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Rotational perspective and learning procedural tasks from dynamic media

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There have been conflicting accounts regarding the effectiveness of animations for learning. Procedural motor learning represents one of the few areas in which animations have consistently shown to be facilitative. Some have suggested that this benefit is related to activation of the mirror neuron system (MNS), with higher activation leading to better performance. This study examines this explanation, and observed the effects of instructional media (animation vs. static), as a function of viewing perspective (face-to-face vs. over-the-shoulder) on understanding a procedural motor task (knot tying). Results indicate that performance was significantly improved with animations over static images, however this appeared to be most pronounced in situations which matched the learners' own perspective (i.e., over-the-shoulder). These findings have implications for the design of instructional media for procedural motor tasks and provide confirmation of the assertion that appropriate activation of the perceptual system can be leveraged to increase performance.

1. Introduction

The notion that dynamic external visualizations can provide some efficacy over alternative presentations such as textual descriptions has been suggested many times (Larkin & Simon, 1987; Tufte, 2001). While there is some evidence suggesting that animations do not facilitate learning (Boucheix & Schneider, 2009; ChanLin, 2000; Hegarty, Kriz & Cate, 2003; Mayer, Hegarty, Mayer & Campbell, 2005; Tversky, Morrison & Bétrancourt, 2002), numerous other studies have found that animations can indeed enhance learning under certain constraints (see Höffler & Leutner (2007) for a review). For example, animations have been shown to be more effective than static visualizations for the acquisition of process knowledge in cell biology (Münzer, Seufert, & Brünken, 2009), and learning concepts in chemistry and earth science (Falvo & Suits, 2009; Sanchez & Wiley, 2010). However, an open question is what leads to this differential pattern of results regarding the effectiveness of animations for learning?

Some have suggested that perhaps animations are particularly well suited for certain content areas, and less so for others. In a meta-analysis conducted by Höffler and Leutner (2007), it was found that animations can be more effective than static images if they are a realistic approximation of the task, and especially so if the task involves procedural motor learning. For example, studies on the learning of basic first aid procedures (e.g., what to do when someone is choking, or how to bandage a hand) found that animations produced higher levels of recall than static images or text alone, and also produced faster rates of learning (Arguel & Jamet, 2009; Michas & Berry, 2000). Similarly, Ayres, Marcus, Chan, and Qian (2009) found that observing animations of knot tying and ring assembly puzzles produced the highest levels of both forward and reverse learning, and increased the ability to recognize next or previous steps versus similar static presentations.

So what is it about procedural motor learning tasks that make them so amenable to animated presentations? As animations demonstrate changes over time and/or sequence, it is possible that the inclusion of this underlying temporal component might produce a higher degree of match to procedural tasks versus other contexts, as these procedural tasks themselves often contain a temporal sequence of

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events. This is consistent with the intuitions of Rieber & Kini (1991), who suggested that animations can reduce the abstract nature of temporal changes, thus providing a more tangible way to understand material. In other words, the representation of time in these dynamic visualizations potentially increases the match between the to-be-learned material, and how said information is instructionally conveyed. Simply, the method of instruction more closely matches the constraints of the content domain it is meant to represent. It has been speculated that this *congruence* between content area and instruction underlies the most effective animations (Rieber, 1990; Tversky et al., 2002).

How then are we able to capitalize on heightened levels of congruence between instruction and content to improve learning and thus realize the full benefit of animations? In other words, what might be the underlying mechanism by which the effects of congruence are realized? While to date this has not been explicitly tested neurologically, it has been proposed that such animations potentially activate the mirror neuron system (MNS). It is believed that this activation facilitates learning in these tasks by providing a perceptual basis to interpret and understand these visualizations (Ayers et al., 2009; Chandler, 2009; Wong et al., 2009), akin to the perceptual benefit originally attributed to static illustrations alone (Larkin & Simon, 1987). From this perspective, activation of the MNS permits an almost effortless simulation or embodiment of the material which can then be used to encourage the activation of relevant knowledge and connections between material, and thus better understanding (van Gog, Paas, Marcus, Ayres & Sweller, 2009).

