), followed by three six-square sequences (3-7-8-2-9-4; 5-9-1-7-4-2; 5-7-9-2-8-4), followed by three seven-square sequences (5-8-1-9-2-6-4; 5-9-3-6-7-2-4; 5-3-8-7-1-2-4), totaling nine sequences (and 54 blocks) that were derived from those used by Kessels et al. (2000). The scoring method, as used by Busch, Farrell, Lisdahl-Medina, and Krikorian (2005), gave one point for each correctly memorized square in the sequences. Hence, the potential total score for spatial memory span ranged from 0 to 54.

3.3.2. *Memory learning tasks*

Following a pilot study, the tasks (permanent and transient) were finalized as remembering the type, color, and position of 12 abstract symbols placed on a rectangular frame on a laptop color monitor of 17” (resolution: 1600 × 900 pixels; refresh rate: 60 Hz). The abstract symbols were modified from glyphs of free computer fonts; they presented three different types and four different colors (see Fig. 1). There were two blue, one orange, five red, and four yellow symbols. In the tasks, the symbols presented a height of approximately 50 pixels on the screen (1° at approximately 70 cm distance).

In the transient task, each symbol was shown in position for 8 s. Thus, the symbols were shown individually in each step. Since there were 12 steps, the total time for the transient task was $12 \times 8 = 96$ s (see Fig. 1A). This design had three important characteristics: The transient presentation (a) did not show any continuous motion but only the appearance and disappearance of symbols; (b) presented transitory information, as every symbol was replaced after 8 s by the following element; and (c) was sequential, showing a predetermined serial arrangement. In contrast, for the permanent task all the 12 symbols were shown simultaneously for 96 s (see the task enlarged in Fig. 1B).

In the present experiment, both permanent and transitory tasks had the same size, lasted 96 s, were silent, and included a progress bar (representing time elapsed) at the bottom of the display. The tasks presented the same 12 symbols, but in different positions on the rectangular frame. Both tasks were attempted twice, to gauge if the potential effects persisted between the first and the second attempts.

In the with-hands conditions (for both permanent and transient formats), one right-hand static image in a precision grip posture was shown near to each symbol, suggesting that it was positioning the element. Assuming that the students were mostly right-handed (in fact, 92% reported right handedness), solely right hands were included in these presentations, in

