Mental Rotation and Learning Procedural Motor Tasks from Instructional Media

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2012 by the
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May 2012

ABSTRACT

There have been conflicting accounts of animation's facilitation in learning from instructional media, being at best no different if not hindering performance. Procedural motor learning represents one of the few the areas in which animations have shown to be facilitative. These studies examine the effects of instructional media (animation vs. static), rotation (facing vs. over the shoulder) and spatial abilities (low vs. high spatial abilities) on two procedural motor tasks, knot tying and endoscope reprocessing. Results indicate that for all conditions observed in which participants engaged in procedural motor learning tasks, performance was significantly improved with animations over static images. Further, performance was greater for rotations of instructional media that did not require participants to perform a mental rotation under some circumstances. Interactions between Media x Rotation suggest that media that was animated and did not require a participant to mentally rotate led to improved performance. Individual spatial abilities were found to influence total steps correct and total number of errors made in the knot tying task, but this was not observed in the endoscope task. These findings have implications for the design of instructional media for procedural motor tasks and provide strong support for the usage of animations in this context.

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INTRODUCTION

The increasing accessibility and ease with which animations can be produced has created a boom in the adoption and usage of this medium when designing new learning media. Unfortunately, this rapid growth in technology has outstripped research on the efficacy of dynamic visualizations for learning over comparable static images (Chandler, 2004). When designing instructional media for safety critical tasks such as using a medical device, inefficiencies in learning can mean the difference between successful operations and errors that result in adverse consequences. Of particular concern is a critical evaluation of whether animations are indeed more effective than static images, and further, do these different medias interact with individual differences in spatial abilities to affect subsequent performance?

The notion that external visualizations can provide some efficacy over textual description via additional perceptual cues has been suggested many times (Larkin & Simon, 1987; Tufte, 2001). Whereas there is some evidence suggesting that animations do not facilitate learning (Bouchiex & Schneider, 2009; Hegarty, Kriz & Cate, 2003; Mayer, Hegarty, Mayer & Campbell, 2005; Tversky, Morrison & Betrancourt, 2002), numerous other studies have found that animations can indeed enhance learning under certain constraints. For example, animations have been shown to be more effective than static representations for the acquisition of process knowledge in cell biology (Müzer, Seufert, & Brünken, 2009), learning chemistry concepts (Flavio & Suits, 2009) and earth science learning for individuals with low spatial abilities (Sanchez & Wiley, 2010). However, what leads to this disparity in findings regarding the effectiveness of animations for learning?

One potential explanation for the conflicting accounts of when animations are effective has been to examine the interactivity of the medium. In other words, if participants are better able to control the speed or presentation of the animation, perhaps this will maximize their benefit? Schwan and Riempp (2004) conducted a study using interactive and non-interactive controls for animations designed to instruct users how to tie nautical knots. This study found that this interactivity (or ability to control the animation) did in fact lead to an enhancement of performance over animations that were non-interactive, though there was no comparison to simple static images (Schwan & Riempp, 2004). Although compelling, unfortunately there are other studies which suggest that interactivity need not play a central role when considering the effectiveness of animations.

Procedural Motor Learning

For example, Wong et al. (2009) compared static and animated presentations for a procedural motor task, and found that though procedural motor learning tasks are indeed facilitated via animations in comparison to static images, interactivity was not necessarily critical for improving performance. This suggests that perhaps interactivity is not the critical key to constructing animations that benefit learning. As such, it is likely that other factors are more relevant when determining what makes animations effective.

Another potential suggestion is that animations are particularly well suited for specific 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 if the task involves procedural motor learning. For example, a study on procedural learning of basic first aid from instructional media found that animations produced better learning than static images (Arguel & Jamet, 2009). Similarly, Ayres, Marcus, Chan, and Qian (2009) found that when observing instructional animations of procedural motor tasks, performance was higher than when only observing static images. Further, in a second experiment which required participants to reassemble a series of metal puzzle rings after watching either an animated or static instructional demonstration of the rings being disassembled, again a facilitation of animations was found in this reverse condition in terms of assembly performance and also for non-manipulative measures like recognizing next or previous steps.

What is it about procedural motor learning tasks that make them so amenable to animated presentations? It has been proposed that when human movement is observed it activates mirror motor systems, which provides some kind of processing support for the learning of these tasks (Ayers et al., 2009; Chandler, 2009; Wong et al., 2009). Related to this notion of processing load, it is possible that individuals who are less able to manage visuospatial information are also more likely to benefit from such animated content. In other words, it is not merely the limitations of the instructional media or content alone that dictate learning from animations, but also the capabilities of the learner themselves.

Spatial Abilities and Learning from Animations

Interpreting and understanding external visualizations places demands on spatial abilities in terms of both spatial orientation (i.e., the ability to imagine the appearance of objects from different perspectives), and spatial visualization (i.e., imagining the movement/change of objects; see Hegarty & Waller, 2005). Individual differences in spatial abilities are well documented and have been shown to be predictive of performance in comprehension of mechanical systems (Hegarty, Kriz & Cate, 2003), in how well animations are utilized of animations in inferring cross sections in a three dimensional object (Cohen & Hegarty, 2007) and correlated with how frequently task relevant views were accessed (Keehner, Hegarty, Cohen, Khooshabeh, & Montello, 2008). There is also evidence of a dissociation between the manner of object-based transformations abilities and one's ability to make egocentric spatial transformations (Hegarty & Waller, 2004).

These results suggest that learning about any spatial phenomenon should be dependent on the learners' inherent spatial ability. Performance for a given task that places demands on learners' inherent spatial ability (i.e. procedural motor learning task) will vary based on individual differences in spatial ability, as those with higher spatial abilities should on average display improved performance over those with lower spatial ability.

Although spatial abilities could play an important role in learning procedural motor tasks they are not the only cognitive capacity tapped during learning from instructional media. In order to parse out the contribution of spatial abilities to these tasks from more general cognitive processes, it behooves us to examine the role of working memory capacity as another factor in learning from instructional media.

Working Memory Capacity

Working memory capacity (WMC) represents a stable individual difference in the ability to store and process information simultaneously (Baddeley & Hitch, 1974; Conway & Engle 1994). Importantly, these span differences are not a result of the total amount of activation available, but rather the need to engage in controlled focusing of attention (Conway & Engle, 1996). Critically, those with higher WMC are able to focus attention in interference rich conditions that would otherwise impede performance, allowing WMC to be used to predict encoding and retrieval success in spite of proactive interference (Conway, Kane & Engle, 2003).

WMC has been found to be highly correlated with reading comprehension measures (Daneman & Carpenter, 1980), science learning (Sanchez & Wiley, 2006), attentional control (Conway & Engle, 1994) and has been widely used across the discipline of psychology as a useful predictor of human performance (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005). WMC was used here as a covariate to control for individual differences in cognitive abilities and general intelligence (Conway, Kane, & Engle, 2003).