1.1. The mirror neuron system and procedural learning

Originally identified in primates, the MNS represents a neurophysiological circuit distributed across the pre-motor cortex that selectively activates when either conducting a specific action, or when observing another individual performing the same action (Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992). It was originally believed that this system offered a perceptual mechanism to understand goal-directed action and intent (Gallese & Goldman, 1998) and perhaps might even serve as a gateway to language and communication (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Arbib, 1998). More recent research has refined this definition and identifies the MNS as critical for not only understanding others' movements, but also generating plans for one's own actions and execution (Fogasi et al., 2005; Meltzoff & Prince, 2002). For example, while simply observing an individual play guitar chords did activate the MNS, watching the same material with the intent to replicate or reproduce (i.e., to learn) the actions produced even higher levels of activation within the MNS (Buccino et al., 2004). As such, some have suggested that this underlying architecture is potentially responsible for our ability to learn through imitation, which is a unique to higher apes and humans (Rizzolatti & Craighero, 2004). Given this conceptualization, it is not surprising that this neural circuit might be especially relevant for procedural learning, as the fundamental goal of any procedural learning task is to successfully imitate or reproduce a given pattern of motor events.

If this mirror neuron explanation is correct, and thus mediates the effectiveness of a given animation, one would expect to see an interaction between animations and the degree to which they activate the MNS. For example, when animations most activate the MNS, we would expect to see the highest levels of learning as these visualizations leverage the perceptual system in such a way as to enable better understanding of the to-be-learned motor task. However, when animations fail to strongly activate the MNS, it is reasonable to expect a similar decline in overall performance as this perceptual processing benefit is not realized. One way to test this explanation would be to systematically vary the degree of activation of the MNS, while holding informational content constant. Shifting action away from first-person perspectives has been shown to moderate activation of the MNS, such that face-to-face presentations activate the MNS to a lesser degree than over-the-shoulder perspectives (Jackson, Meltzoff & Decety, 2006; Maeda, Kleiner-Fisman & Pascual-Leone, 2002). In other words, watching someone else demonstrate an action has been shown to produce lower levels of activation in the MNS than watching action from a perspective more akin to actual experience (e.g., through your own eyes). The question then is: does reducing activation of the MNS simultaneously produce lower levels of learning from animations when informational content is the same? If the suggestion that the MNS is largely responsible for the facilitation of animations in procedural learning, than one would expect lower facilitation in situations that less strongly activate the MNS.

Finally, previous research has indicated that individual differences in visuospatial and attentional ability might also moderate the instructional effectiveness of any kind of visualization, including animations. Visuospatial ability has been shown to interact with animations to affect learning of mechanical information (Mayer, 2001; Mayer & Sims, 1994), and spatial science topics (Höffler & Leutner, 2011; Sanchez & Wiley, 2010; Yang, Andre, Greenbowe & Tibell, 2003). Similarly, Cognitive Load Theory (van Merriënboer & Sweller, 2005), Mayer's (2005) Cognitive Theory of Multimedia Learning, and Schnotz's (2005) Integrative Model of Text and Picture Comprehension all speculate that appropriate visualizations offload processing demand from the working memory system, thereby freeing resources to better dedicate to the learning process. Given these proposed connections between learning from visualizations and individual differences in cognitive ability, it seems prudent to control for these abilities when evaluating a causal theory such as the MNS explanation.

1.2. Current study & hypotheses

To explore learning in procedural motor tasks and how they may interact with our perceptual system and presentation, a study was conducted which manipulated both of these characteristics. Participants were shown a procedural knot tying task from either an animated or static media, which was either consistent with their perspective when completing the task themselves (i.e., over-the-shoulder, OTS), or instead rotated 180° into a face-to-face (FTF) orientation. It is hypothesized that for procedural motor learning tasks, instruction via animations instead of static images will facilitate overall performance resulting in faster time, fewer errors and more steps correct. This would be consistent with a host of psychological research regarding the efficacy of such dynamic media (Höffler & Leutner, 2007). Further, this performance benefit may also interact with perspective of the demonstration. If the mirror neuron explanation is correct, those orientations that would activate the MNS most strongly will realize the largest benefits of animation. Conversely, those that lessen activation of the MNS should perform less well. In order to control for individual differences in general cognitive processing and visuospatial manipulation, both of which have been suggested to influence learning from animations (Hegarty & Waller, 2005; Mayer & Moreno, 1998), additional measures of these cognitive abilities were collected and entered into subsequent analyses.