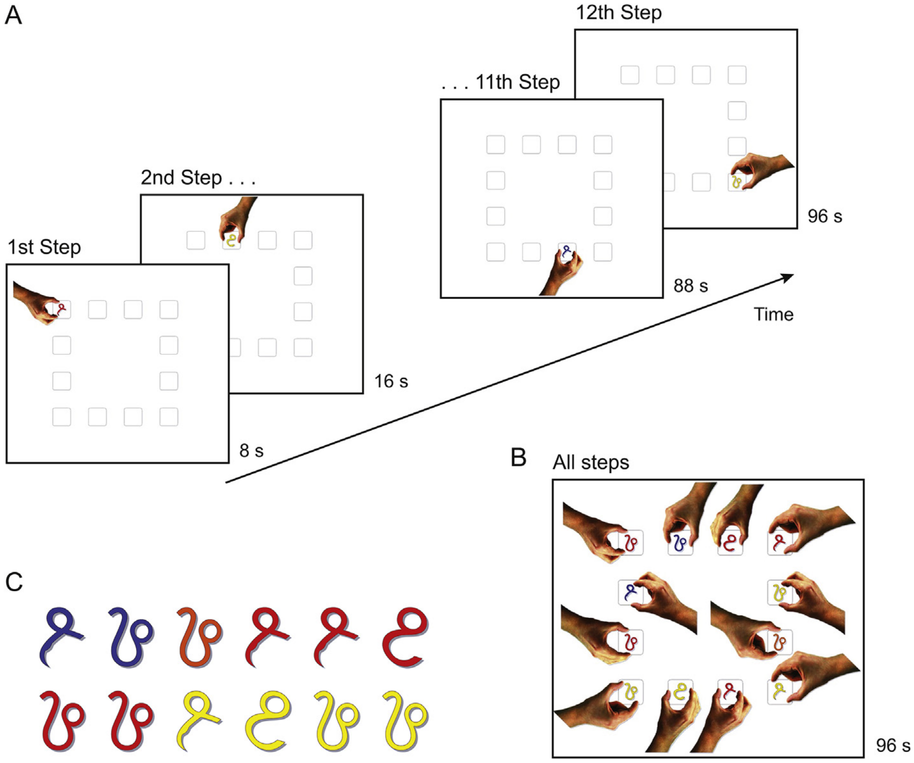

Fig. 1. Transient (A) versus permanent (B) tasks for the with-hands condition. The 12 colored symbols employed in all tasks (C). Note that the figure in (B) was enlarged here for better clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

order to maximize embodied effects (cf. Tseng & Bridgeman, 2011). All tasks were designed with the package Adobe Web Premium CS4 and programmed in Flash Actionscript 3 (Adobe, 2008).

3.3.3. *Self-rating of mental effort*

To measure mental effort (cognitive load), a pen-and-paper self-rating scale was designed using a 9-points-Likert, modified from the original scale of Paas (1992; see also Paas, Tuovinen, Tabbers, & Van Gerven, 2003). The scale asked participants: “How much mental effort did you invest in completing the task?”, and ranged from 1 (*extremely small amount*) to 9 (*extremely large amount*). This instrument was given to the students when they finished every attempt of the tasks.

3.4. *Procedure*

Full ethical approval from the Human Research Ethics Advisory of the university was granted for the present study (University of New South Wales, Approval No. 14040). The experiment was conducted on individual participants, where the researcher was present all the time. Commencing the experimental session, the participants signed the ethic consent form and answered the written survey. Then, the students did the computerized Block-Tapping Test (spatial memory span). Next, they completed the pen-and-paper Card Rotations Test (spatial ability) in 6 min. Then, the participants were read the instructions, according to their experimental condition, and were given a practice task to be familiarized with the tasks and symbols on the computer.

Subsequently, the first 96-s task (either permanent or transient) was presented for the first time, and then it was blocked from view. Then, the participants attempted the first task, by dragging the 12 virtual symbols with the laptop's mouse, from the side of the rectangular frame into the positions they memorized on the frame on the screen. No time limits were imposed and the symbols could be dragged in any order. Immediately after this first attempt, the participants completed the pen-and-paper rating of mental effort for the first time. Then, the first task was shown and attempted for a second time, and the rating of mental effort was completed again. Next, the second 96-s task (either permanent or transient) was shown and attempted twice, and after each attempt the self-rating was completed. Ending these tasks, the participants received a gift card.

3.5. *Dependent variables*

We employed two dependent variables: *accuracy score*, and *mental effort rating*. They were measured on four occasions, as each of the two tasks was attempted twice. Accuracy was scored as 1 point per correctly placed symbol on the position of the frame. The point was awarded only if both the type and color of the symbol were correctly recalled. Thus, the range of the accuracy score was 0–12. The range for mental effort rating was 1–9.

4. Results

Firstly, we conducted three-way (Hands x Order x Gender) analyses of variance (ANOVAs) to examine possible differences between the experimental groups according to the pre-tests (spatial ability and spatial memory span). For the Card Rotations Test of spatial ability, no significant results were revealed (all *ps* > 0.254). Similarly, there were no significant findings for the Block Tapping Test of memory span (all *ps* > 0.097). In consequence, we conducted the following analyses without any covariates. We present 95% confidence intervals [CI].