Objectives

The proposed studies examine performance on two procedural motor tasks; a knot tying task, and the simulation of the manual cleaning portion of an endoscope reprocessing procedure. Across these tasks, instructional presentations were manipulated between participants in terms of the type of media (animated vs. static) and the spatial perspective of the media (as though they were facing someone performing the task vs.as though they were observing someone perform the task from over their shoulder).

Hypothesis

It is hypothesized that for participants engaged in procedural motor learning tasks performance, as measured by total time to completion, number of errors made, and successful steps completed, will improve more so with animations than static images, resulting in faster time, fewer errors and more steps correct, as animations have been shown to provide facilitation in procedural motor tasks. Further, performance will be similarly improved for orientations of instructional media that do not require participants to perform a mental rotation than orientations that require a mental rotation. Similarly, performance of participants with higher spatial reasoning scores should also be greater under such conditions, than the performance of those with lower spatial reasoning scores.

The implications of this study include potential interventions in the design and implementation of instructional techniques for complex procedural motor tasks, improvements to the endoscope manual cleaning procedure, in addition to a greater understanding of the role the spatial orientation of instructional media has in learning from animations and procedural learning tasks.

EXPERIMENT 1

The first experiment consists of a knot tying task similar to those conducted by Schwan and Riempp (2004) and Ayers et al. (2009). Participants were asked to complete various nautical knots following the viewing of an instructional media (animated vs. static). However, the instructional media's spatial orientation were also manipulated such that it requires the participant to observe the procedure as though they were facing someone performing the task or as though they were watching over the shoulder of the individual performing the task.

Method

Participants

Eighty participants were drawn from the ASU CS&E participant pool. Participants were evaluated on their prior experience with nautical knot tying before participation and excluded from the study if they reported experience. All participants were compensated with course credit in an introductory psychology class.

Materials

Initial Survey. All participants completed a survey recording demographic information.

Spatial Abilities Assessment. All participants completed 2 measures of spatial ability: the Surface Development task (VZ-3) and Cube Comparisons task (S-2; French, Ekstrom & Prince, 1963).

Instructional Media. All participants studied a selection of instructional media detailing the knot tying procedure broken down into its four component steps. Based on assignment, this either consisted of an animation or a series of static images whose progression is controlled by the participant. Both animations and static images contain equivalent information necessary to successfully complete the task, as the static images are taken from screen shots of the videos. Each animation was approximately 30 seconds, consisting of either perspective condition rotated (e.g., Figure 1) or non-rotated (e.g., Figure 2). Participants were given two minutes to study the instructional material before being asked to tie the knot shown. Participants then repeated this procedure with the remaining 5 knots, whose order was randomized within subjects.

Additionally, the orientation of the instructional media was manipulated between participants. Participants were either given a view corresponding to watching the task being performed as though they were facing someone else (e.g. Appendix A, Figure 1) or as though they were watching the task over the shoulder of the individual performing it (e.g. Appendix A, Figure 2). Each participant viewed all instructional media from only one perspective.

WMC Assessment. All participants working memory capacity was assessed using an automated version of the Operation Span task originally developed by Turner and Engle (1989) (AOSPAN) which requires participants to complete simple mathematical problems while also remembering an irrelevant word (Unsworth, Heitz, Schrock & Engle, 2005). Criteria for evaluating participants scores followed recommendations made in Conway et al. (2005). AOSPAN measures were collected in a separate half-hour session.

Procedure

Participants individually completed the task with the experimenter observing. Participants were given 20 minutes to complete the initial survey and spatial abilities tasks. Upon completion they were directed to a computer terminal displaying the instructional media and asked to study the material detailing the procedure before completing the steps themselves. Each of the 6 knots was broken into 4 steps. Participants were then be given 2 minutes to study the instructional material for each knot, and 2 minutes to complete the knot before being asked to move onto the next trial, for a total of 24 minutes. After completion, participants were debriefed and dismissed. Participants completed the WMC assessment in a separate half-hour session.

Design

The experiment is a 2 x 2 design with perspective rotation (rotated vs. non), and instructional media (animation vs. static) as between subject factors influencing knot tying performance. Spatial ability and WMC were used as continuous predictors within each of these conditions.

Results and Discussion

Participant's performance was assessed by an expert coder utilizing videos from participants knot tying task trials. Task performance was measured in the following ways: total time to completion, number of errors made, and number of successful steps completed. To test whether the rotation of the media and instructional media differed, an ANCOVA [between-subjects factors: media (static, video), rotation (over the shoulder, face-to-face); covariates: WMC, Spatial abilities] was performed for each of these performance metrics. Three knots were selected for this analysis based on highest correlation to one another across DVs, the constrictor knot, cow hitch and clove hitch.

Only the surface development task was used as a spatial abilities measure, as the cube rotation task was found to be non significant across all trials. The surface development task is a measure of how well an individual mentally folds an object into a whole figure, which is directly relevant to the physical folding of rope into a knot. In contrast the cube rotation spatial assessment did not add to the model and obscured the impact of the more task relevant surface development assessment (see Figure 1). As such, results reported here only include the surface development measures, and not the cube rotations measures. Overall descriptive statistics are presented in Table 1.

Media and rotations effects on time to completion

Overall time to completion indicated significant main effects for media (video, static) $F(1, 73) = 34.74$, $p < .001$, $MSE = 6084.10$ $\eta_P^2 = .33$, such that participants in the video conditions completed the task significantly faster than those given static images (see Figure 3). A significant main effect for rotation was also observed $F(1, 73) = 9.14$, $p = .003$, MSE = 6084.10 $\eta_P^2 = .11$, with performance on the over the shoulder condition yielding faster total completion times than those in the face-to-face condition (see Figure 4). The interaction between media and rotation was also significant, $F(1, 73) = 5.99$, $p = .017$, $MSE = 6084.10$, $\eta_P^2 = .08$, video participants in the over the shoulder (OTS) video condition outperformed participants in all other conditions. A similar improvement for video in the face (FTF) condition was observed, but it was not as pronounced as video and OTS. Participants in static OTS and FTF conditions were nearly equivalent (see Figure 5).

However non significant main effects were observed for spatial abilities $F(1, 73) = .67$, $p > .05$, $MSE = 6084.10$,$\eta_P^2 = .01$ and WMC $F(1, 73) = 1.39$, $p > .05$, $MSE = 6084.10$, η_P^2= .02 this suggests that differences between participants' general cognitive abilities did not contribute to how quickly participants were able to complete the knots (see Figure 2).

Effects of media conditions and spatial abilities on errors

For Total errors there was a significant main effect for media $F(1,73) = 36.85$, $p < .001$, $MSE = 57.01$, $\eta_P^2 = .34$, with fewer errors made across video conditions than the static conditions (see Figure 6). However, there was a non significant main effect for rotation (over the shoulder, face) *F*(1,73) = 1.07, $p > .05$, *MSE* = 57.01, $\eta_P^2 = .01$. However, a significant interaction between media and rotation was observed *F*(1,73) = 4.99, $p < .05$, *MSE* = 57.01, $\eta_P^2 = .06$. As in the total time condition, performance for OTS x video resulted with the fewest errors and video x FTF resulted in fewer errors. Interestingly OTS x static produced more errors than static x FTF, suggesting that although the OTS perspective is easier to take advantage when given video stimuli, but detrimental when given static images. (See Figure 7.)