2. Method

2.1. Participants

Eighty-six undergraduates from a large public university were solicited for participation in this experiment. To control for differences in prior knowledge, participants were asked to self-report any formal prior experience with knot tying before participation. Participants who reported any formal familiarity with knot tying were excluded from the final analysis. Based on this strict criteria, 6 participants were excluded from the final analysis, resulting in eighty participants overall. All participants were compensated with course credit in an introductory psychology class.

2.2. Materials

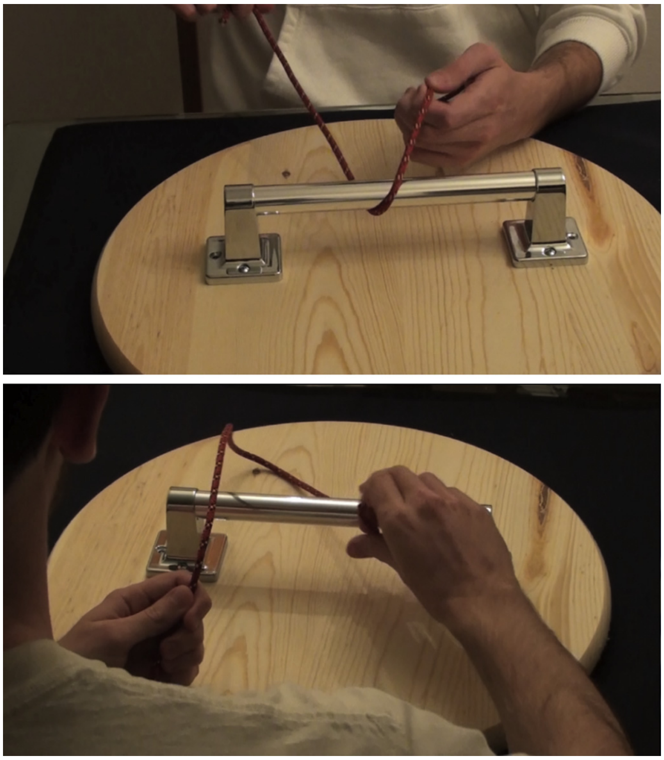
2.2.1. Instructional media

All participants studied instructional media detailing the knot tying procedure of 3 different knots (constrictor knot, cow hitch and clove hitch, all of which involve tying a rope around a bar; Budworth, 2004). Each of these media broke down the knot-tying procedure for each knot into 4 constituent steps. Based on assignment, this media either consisted of an animation or a series of static images whose progression was controlled by the participant. Participants were also able to control the animations using standard playback buttons. Thus, interactivity with the media was permitted in both conditions. Importantly, both animations and static images contained equivalent information necessary to successfully complete the task, as the static images were derived from screen shots of the videos. There were 4 total images (corresponding to the final state of each step) in the static condition, and each animation lasted approximately 30 s. Participants were given 2 min to study the instructional material before being asked to tie the knot shown, and during that time were permitted to interact with the material however they saw fit. Participants repeated this procedure with the remaining 2 knots, whose order was randomized within subjects. Participants learned all knots from a single media type.

Additionally, the orientation of the instructional media was manipulated between participants (Fig. 1). Participants were either given a view corresponding to watching the task being performed as though they were facing someone else (face-to-face; FTF) or as though they were watching the task over the shoulder of the individual performing it (over-the-shoulder; OTS). Each participant viewed all instructional media from only one perspective.

Learning performance was evaluated in 2 ways, the total time spent attempting to tie the knots until they either correctly solved the knot, or instead reached the 2 min time limit. Participants were also evaluated for the number of attempts they made for each of the 4 steps for each knot, and also how many correct steps they were able to produce. Note, this allowed the participants to receive partial credit for learning a knot, even if they were unable to completely solve the knot. The number of attempts and the number of correct attempts were then used to compute an overall ratio, indicative of the proportion of overall correct responses.