4.1. Initial analyses

To preliminarily assess possible task order and gender effects, we conducted 4 mixed-design ANOVAs, for accuracy scores on the first and the second attempts of the tasks, as well as for mental efforts on both attempts. In these mixed design analyses, task (permanent vs. transient) was the within-subjects factor, and (a) hands (no-hands vs. with-hands), (b) order (permanent first vs. transient first), and (c) gender (males vs. females) were the between-subjects factors. The analyses did not show significant main effects for order (all *ps* > 0.119) or for gender (all *ps* > 0.089). Similarly, there were no Order × Gender interactions (all *ps* > 0.189). Thus, both factors were not investigated further in the following mixed design ANOVAs, which were completed using task as the within-subjects factor and hands as the sole between-subjects factor.

4.2. Main analyses

4.2.1. Accuracy scores

The means and standard deviations for the accuracy scores and the mental effort ratings are shown in Table 2. For the accuracy scores on the first attempt of the tasks, we observed a significant main effect of task, $F(1, 102) = 25.30$, $p < 0.001$, $\eta_p^2 = 0.20$, where participants overall scored significantly higher in the permanent task ($M = 7.85$ [CI = 7.25–8.45]) than in the transient task ($M = 6.19$ [5.70–6.69]). There was also a significant main effect of hands, $F(1, 102) = 11.92$, $p = 0.001$, $\eta_p^2 = 0.11$, where participants overall scored higher in the no-hands condition ($M = 7.79$ [7.16–8.41]) as compared to the with-hands condition ($M = 6.25$ [5.63–6.88]). There was no Task × Hands interaction, $F(1, 102) = 1.11$, $p = 0.295$, $\eta_p^2 = 0.01$ (see Fig. 2).

To test the accumulative property of the transient information effect, we investigated whether the main effect of task on the first attempt depended on the position of the symbols being memorized. Hence, we divided the tasks in groups of four symbols (beginning Symbols 1–4, middle Symbols 5–8, and ending Symbols 9–12). Then, collapsing the factor hands, we performed three ANOVAs, one for each of these groups, comparing permanent to transient. In all the analyses, permanent significantly outperformed transient: (a) for Symbols 1–4, $F(1, 103) = 6.45$, $p = 0.013$, $\eta_p^2 = 0.06$, with permanent ($M = 2.78$ [2.54–3.02]) and transient ($M = 2.38$ [2.13–2.62]); (b) for Symbols 5–8, $F(1, 103) = 14.10$, $p < 0.001$, $\eta_p^2 = 0.12$, with permanent ($M = 2.71$ [2.46–2.96]) and transient ($M = 2.11$ [1.86–2.35]); and (c) for Symbols 9–12, $F(1, 103) = 15.89$, $p < 0.001$, $\eta_p^2 = 0.13$, with permanent ($M = 2.36$ [2.07–2.64]) and transient ($M = 1.71$ [1.47–1.95]). Note that, although the accuracy score on the first attempt was always significantly higher in the permanent than in the transient condition, the effect increased from Symbols 1–4 (accuracy difference = 0.40) to Symbols 5–8 (diff. = 0.61) to Symbols 9–12 (diff. = 0.64).

Concerning the accuracy scores on the second attempt of the tasks, the mixed design Task x Hands ANOVA revealed a main effect of task, $F(1, 102) = 4.14$, $p = 0.044$, $\eta_p^2 = 0.04$, a main effect of hands, $F(1, 102) = 4.82$, $p = 0.030$, $\eta_p^2 = 0.05$, and an interaction, $F(1, 102) = 4.14$, $p = 0.044$, $\eta_p^2 = 0.04$ (see Fig. 2). Follow-up simple effects tests revealed a significant difference in the no-hands condition, $F(1, 102) = 8.29$, $p = 0.005$, $\eta_p^2 = 0.08$, where permanent/no-hands ($M = 10.67$ [10.02–11.33])

Table 2
Means (and SD) for Accuracy scores and mental effort ratings.