There was also a significant main effect for spatial abilities *F*(1,73) = 4.65, $p < .05$, *MSE* = 57.01, $\eta_P^2 = .06$, suggesting that those with higher spatial abilities committed fewer errors. However, WMC was not a significant predictor of errors *F*(1,73) = .13, $p > .05$, *MSE* = 57.01, $\eta_P^2 = .00$, suggesting that participants were not due to general cognitive ability.

Effects of media, rotation and spatial abilities on total steps correct

For total steps correct again a significant main effect for media was observed (video, static) *F*(1,73) = 56.70, $p < .001$, *MSE* = 4.97, $\eta_P^2 = .44$, supporting the superiority of animated media over static images (Figure 8). A significant main effect for spatial abilities *F*(1,73) = 6.85, $p < .01$, *MSE* = 4.97, $\eta_P^2 = .09$, with high spatial individuals able to mentally manipulate the instructional media more effectively leading to increased steps correct.

A significant main effect for rotation was also observed (over the shoulder, face) *F*(1,73) = 5.38, $p < .05$, *MSE* = 4.97, $\eta_P^2 = .07$, with the over the shoulder view resulting in greater numbers of steps correct than the face to face condition (see Figure 9). WMC was again not a significant predictor *F*(1,73)= 2.21, $p > .05$, *MSE* = 4.97, $\eta_P^2 = .03$, suggesting that general cognitive capacity did not contribute to differences between conditions.

Interestingly a non significant interaction between media and rotation was also observed $F(1,73) = 1.04$, $p > .05$, $MSE = 4.97$, $\eta_P^2 = .01$, suggesting that there was no differential benefit for different media across rotation conditions (see Figure 10).

In sum, as expected significant differences between instructional media (animation vs. static) were observed, with animations yielding improved performance vs. static media across all DVs, consistent with findings in the literature (Ayers et al. 2009; Wong et al. 2009.).

The hypothesized ease with which participants would learn from the over the shoulder view was observed for total time to completion, and total steps correct. Interestingly the main effect for rotation was not observed for the number of errors, however an interaction between Media x Rotation was observed in this condition which may have obscured such a main effect. As expected the over the shoulder view yielded improved performance over the facing view in video conditions. However in static conditions OTS was nearly equivalent to the FTF condition in terms of time to completion and OTS perspective actually lead to an increased number of errors. This facilitation in video is likely due to decreased demand placed on spatial abilities by not needing to mentally rotate the materials. However in the static presentation the two images are nearly of equivalent difficulty, and the familiar OTS condition leading to increased errors over the rotated FTF is puzzling, as facilitation was expected.

A significant effect for spatial abilities (low vs. high) was hypothesized, with individuals with high spatial abilities yielding improved performance over low spatial ability individuals, and this was observed in the total error and total steps correct DVs.

EXPERIMENT 2

The second experiment represents an extension of the first experiment into a more complex procedural motor task endoscope reprocessing. Manual cleaning an endoscope (i.e. reprocessing) involves the insertion of brushes through various channel ports throughout the endoscope. Following this the channels are flushed with enzymatic cleaner and then water, in order to remove debris and potential contaminants (Rutala & Weber, 2004). Participants were asked to complete the flushing portion of the manual cleaning task following the viewing of an instructional media (animation vs. static), however again, as in the first experiment, perspective of the media was also be manipulated (as though they were facing someone performing the task vs. over the shoulder of an individual performing the task)

Method

Participants

Twenty participants who did not participate in Experiment 1 were recruited from the ASU CS&E subject pool, five per experimental condition (rotation, non rotation, animation, and static). Participants were excluded from participation in this study if they demonstrated prior experience reprocessing medical devices or had other experience with the endoscopes. Participants were compensated with course credit in an introductory psychology class.

Materials

Initial Survey. All participants were required to complete a survey recording demographic information.

Spatial abilities assessment. Participants completed the same spatial ability measures as Experiment 1

Instructional Media. All participants observed a piece of instructional media detailing a portion of the manual cleaning section of the endoscope reprocessing procedure broken down into component steps. Depending on experimental group this either consisted of an animation or a static image displayed on a website whose progression is controlled by the participant. The rotation of this media was also manipulated either over the shoulder (Appendix A Figure 3) or as though they were facing another person (Appendix A Figure 4) Participants were allocated 2 minutes and 30 seconds per each segment to study the instructional material before being asked to complete the step shown within another 2 minutes and 30 seconds. Order was not randomized in order to simulate actual endoscope reprocessing. As in Experiment 1, this media was either from a rotated perspective or not.

WMC Assessment. Participants completed the same AOSPAN measures as in Experiment 1 during a separate half-hour session.

Procedure

Several slight modifications to the first experiment were made due to an increase in task complexity. Experimental participation was conducted individually with an experimenter filming. As in Experiment 1, participants were given 20 minutes to complete the initial survey and spatial abilities assessments. Upon completion participants were given a brief overview of the use and handling the endoscope and one minute to familiarize themselves with the endoscope and its components including the materials required to perform the task. Participants were then asked to put on a smock and gloves to simulate what is actually warn during endoscope reprocessing and to prevent the participant from getting wet during the experiment.

Participants were then directed to a computer terminal displaying the instructional media and asked to study the material detailing the procedure before completing the steps themselves. The reprocessing procedure was broken down into five stages, each consisting of five steps. Participants were then given 2 minutes 30 seconds to study each stage and 2 minutes 30 seconds to complete them before moving onto the next, for a total of 28 minutes. These stages were not randomized in interest of simulating the actual reprocessing procedure. Participants were then debriefed. Participants completed the WMC assessment in a separate half-hour session.

Design

The experiment was run as a 2 x 2 design with rotation (over the shoulder vs. face to face) x instructional media (animation vs. static) as between subjects factors on performance on the endoscope manual cleaning task. Spatial abilities measures and WMC were used as a continuous predictor within each of these conditions.

Results and Discussion

Participant performance was examined using the same analyses in the first experiment. Task performance was measured in the following ways: total time to completion, number of errors made, and number of successful steps completed. To test whether the rotation of the media and instructional media differed, an ANCOVA [between-subjects factors: media (static, video), rotation (over the shoulder, face-to-face); covariates: WMC, Spatial abilities] was performed for each of these performance metrics. This study was expected to be a direct replication of the findings observed in the first study, however that was not the case across all conditions. The flushing water through the channel ports task was omitted from analysis due to perfect success rate across conditions. As in experiment 1 the cube rotation task was omitted and only the surface development task was used. For descriptive statistics consult Table 2.