Performance on each of the 3 knots was also aggregated in an attempt to provide a larger and more consistent sampling of data, and thus hopefully also provide a more accurate picture of performance which minimized any difficulties or eccentricities inherent to a single knot procedure. This is consistent with prior research on knot tying (Ayers et al., 2009).



F. ig. 1Screenshots demonstrating the difference between the OTS and FTF presentations.

2.2.2. Visuospatial assessment

All participants completed 2 measures of visuospatial ability: the Surface Development task (VZ-3) and the Cube Comparisons task (S-3) from the Kit of Factor-referenced Cognitive Tests (French, Ekstrom & Prince, 1963). The VZ-3 task is considered a measure of spatial visualization, and the S-3 task is considered of measure of spatial relations (or mental rotation). In the VZ-3 task, individuals are asked to mentally fold a three dimensional figure from an unfolded flat representation by matching sides of the unfolded representation to the folded 3-dimensional figure. There are five questions for each shape, and total of 6 shapes for each of the 2 parts of this test. Points are awarded for every correct match, with a maximum score of 60 points for the test. Participants are given 3 min for each part of the test.

The S-3 task requires participants to make same/different judgments for pairs of cubes that may or may not be rotated versions of one another. This task consists of 2 parts, each 3 min long, both of which contain 21 pairs of cubes. Points are awarded for correct judgments, with a maximum score of 42 for the entire test.

2.2.3. WMC assessment

To control for general cognitive ability and differences in attentional control (Conway et al., 2005), all participants completed an assessment of working memory capacity using an automated version of the Operation Span task (AOSPAN; Unsworth, Heitz, Schrock & Engle, 2005). The AOSPAN task requires participants to complete simple mathematical problems while also remembering an unrelated letter for a later test (e.g., IS $(8/4)-1 = 1$? C). These equation-letter strings were presented in sets that contained between two to seven strings. At the end of each set, participants are asked to recall the letters that followed the equations in correct serial order, and are awarded a single point for every letter recalled correctly. Participants completed 3 trials of each set size, and the order of these sets was randomized. All administration and scoring followed the recommendations of Unsworth et al. (2005).

2.3. Procedure

Participants completed the task individually with the experimenter observing. Participants first completed the initial visuospatial assessments. Upon completion, they were directed to a computer that was used to display the instructional media, and asked to study the material detailing the procedure before completing the steps themselves. Again, the procedure for each of the 3 knots was broken into 4 steps. Participants were then given 2 min to study the instructional material for each knot, and 2 min to complete the knot before being asked to move onto the next knot, for a total overall time of 12 min. After completion, participants were then debriefed and dismissed. Participants completed the WMC assessment in a separate half-hour session.

3. Results & discussion

Participant's task performance was measured in the following ways: total time on task, and proportion of correct attempts. Descriptive statistics are available in Table 1. To test whether the rotation of the media and instructional media differed, a hierarchical OLS regression was performed for each of these performance metrics. Type of Media, perspective, WMC and visuospatial ability measures were entered into the first block of the analysis, and then an interaction term between media and perspective was entered in the second block of analysis to test for any potential interaction between these variables. Media (static = 0, animations = 1) and perspective (OTS = 0, FTF = 1) were both dummy-coded prior to being entered into the model. Importantly, this procedure allowed for the statistical control of the influence of cognitive abilities, thus permitting an examination of the independent influence of the variables of interest (e.g., media and perspective).

3.1. Time on task

This measure reflects the sum total amount of time the participant worked on all three of the knots. Time was called for each knot when they either (1) successfully produced each knot, or (2) reached the end of the 2 min time limit for each knot. Thus, the maximum bound on this measure is 360 s (6 min; 2 min for each of the 3 knots). Lower overall time on task is thus indicative of faster, and likely more accurate, performance.

Results from the first block of analysis indicate that the model predicted a significant proportion of time variance ($R^2 = .40$, $F(5, 74) = 9.73$, $p < .01$). Both media type ($\beta = -.52$) and perspective ($\beta = .27$) were significant predictors ($p < .01$) of performance time, with animations and OTS perspectives producing faster overall performance. However, the VZ-3 ($\beta = -.10$), S-3 ($\beta = -.10$) and WMC ($\beta = -.11$) measures all failed to significantly predict how quickly participants completed the knot-tying tasks.