Condition	First attempt		Second attempt	
	Permanent	Transient	Permanent	Transient
Accuracy score[a]				
No-hands	8.79 (2.73)	6.79 (2.43)	10.67 (2.00)	9.50 (2.59)
With-hands	6.90 (3.40)	5.60 (2.64)	9.23 (2.73)	9.23 (2.52)
Total	7.85 (3.21)	6.19 (2.60)	9.95 (2.49)	9.37 (2.54)
Mental effort rating[b]				
No-hands	7.06 (1.32)	7.50 (1.04)	5.94 (1.80)	6.35 (1.64)
With-hands	7.17 (1.51)	7.15 (1.43)	6.58 (1.59)	6.69 (1.48)
Total	7.12 (1.41)	7.33 (1.26)	6.26 (1.72)	6.52 (1.56)

Note. The factors order and gender have been collapsed. For all these conditions, $n = 52$ (50% females).

[a] Potential range = 0–12.

[b] Potential range = 1–9.

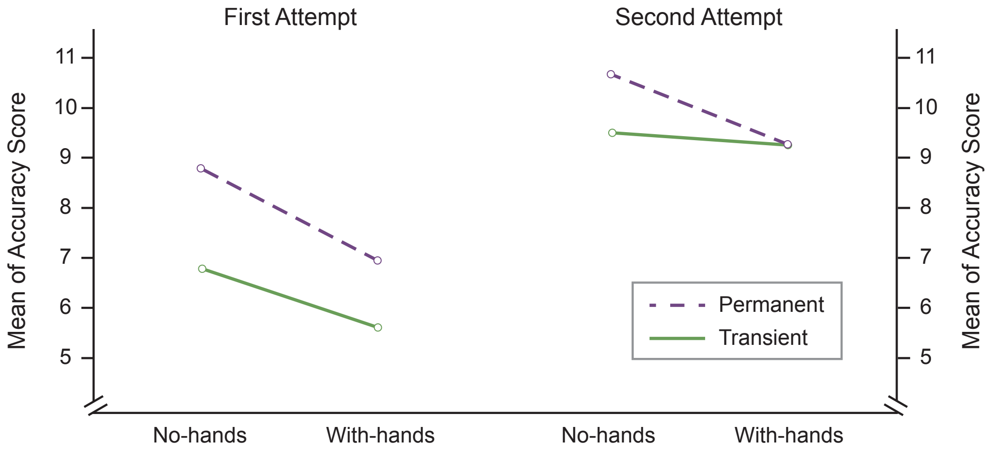

Fig. 2. Means of accuracy scores on both attempts, as a function of hands and task. First attempt (left) and second attempt (right).

outperformed transient/no-hands ($M = 9.50$ [8.80–10.20]). In contrast, no significant difference was found for the with-hands conditions ($F < 1$, *ns*) when comparing permanent/with-hands ($M = 9.23$ [8.57–9.89]) to transient/with-hands ($M = 9.23$ [8.53–9.93]).

4.2.2. *Mental effort ratings*

For the mental effort self-ratings on the first attempt of the tasks (see Table 2), the mixed design ANOVA showed no significant main effect of task, $F(1, 102) = 3.26$, $p = 0.074$, $\eta_p^2 = 0.03$, no main effect of hands ($F < 1$, *ns*), but a close to significant interaction between the factors, $F(1, 102) = 3.87$, $p = 0.052$, $\eta_p^2 = 0.04$. Simple effect tests showed a significant difference in the no-hands condition, $F(1, 102) = 7.12$, $p = 0.009$, $\eta_p^2 = 0.07$, where transient/no-hands ($M = 7.50$ [7.16–7.84]) invested more effort than permanent/no-hands ($M = 7.06$ [6.67–7.45]). In contrast, there was no difference ($F < 1$, *ns*) when comparing permanent/with-hands ($M = 7.17$ [6.78–7.56]) to transient/with-hands ($M = 7.15$ [6.81–7.50]). For the mental effort self-ratings on the second attempt, the mixed design ANOVA revealed no significant main effect of task, $F(1, 102) = 3.17$, $p = 0.078$, $\eta_p^2 = 0.03$, no main effect of hands $F(1, 102) = 2.97$, $p = 0.088$, $\eta_p^2 = 0.03$, nor a significant interaction ($F < 1$, *ns*).