Effects of media conditions on time to completion

For overall time to completion there was a significant main effect for media (video, static) $F(1, 11) = 23.42$, $p < .001$, $MSE = 6959.755$, $\eta_P^2 = 680$ corroborating findings in Experiment 1, that video was superior to comparative static images in influencing how quickly participants finished (see Figure 13).

A non significant main effect was observed for rotation (Over the shoulder, Face) $F(1, 11) = .05$, $p > .05$, $\eta_P^2 = .01$, in contrast to findings in the first experiment. Non significant main effects were also found for spatial abilities $F(1,11) = .01$, $p > .05$, $MSE = 6959.76$, $\eta_P^2 = .00$ (see Figure 11) and WMC $F(1,11) = .24$, $p > .05$, $MSE = 6959.76$, $\eta_P^2 = .00$ (see Figure 12). As in the first experiment a significant interaction between Media x Rotation was also observed, $F(1,11) = 12.24$, $p <.01$, $MSE = 6959.76$, $\eta_P^2 = .53$, video resulted in faster time to completion measures across rotations, however in this experiment video in the FTF rotation resulted in faster time to completion than OTS (see Figure 14).

The effects of media on total errors

The analysis of total errors indicated a significant main effect for media (video, static) $F(1, 11) = 23.96$, $p < .01$, $MSE = 32.49$, $\eta_P^2 = .69$, consistent with findings in Experiment 1 of videos superiority over comparable static images (see Figure 15). Non significant main effects were observed for rotation $F(1, 11) = .28$, $p > .05$, $MSE = 32.49$, $\eta_P^2 = .03$, consistent with findings in Experiment 1. Surprisingly there was also a non significant effect for spatial abilities $F(1,11) = .03$, $p < .05$, $MSE = 32.49$, $\eta_P^2 = .00$, and WMC $F(1,11) = .58$, $p < .05$, $MSE = 32.49$, $\eta_P^2 = .05$. In contrast to Experiment 1 the interaction between media and rotation was also non significant, $F(1,11) = .01$, $p > .05$, $MSE = 32.49$, $\eta_P^2 = .00$, suggesting that rotation and media were not interrelated in how they impacted the number of errors made (see Figure 16).

Effects of media on total steps correct

The analysis of total steps correct indicated significant main effects for media (video, static) $F(1, 11) = 12.13$, $p = .005$, $MSE = 1.93$, $\eta_P^2 = .52$, consistent with findings in Experiment 1 of the superiority of video to static (see Figure 17). Non significant main effects were observed for rotation $F(1, 11) = .01$, $p > .05$, $MSE = 1.93$, $\eta_P^2 = .00$, spatial abilities $F(1,11) = .19$, $p > .05$, $MSE = 1.93$, $\eta_P^2 = .017$ and WMC $F(1,11) = .15$, $p > .05$, $\eta_P^2 = .01$. The interaction between media and rotation was also non significant, $F(1,11) = .00$, $p > .05$, $MSE = 1.93$, $\eta_P^2 = .00$ (see Figure 18).

However there was a violation of homogeneity of variance assumption indicated by significant Levene's test $F(3, 13) = 9.494$, $p < .001$ this is likely attributable to non-equal group sizes across conditions. Windsor, logarithmic and inverse transformations were applied, but heterogeneity of variance remained. This is likely attributable to low sample (n=3) size in the face static condition. However, given the consistent pattern of results, the superiority of video over static is not likely an artifact of the violation of assumptions.

A significant effect of instructional media (animation vs. static) was expected and observed across all dependent variables, with animation yielding improved performance vs. otherwise equivalent static media as consistent with findings in the literature (Ayers et al. 2009; Wong et al. 2009).

A significant difference for orientation (facing vs. over the shoulder) was expected, with the over the shoulder perspective resulting in significantly better performance, however this was not observed in any of the DVs.

A significant main effect for spatial abilities (low vs. high) was also expected, such that individuals with high spatial abilities would demonstrate improved performance over low spatial ability individuals, however this was not borne out. This is likely due to low sample size resulting in diminished power of this analysis as there were particularly few individuals in the static conditions due to having several participants excluded from this study due to familiarity with the device and failure to follow instructions. Furthermore, unlike the rope in Experiment 1, an endoscope is not an ambiguous device; the surface development spatial measure used in assessing how well an individual can mental fold an object may be task irrelevant here. Non significant results were also found when the cube rotation task was implemented in its place, as a more general measure of mental rotation.

The lack of finding a significant interaction between spatial abilities vs. instructional media follows from the findings in experiment one. Oddly the observed interaction identified in the 1st experiment between Media x Rotation was only present in total time DV and unexpected in the fact that it is the opposite of Experiment 1, that animations and of the face condition were more effective than the over the shoulder view. In contrast the static conditions effectively replicates the first experiment finding that OTS is superior to the FTF.

This again supports the superiority of videos influence on time to completion. Interestingly the efficacy of the face rotation compared to the over the shoulder condition influence on the instructional may have been influenced by the task. Unlike the knots in experiment one the manipulation of an endoscope is not ambiguous as a piece of rope and there are specific lockouts where components attach. Peculiarly the view that is not equivalent to actual use of the device was found to be most useful. However with the small sample size this finding may be an artifact of having few participants in the static conditions.

GENERAL DISCUSSION

These experiments have demonstrated the superiority of animation over equivalent static images for procedural motor learning, consistent with findings from the literature (Ayers et al., 2009; Höffler & Leutner, 2007; and Wong et al., 2009). Differences between the two tasks studied aimed at parsing out how well this facilitation from animations differs with the complexity of differing procedural motor tasks and if the claims made could be extended to more applied environments in the case of endoscope reprocessing. Additionally both experiments were designed to assess only human motor actions impact on procedural motor learning addressing findings from Tyversky et al. (2002) and Hegarty, Kriz and Cate (2003) of the lack of facilitation of animation in non human mechanical systems.

The significant main effects from Experiment 1 of rotation influencing total time to completion and total steps correct DVs suggest that presenting a perspective that is the same as the participant removes some of the burden associated with manipulating the materials. Furthermore this manipulation of the instructional medias was mental, none of the participants physically rotated the knots to be in line with the presentation they were given in the face condition. As to what cognitive processes are implicated in this rotation task remains unknown, as unexpectedly there were non significant interaction with any of spatial or cognitive measures assessed. The second study is at odds with this conclusion, and likely erroneously so due to the small sample size and weak power, and unlike a piece of rope, perspective when examining an endoscope is far less ambiguous, controls are specifically designed to be operated and interacted with from one perspective.

The significant interaction in Experiment 1 between Rotation x Media for total steps correct and total errors, was an unexpected finding, as was the lack of the expected significant interaction between Media x Spatial Abilities. Essentially to facilitate task speed and mitigate errors it is essential to design instructional media that replicates the individual performing the task in full motion. Interestingly when a non-motion OTS perspective is given errors are actually worse than the comparative FTF view. What changes between the two perspectives influencing this spike in errors that is otherwise facilitative remains in question. The conflicting finding in Experiment 2, the significant Rotation x Media interaction, is likely an artifact of low sample size and low power, but may suggest that there are task dependent differences in what perspectives are facilitative.