The addition of the interaction term in the second block also produced a significant overall model ($R^2 = .44$, $F(6,73) = 9.65$, $p < .01$), and accounted for a significant additional portion of overall variance ($R^2\ \Delta = .05$, $p < .05$). The interaction between media and perspective was significant ($\beta = .38$), which suggests that in conditions which were both animated and OTS, performance was fastest. To illustrate this interaction better, simple *t*-tests were conducted comparing the media conditions within each perspective. As expected, animations in the OTS perspective were significantly faster than animations in the FTF perspective ($t(38) = 3.27$, $p < .01$), and there was no difference between

Table 1
Descriptive statistics for dependent variables in each condition, M(SD).

	Time on task (seconds)	Proportion correct responses	Proportion error responses
Static illustrations			
OTS	290.15 (74.57)	.22 (.12)	.78 (.12)
FTF	290.60 (62.55)	.19 (.08)	.81 (.08)
Animated illustrations			
OTS	134.80 (73.61)	.64 (.27)	.36 (.27)
FTF	226.00 (100.51)	.43 (.24)	.57 (.24)

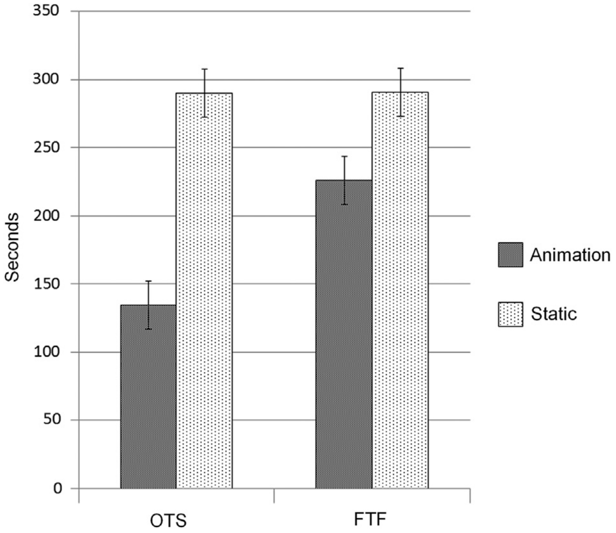


Fig. 2. Total completion time by media condition and perspective. Error bars represent the standard error of the mean.

the perspectives in the static condition ($t < 1$). This interaction is also illustrated in Fig. 2, and suggests that while animations led to faster overall performance generally, this was most pronounced in the condition that matched the learner's own perspective.

3.2. Proportion steps correct

When the number of correct attempts was averaged over the number of total attempts, an identical pattern emerged. Results from the first block of analysis again indicated that the model predicted a significant proportion of performance variance ($R^2 = .49$, $F(5, 74) = 14.13$, $p < .01$). Both media type ($\beta = .61$) and perspective ($\beta = -.27$) were significant predictors ($p < .01$) of correct performance, with animations and OTS perspectives again producing more correct overall attempts. As before, the VZ-3 ($\beta = .19$), S-3 ($\beta = -.03$) and WMC ($\beta = .06$) measures all failed to significantly predict how correctly participants completed the knot-tying tasks.

The addition of the interaction term in the second block also produced a significant overall model ($R^2 = .52$, $F(6,73) = 13.03$, $p < .01$), and accounted for a significant additional portion of overall variance ($R^2\Delta = .03$, $p < .05$). The interaction between media and perspective was significant ($\beta = -.30$), which suggests again that in conditions that were both animated and OTS, performance was best. Simple *t*-tests were again conducted to unpack this interaction, and found that, just as with the total time measure, animations in the OTS perspective outperformed animations in the FTF perspective ($t(38) = 2.57$, $p < .01$), and there was no difference of perspective in the static condition ($t < 1$). Again, this suggests that the animation benefit is largest in the condition which was identical in perspective to the learner (Fig. 3).