4.3. *Considering individual characteristics*

We assessed the influence of individual characteristics (pre-tests of spatial ability and spatial memory span) on the accuracy scores of both permanent and transient tasks. For this purpose, we obtained correlations between the pre-tests and the four accuracy scores (two attempts for each task), separated by gender (see Table 3). We observed higher correlations in males than in females between the pre-tests and the accuracy scores, indicating that females may have used different strategies than males to solve the transitory task, and these strategies seem to rely less on spatial ability and spatial memory when compared to males' strategies. Nevertheless, these differences in strategies did not result in significantly different accuracy outcomes between males and females, as the initial ANOVAs (Section 4.1) showed no gender effects.

To gauge more precisely the effects of gender, the pre-tests and the hands factor on the accuracy of both tasks, we performed multiple regression analyses on the whole sample. These regression analyses were conducted on the accuracy averages between the two attempts, on both the permanent and the transient tasks. As hands revealed significant findings in the ANOVAs, but gender did not, the steps for the regression models followed the sequence: (a) hands, (b) spatial ability, (c), spatial memory span, and (d) gender. For the permanent task (average scores between attempts), the forced entry regression model with the four predictors, $R^2 = 0.20$, $F(4, 99) = 6.08$, $p < 0.001$, showed significant effects for hands ($B = -1.69$ [−2.56,

Table 3
Intercorrelations for pre- and post-test variables as a function of gender.

Variable	1	2	3	4	5	6
1. Spatial ability test	–	0.55^{***}	0.17	0.41^{**}	0.31^{*}	0.54^{***}
2. Spatial span test	0.08	–	0.11	0.32^{*}	0.18	0.42^{**}
3. Permanent, 1st attempt	0.14	-0.06	–	0.44^{**}	0.49^{***}	0.23
4. Transient, 1st attempt	0.05	0.14	0.23	–	0.30^{*}	0.58^{***}
5. Permanent, 2nd attempt	0.34^{*}	0.02	0.44^{**}	0.19	–	0.27
6. Transient, 2nd attempt	0.14	0.11	0.18	0.30^{*}	0.33^{*}	–

Note. Intercorrelations for male participants ($n = 52$) are presented above the diagonal, and intercorrelations for female participants ($n = 52$) are presented below the diagonal. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

−0.82], $\beta = -0.35$, $p < 0.001$) and spatial ability ($B = 0.02$ [0.01, 0.03], $\beta = 0.28$, $p = 0.005$), but not for spatial memory span ($B = -0.02$ [−0.11, 0.08], $\beta = -0.04$, $p = 0.723$) and gender ($B = -0.39$ [−1.28, 0.49], $\beta = -0.08$, $p = 0.379$). For the transient task (average scores between attempts), the regression analysis, $R^2 = 0.22$, $F(4, 99) = 7.08$, $p < 0.001$, showed a significant effect for spatial ability ($B = 0.02$ [0.01, 0.03], $\beta = 0.33$, $p = 0.001$), close to significant effects for both factors hands ($B = -0.75$ [−1.52, 0.02], $\beta = -0.17$, $p = 0.057$) and spatial memory span ($B = 0.08$ [−0.00, 0.16], $\beta = 0.19$, $p = 0.053$), and no effect for gender ($B = -0.06$ [−0.84, 0.73], $\beta = -0.01$, $p = 0.885$).

Summarizing the multiple regression analyses, for both the permanent and the transitory tasks, the accuracy scores can be predicted by spatial ability (i.e., the higher the mental rotation score, the higher the accuracy), but not by gender. In addition, the negative influence of the hands factor is much stronger for the permanent than for the transient task, implying that, although no-hands can result in higher scores in both tasks, this effect is significant only for permanent (and close to significant for transient). In contrast to this no-hand effect being stronger in the permanent task, there is a spatial memory span effect that is greater on the transient task. In fact, there is a close to significant trend in the transitory task (but not in the permanent) in which the higher the spatial memory span, the higher the accuracy score.