Finding a non significant contribution of WMC across all conditions examined is at odds with the hypothesized explanation by Wong, et al. (2009) of a conjectured linkage between the working system and mirror neuron systems contributing to the facilitation of procedural motor learning through animation. Results from Experiment 1 suggest instead that task relevant spatial abilities are a significant component in how individuals correctly learn and execute a procedural motor task.

The lack of findings in Experiment 2 may be due to the irrelevance of spatial abilities measure to the task, or perhaps due to the unexpected ease of the task as the device was less ambiguous than knots. Whether the underlying reason for such facilitation is a mirror motor system remains inconclusive and is beyond the scope of this study to answer, but it is clear that spatial abilities play a role in successful utilization of instructional media for procedural motor tasks.

These studies provide a basis for further support of animation’s facilitation in the learning of procedural motor tasks, over similar static images, consequently influencing training and informing design of instructional materials for such tasks. By addressing issues in training and instructional materials in safety critical procedural motor tasks a significant reduction in errors is also possible. Furthermore one should consider the orientation of the instructional media to minimize the demands placed on individuals. It behooves the instructional media designer and researcher to consider the spatial abilities of the learner when implementing and assessing new designs, particularly in the case of procedural motor tasks of a safety critical nature.

Future research on the topic will contribute to the replication 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. Subsequent studies addressing a more generalized sample featuring a mix of users of various skill levels (e.g., novice, moderate, expert) would allow for inferences about the general population and assessing differences in task performance and learning style based on experience to be made.

This study forms a basis for further research on usability interventions in endoscope reprocessing with higher fidelity instructional media explicitly designed to take advantage of the procedural motor demands inherent within the task being the next logical step. Likewise an assessment of the errors and correct steps findings could influence interventions to design of future endoscopes and similar reusable medical devices, reflecting errors identified in usability testing in both cleaning and practitioner usage. Expansion into research in other safety critical systems and tasks that are reliant on procedural motor tasks also represent a wide area of research.

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TABLES

Table 1

Experiment 1 Descriptive Statistics

Dependent Variable: Total Time to Completion (seconds)

Rotation	Media	Mean	SD	n
OTS	Static	286.632	74.887	19
	Video	148.8	73.612	20
	Total	208.769	106.192	39
FTF	Static	290.6	62.551	20
	Video	226	100.505	20
	Total	258.3	88.867	40
Total		467.069	195.059	79

Dependent Variable: Total Errors

Rotation	Media	Mean	SD	n
OTS	Static	20.68	9.34	19
	Video	6.1	5.4	20
	Total	13.21	10.51	39
FTF	Static	17.8	8.5	20
	Video	10.95	7.64	20
	Total	14.38	8.7	40
Total		27.59	19.21	79

Dependent Variable: Total Steps Correct

Rotation	Media	Mean	SD	n
OTS	Static	6.11	2.81	19
	Video	10.65	1.9	20
	Total	8.44	3.29	39
FTF	Static	5.85	2.32	20
	Video	9.3	2.72	20
	Total	7.58	3.05	40
Total		16.02	6.34	79

Table 2

Experiment 2 Descriptive Statistics

Dependent Variable: Total Time to Completion (seconds)

Rotation	Media	Mean	SD	n
OTS	Static	523	79.586	4
	Video	465	74.956	5
	Total	490.778	78.223	9
FTF	Static	665.333	113.072	3
	Video	314	53.084	5
	Total	445.75	195.771	8
Total		936.528	273.994	17

Dependent Variable: Total Errors

Rotation	Media	Mean	SD	n
OTS	Static	19.5	5.92	4
	Video	5.4	4.4	5
	Total	11.67	8.85	9
FTF	Static	18	9.53	3
	Video	1.6	1.67	5
	Total	7.8	9.98	8
Total		19.42	18.83	17

Dependent Variable: Total Steps Correct

Rotation	Media	Mean	SD	n
OTS	Static	5.85	2.32	4
	Video	9.3	2.72	5
	Total	7.58	3.05	9
FTF	Static	6.11	2.81	3
	Video	10.65	1.9	5
	Total	8.44	3.29	8
Total		16.02	6.34	17

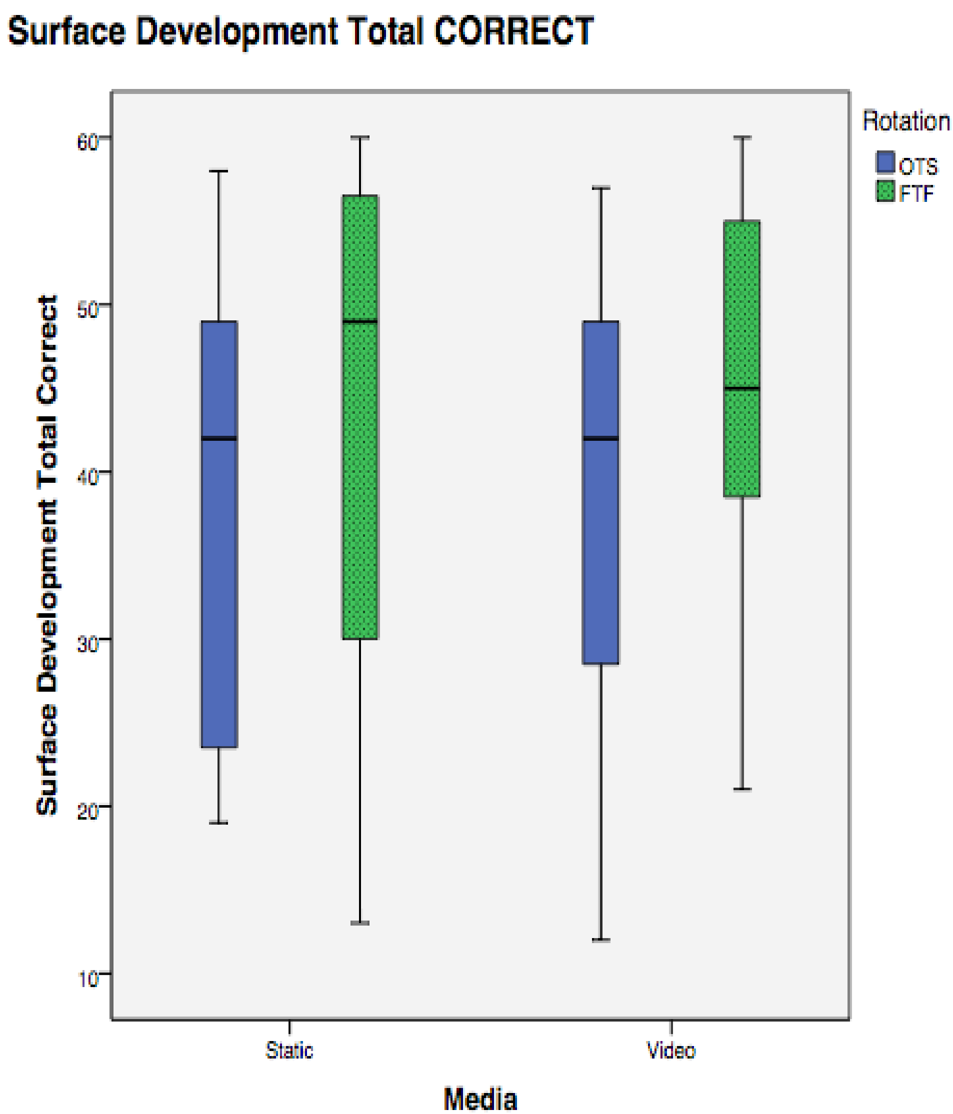

Figure 1. Surface development total correct scores representing participants spatial abilities for each target category. A significant difference was found in the total errors and total steps correct, but not the total time to completion task.