Finally, one could also flip these proportion scores, and instead look at the proportion of responses that *did not* result in correct attempts, which conceptually could be deemed 'errors' in performance. As proportion of errors is simply the difference between the proportion of correct responses and 100% correct performance (i.e., 1- proportion of correct responses), the identical pattern emerges as evidenced in the

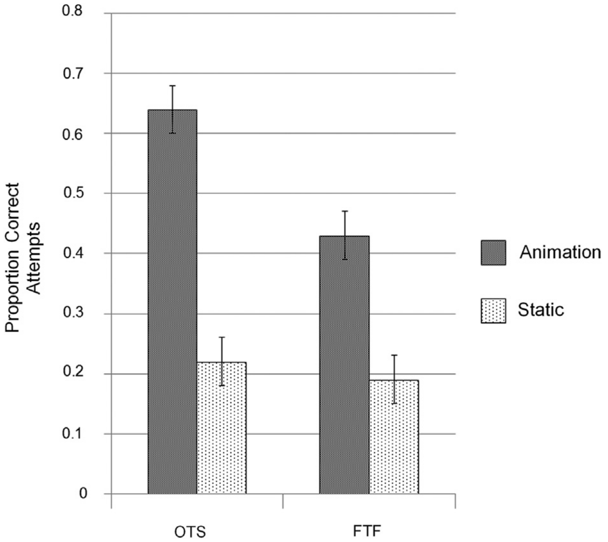


Fig. 3. Proportion of correct attempts by media condition and perspective. Error bars represent the standard error of the mean.

correct response analysis, and all statistical values are also identical to those already provided for correct responses. To reiterate, animations outperformed static images, OTS produced better performance than FTF, and there was also a significant interaction, such that the animated-OTS condition produced the fewest errors overall. While mathematically redundant, it is worth mentioning this perspective on the data as it suggests a potential mechanism by which animations and perspective may facilitate performance: that being the reduction of erroneous responses. This also might inform the overall time metric, as it seems reasonable to assume that reduced error attempts would naturally result in faster performance.

4. Conclusions

This experiment was designed to test two previous assertions regarding the potential benefit of animations in educational contexts: do animations enhance performance in procedural motor tasks, and more importantly, can such increases be directly tied to activation of the perceptual MNS? While animations did lead to better performance over static images for both the time required to reach a solution, and also the number of correct steps learned, it appears that these effects were largest for those conditions that maximized the activation of the MNS. In other words, systematically varying perspective 180° (e.g., from FTF to OTS condition or vice-versa) while holding informational content constant, significantly changed the magnitude of effectiveness for the animations. The FTF perspective led to lower facilitation by animations, and the OTS perspective produced the largest benefit for understanding the task. Perspective shifts out of the first-person perspective have been demonstrated to reduce (but not eliminate) the activation of the MNS (Jackson et al., 2006; Maeda et al., 2002), and given these findings it is likely that this reduced activation produced a lesser degree of perceptual facilitation when interpreting the animations used here. In sum, this suggests that animations that most highly activate the MNS produce the largest benefit when learning a new procedural motor task.

However, it is also important to recognize that this perspective manipulation did not completely eliminate the benefit of animations. FTF animations still outperformed all variations of static images in both time to solution and rate of correct solution. This suggests that animations might also facilitate the development of understanding over static images in other additional ways that are not so strongly tied to the MNS. This offers an interesting avenue for future research on what other ways animations might positively affect the understanding of procedural information above their less dynamic (i.e., static) counterparts. This study thus builds on previous work in animations (Ayers et al., 2009; Höffler & Leutner, 2007; Wong et al., 2009), and identifies further constraints on *why* animations are effective, at least for procedural tasks.