5. Discussion

In this study, university participants memorized the type, color, and position of 12 abstract symbols, shown in both permanent (static) and transient (dynamic) visualizations. We controlled several factors that could influence in the permanent versus transient comparison. In addition, half of the students watched the visualizations including a static hand in a precision posture near each abstract symbol (with-hands condition), and they were compared to the other half who watched the symbols without these hands (no-hands condition). We measured the recall accuracy and the perceived mental effort invested in the tasks. As each of the two tasks was attempted twice, we collected these data on four occasions. Also, we assessed if spatial ability (mental rotation), spatial memory span, and gender influenced the learning accuracy in the tasks. The findings will be discussed according to our hypotheses.

5.1. Support for the hypotheses

5.1.1. The permanent presentation would lead to higher recall than the transient presentation, and this effect will be greater at the end of the presentations

The prediction that a permanent format can lead to better memorization than a transient format (Hypothesis 1a) was supported in this study and provides an answer to Research Question 1. In the first attempt of the tasks, participants more accurately recalled the symbols' properties after a permanent rather than a transient presentation. Also in the first attempt, half of the participants (no-hands condition) self-rated investing more mental effort with the transient presentation than with the permanent format; the other half (with-hands) presented no significant differences. Finally, in the second attempt of the task, half of the group (no-hands) was more accurate in the permanent as compared to the transient task, whereas the other half (with-hands) showed no effects.

In the first attempt, when analyzing the effect of task by groups of four symbols, the difference favoring permanent tended to increase in time, as predicted by Hypothesis 1b. In other words, permanent outperformed transient to a lesser extent in Symbols 1–4, then somewhat more in Symbols 5–8, and reached its maximum in Symbols 9–12. In answer to Research Question 2, these results suggest that, in the beginning of the tasks (Symbols 1–4) the participants coped with the transient visual information better than when ending the tasks (Symbols 9–12), when the negative transitory effects had accumulated.

To sum up, after memorizing the symbols' type, color, and placement in a transient display, the participants were less accurate and invested more mental effort than when given a permanent presentation. The transient information effect of cognitive load theory predicted that the permanent design would be more effective than the transient format (e.g., Castro-Alonso et al., 2014). This is caused by transient information on the screen, which disappears before it can be effectively processed in working memory (e.g., Ayres & Paas, 2007; Lowe, 1999). Moreover, the problematic transient feature was expected to be accumulative, and thus more noticeable with more elements to be recalled. As such, we expected permanent to outperform transient to a greater extent at the end of the tasks (Symbols 9–12) rather than at the beginning (Symbols 1–4), when the information to be retained could still be managed. As predicted, our results in the first attempt confirmed the accumulation of the detrimental transient information effect.

5.1.2. The with-hands condition would lead to higher recall than the no-hands condition

Research Question 3 investigated whether watching precision hands near the recalling elements could lead to better performance than not watching the hands. The prediction of a positive embodied effect (Hypothesis 2) was not supported in this study. In other words, we did not observe a beneficial parvocellular embodied effect expected for the visualization of a static hand in a grasping posture near the recalling elements (e.g., Thomas, 2015). Quite the contrary, on the first attempt of both tasks, no-hands participants were more accurate than those in the with-hands condition. In addition, the regression analyses showed that no-hands could partially predict high accuracy scores on the first attempt, especially for the permanent task. It appears that the provision of images of hands is not necessary, and even hinders solving the tasks. This can be aligned with the *redundancy principle* (see Kalyuga & Sweller, 2014) and the *coherence principle* of cognitive load theory and the cognitive theory of multimedia learning (see Mayer & Fiorella, 2014; see also Sung & Mayer, 2012), where eliminating unnecessary visual information, in this case the images of hands, can boost learning. Arguably the hands competed for attention with the symbols, so not showing the hands could allow students to focus on the important elements to memorize. This distractor effect of hands (see *the distraction hypothesis* in Harp & Mayer, 1998) was possibly higher in the permanent visualization, because many hands were presented simultaneously with the symbols (see Fig. 1B). In short, it appears that for the present learning tasks with abstract symbols, the positive parvocellular visual recognition effect, generally reported when observing one static hand in a precision posture, was surpassed by the negative effect of redundant visual information presented.