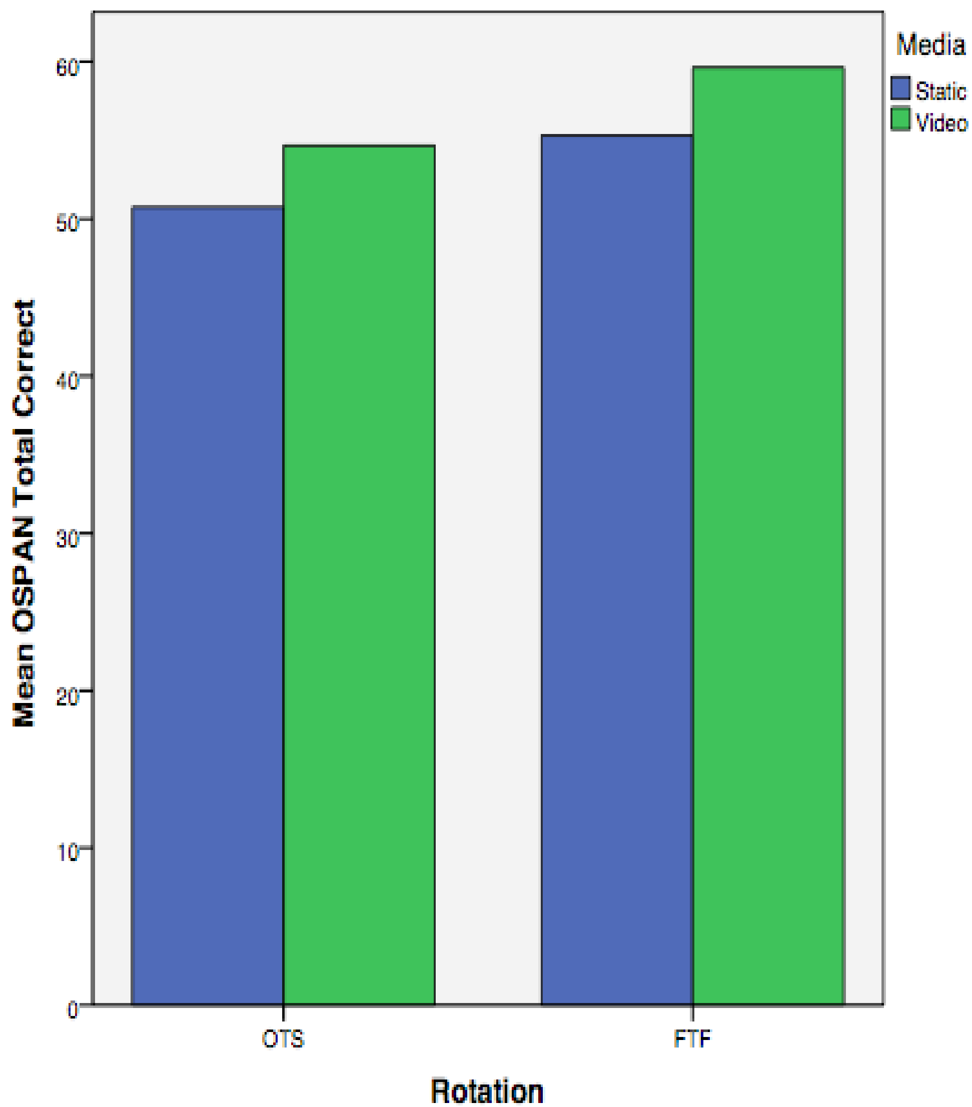

Figure 2. Mean values for the OSPAN working memory capacity test representing WMC for each target category. No significant difference was found in any dependent variable assessed.

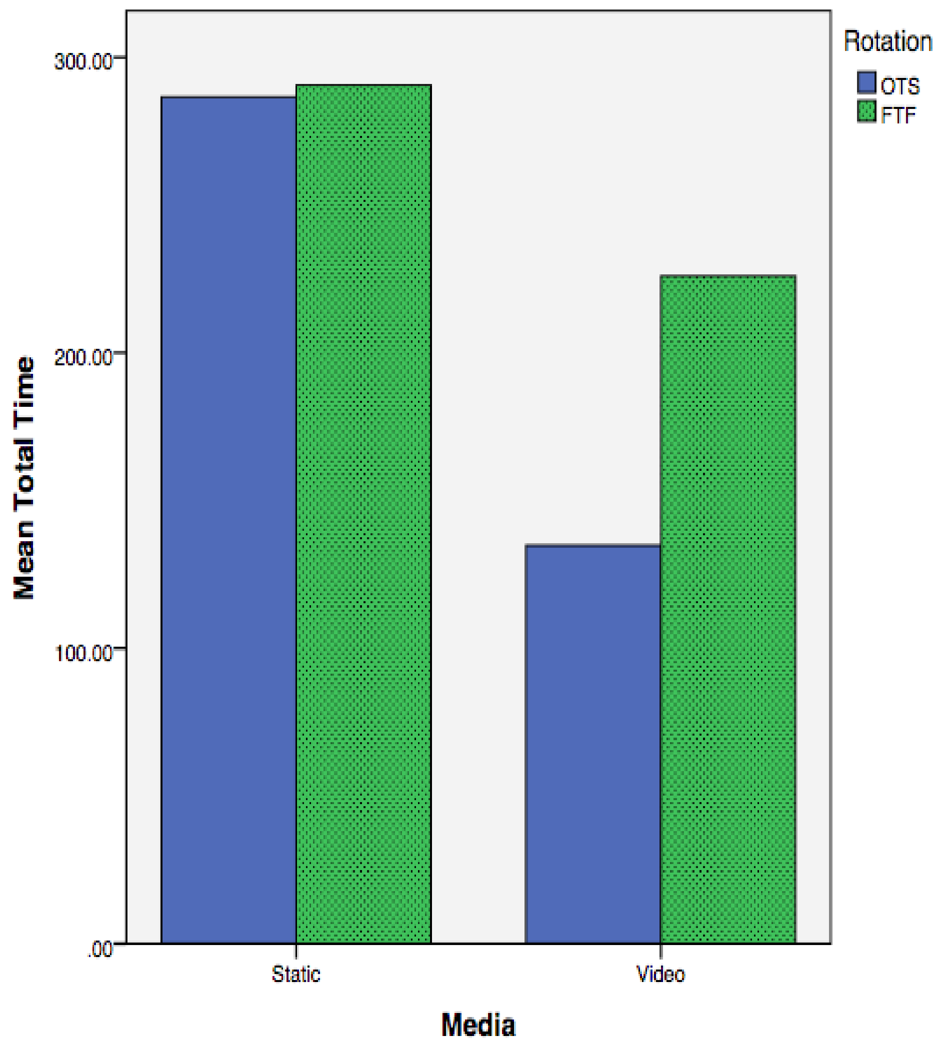

Figure 3. Mean total time values (seconds) for overall knot completion across target conditions. A significant difference was found for type of media, with video resulting in faster performance than static across conditions.