Regarding static pictures, it appears that their usage is somewhat insensitive to perspective shifts. Whether static illustrations were presented in FTF or OTS orientations did not appear to affect (positively or negatively) how quickly or successfully these illustrations were used to learn the knots. This suggests that these illustrations are not differentially activating the MNS, as was likely the case with animations. Given the procedural nature of the images, and the fact that they also included hands (which is a characteristic that has been shown to activate the MNS; Rizzolatti & Craighero, 2004), it is worth considering why there was no interaction between these media and the MNS. It is possible that the static illustrations, as they were presented without perceptual signaling cues (e.g., arrows, etc.), might have provided a level of de-contextualization for learners that did not strongly activate the MNS. Such lack of context has been shown to decrease activation of the MNS when viewing images that included hands (Iacaboni et al., 2005). Perhaps the inclusion of additional contextual information (e.g., arrows) could increase activation of the MNS, which would then potentially produce a higher degree of facilitation in the static conditions. This suggestion is consistent with behavioral research that has shown that static images that do contain signaling cues reduce (but do not eliminate) the animation advantage (Höffler & Leutner, 2007). Finally, although performance was also lowest in this condition overall, we would caution the conclusion that static illustrations are completely ineffective, largely because there was not a purely textual comparison condition included here.

Somewhat surprisingly, neither visuospatial abilities nor working memory capacity produced a substantial impact on developing understanding from visualizations overall. While quizzical, it is possible that the lack of such an effect may be due to the fact that variance normally attributed to these variables was already subsumed within, or accounted for by, those variables designed to manipulate MNS activation. If true, this represents a potentially exciting avenue for future research to explore whether this is indeed the case. In other words, is the MNS a perceptual component that interfaces with both the visuospatial and working memory systems to produce some of the positive effects normally attributed to these individual difference variables? Whether or not this is the case, it provides a unique opportunity to examine the interaction between the perceptual and cognitive systems.

The results of this study are important for several reasons for both educators and consumers of information. Nowadays, it is common practice to search any number of online video repositories (e.g., YouTube™) for animated or video examples of how to complete simple procedural tasks, from changing a bike tire to performing CPR. Similarly, formal job training is also being digitized at a rapid pace to realize staffing and logistical efficiencies (Driscoll, 2010). Further, this trend is not limited to desktop environments, and this information is often available and distributed on multiple platforms including mobile devices and other less traditional interfaces like tablets. This research confirms that animations are indeed best for this type of procedural learning task, and further, the ideal perspective for such media is that which will match the eventual perspective of the learner, namely OTS. This could be especially critical for the instruction of high-stakes procedural tasks such as those common in the medical field (i.e., surgery, first-aid, medical reprocessing) and other vital areas (i.e., shutting down a nuclear reactor, flying a plane) that require high degrees of accuracy and have a low tolerance for error. Creating effective media that maximizes the likelihood that a learner will understand information will not only reduce learning time, but also reduce the likelihood of error commission following training. This research presents confirmation of one important heuristic towards this goal of designing effective media.

While the current investigation was indeed limited to a desktop environment, it is possible that there might be additional moderating factors introduced by display on other platforms such as mobile devices. An interesting question is whether presentation on such devices fundamentally changes the nature of this heuristic, or instead represents a general attenuation of the effect due to simple factors such as display impoverishment due to illegibility, etc. All things being equal, it is assumed that this pattern of results would hold for most current computing platforms. However, this represents an intriguing opportunity for future research on whether more pervasive computing access equates to better or more efficient transmission of knowledge.

Finally, regarding general instruction, the results of this study also cast a cautious eye on traditional classroom instruction. In this traditional means of student–teacher interaction, which normally entails an instructor facing a group of students to demonstrate material, this research suggests that conveying material in this FTF way might not provide an optimal instructional experience for learners. This research thus also informs the development of better educational materials that most advantage learners in contexts that are not only online, but also in the classroom.

Future research on the topic should explore this pattern of results in other similar procedural motor tasks in order to assess the robustness of effects across material and extend findings found here into increasingly more complex procedural motor tasks, and perhaps into non-procedural content areas. For example, it would be interesting to see whether the relationship between MNS activation and animations holds in instances that are not procedurally based. Further, it would also be interesting to explore these effects across a mix of various skill levels (e.g., novice, moderate, expert) as it has been suggested that prior knowledge can also have a profound impact on the utility of animations and other visualizations (Hegarty & Kriz, 2008). Similarly, interactions with cognitive ability might also inform how the perceptual system interacts with the cognitive, and it would be of interest to determine whether this pattern of results holds for all learners, or instead interacts with experience level or ability.

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