5.1.3. *Individual characteristics hypotheses*

Research Question 4 investigated whether three individual characteristics would impact on the performance of the permanent and transient tasks. The prediction that spatial ability would positively affect recall from the permanent or the transient task (Hypothesis 3) was supported on the regression analyses, which showed that spatial ability could predict the accuracy scores for both tasks. Specifically, we measured the mental rotation subfactor of spatial ability. Converging literature shows that spatial ability and mental rotation help learning from visualizations (see Höffler, 2010). The argument that spatial memory span would favorably affect memorizing the materials (Hypothesis 4) was partially supported, but only showing a close to significant effect ($p = 0.053$) for the transient but not for the permanent task. Thus, especially in the challenging conditions of transitory visualizations, having a high spatial memory span seems to be advantageous. For males, we found a significant correlation between spatial ability and spatial memory span, supporting previous findings (e.g., Miyake et al., 2001; So et al., 2015), and implying that both individual characteristics are important assets for males to learn from difficult visualizations. Finally, gender effects where males outperform females on visuospatial tasks (Hypothesis 5) were not observed in this study. Although the correlational data hinted that males and females could be employing different strategies to solve the tasks (e.g., for the transient task males may have relied more than females on their spatial ability and spatial span), these differences did not affect their accuracy. This lack of a gender effect seems to contradict other findings where dynamic (transitory) pictures have been more helpful to females (Sánchez & Wiley, 2010; M. Wong et al., 2015) or to males (Griffin et al., 2006). The discrepancy may depend on the learning task investigated: Our study used a rather abstract task, but M. Wong et al. (2015) employed a manipulative Lego task, and both Griffin et al. (2006) and Sánchez and Wiley (2010) used STEM topics. Altogether, to memorize abstract visualizations like ours it appears that: (a) spatial ability is the most useful individual characteristic, followed by spatial memory span; and (b) gender is not influential.

5.2. *Instructional implications*

We give three implications to consider when presenting abstract tasks that need learning the visual elements. First, permanent instructional formats may be more helpful tools than transient presentations. Second, static images of a precision hand may not always prove useful to study the elements, especially if the hands clutter the display. Third, the three participant's individual characteristics influence at different degrees their learning performance. It appears that spatial ability is the most effective characteristic, followed by spatial memory span; in contrast, the gender variable may be less important for these abstract tasks.

5.3. *Limitations and future directions*

One limitation of the present study is that we did not employ brain measurements to assess whether the presence of hands activated the mirror neurons, the parvocellular visual pathway, or similar embodied cognitive mechanisms that we hypothesized. An example of these techniques is reported by Brucker et al. (2015), who used brain spectroscopy to measure certain regions of the mirror neuron system. Similar methods could be used in future experiments involving depiction of hands.

Another limitation concerns the debatable potential to generalize these finding to other learning or memory tasks, particularly dealing with visual STEM concepts. The task used here was deliberately abstract, in order to be (a) a fundamental example of permanent and transient presentations, and (b) equally demanding for both STEM and non-STEM students. Nevertheless, clearly the materials were not part of an academic syllabus, so future research could extend these findings with tasks of formal educational areas, such as STEM disciplines.

6. Conclusions

By providing a controlled design to compare permanent to transient presentations of an abstract-symbol learning task, we observed that the transient format was not a very effective resource. Presentations that convey transient information are difficult to follow. This problem was more noticeable with more visual elements involved. The addition of static precision hands that could trigger beneficial embodied mechanisms was not an effective asset in our study. Finally, two individual participants' characteristics, spatial ability more than spatial memory span, impacted the effectiveness of the permanent and the transient presentations.

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