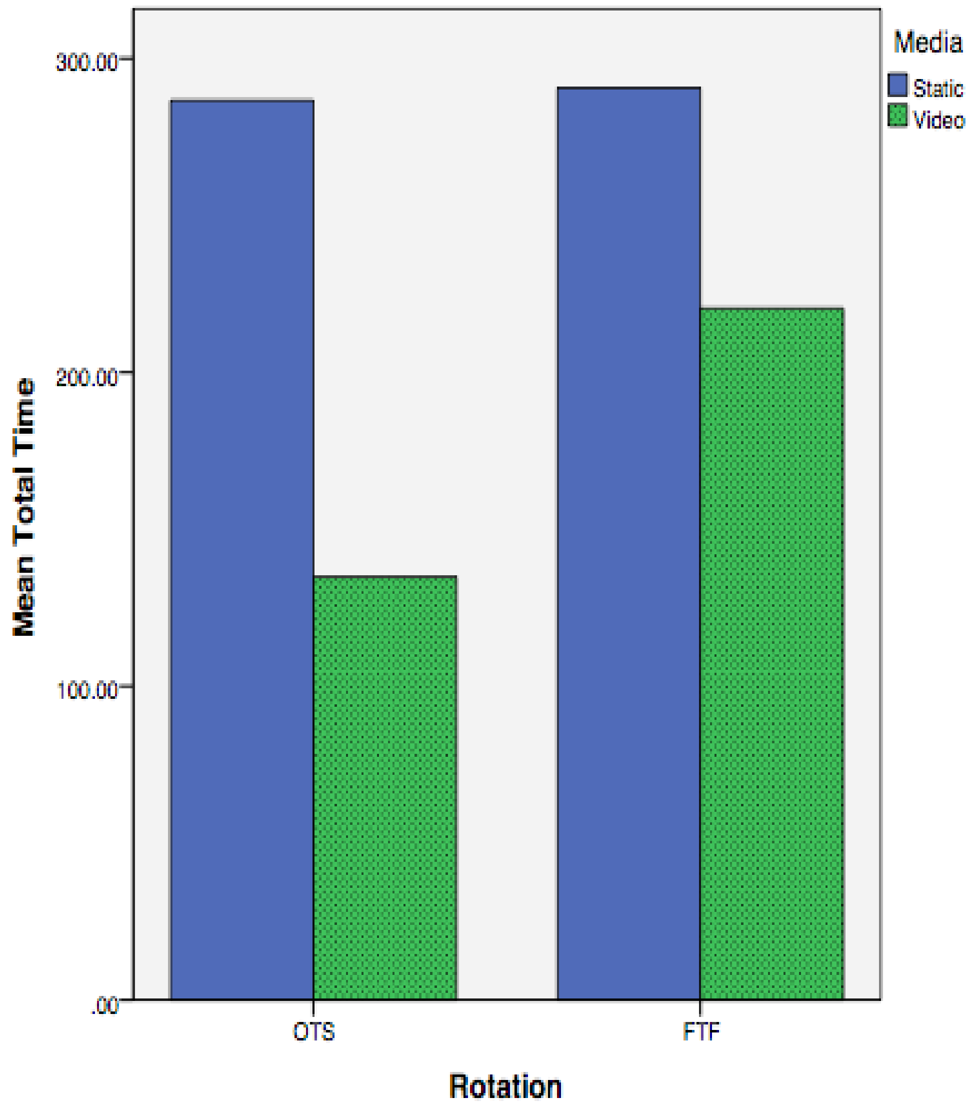

Figure 4. Mean total time values (seconds) for overall knot completion across each category. A significant difference was found for type of rotation, with OTS resulting in faster performance than FTF.

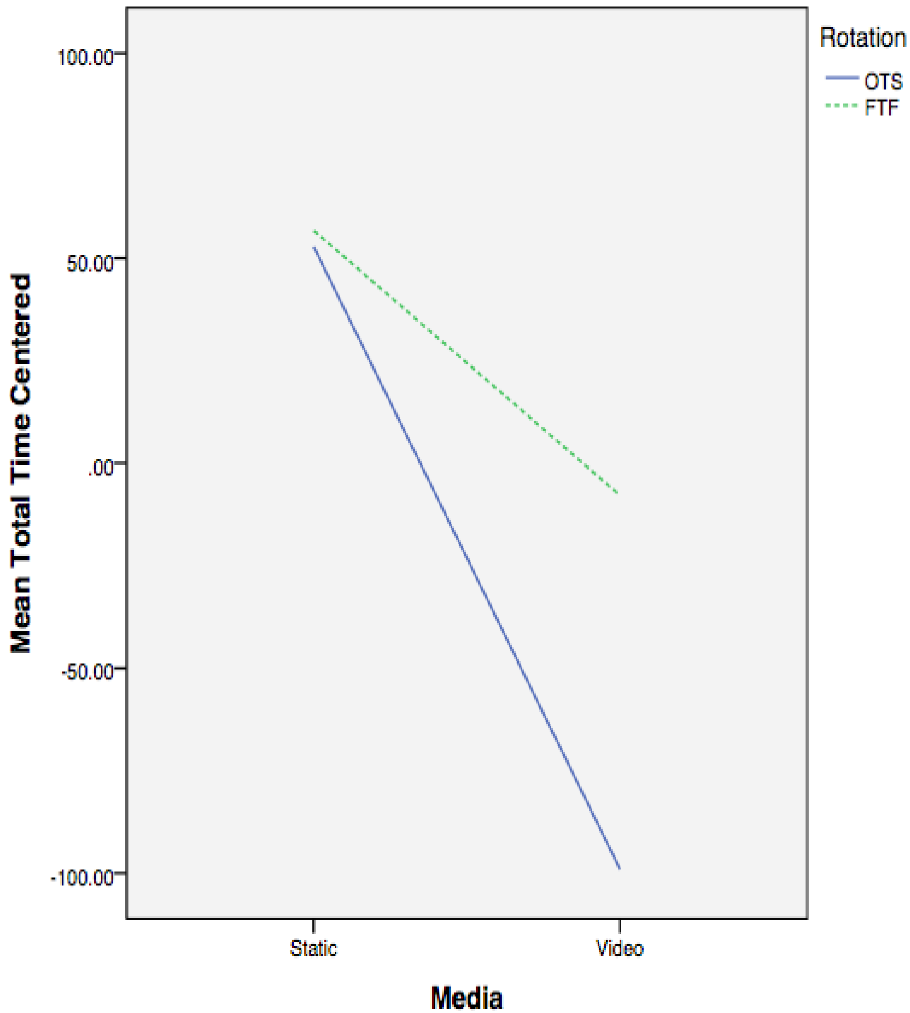

Figure 5. Mean total time value (seconds) that were subsequently centered, representing total time to completion across categories and the influence of Media on Rotation. A significant interaction between Media x Rotation, where video results in better performance across rotation conditions, but with static conditions approaching nearly the same with as slight improvement of OTS over FTF.

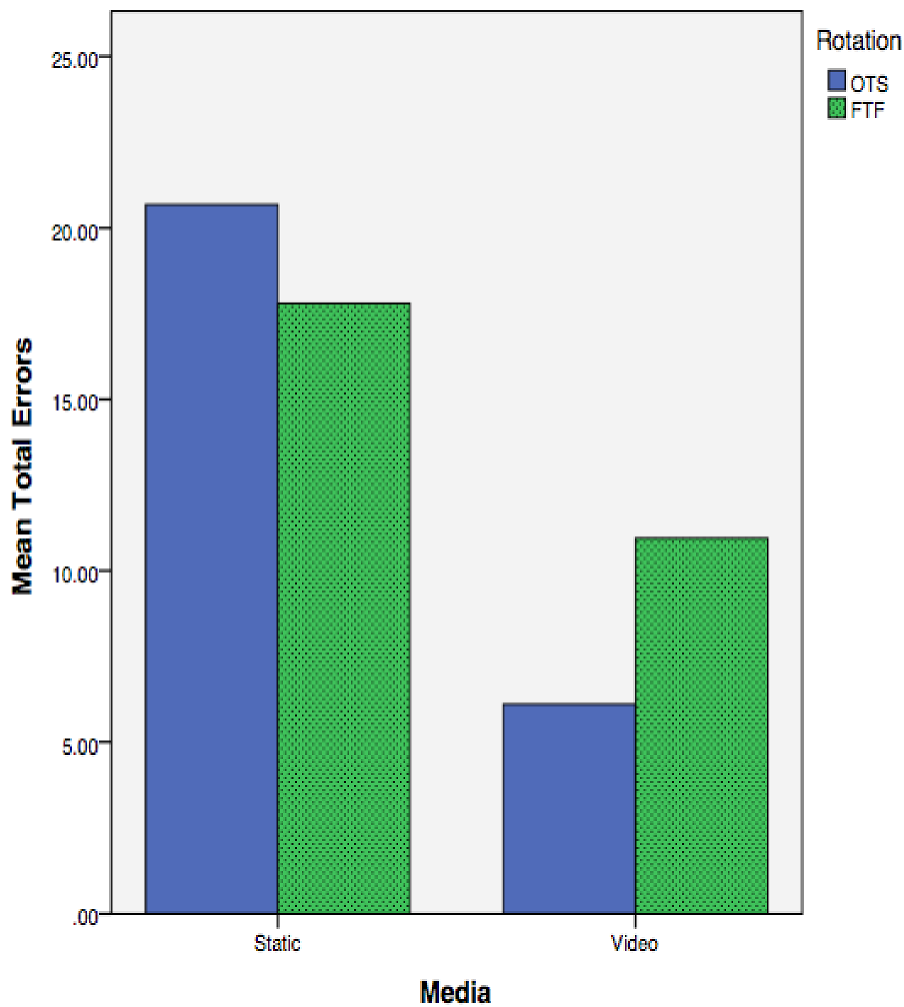

Figure 6. Mean total errors representing total number of errors made across each category. A significant difference for Media was observed with Video resulting in decreased number of errors across condition.

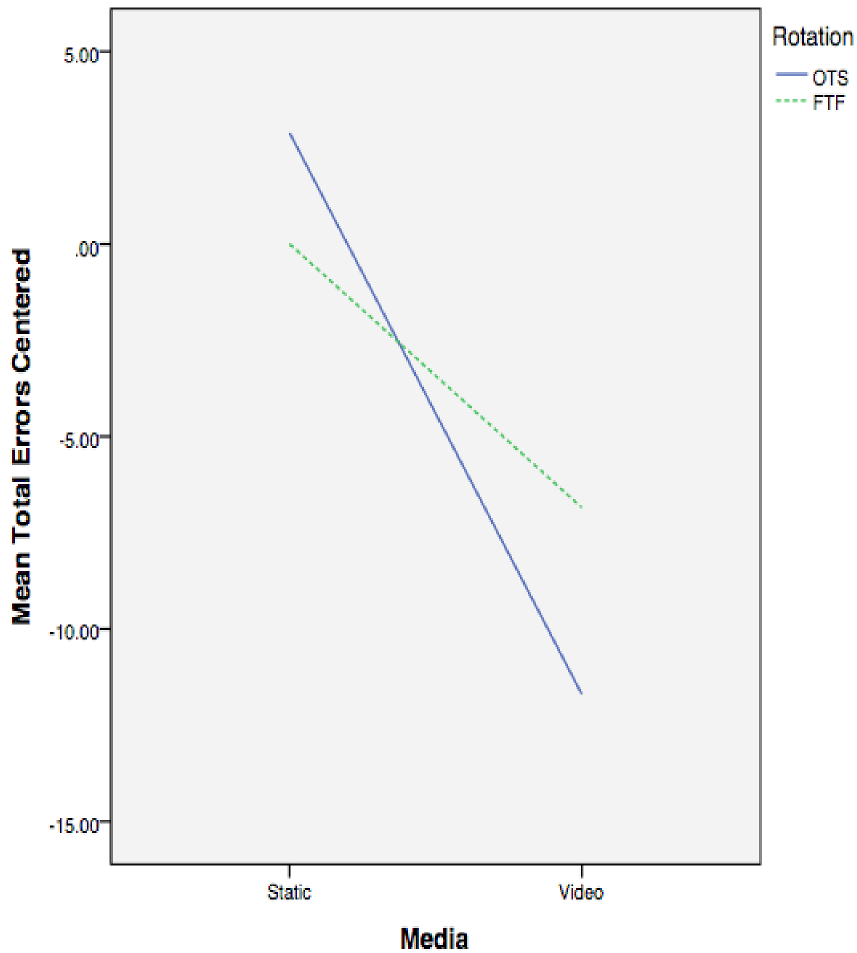

Figure 7. Mean total errors that were subsequently centered, representing total errors made across categories and the influence of Media on Rotation. A significant interaction between Media x Rotation was observed, where video results in fewer errors across rotation conditions with OTS producing the fewest errors. Interestingly OTS results in increased errors in static conditions over FTF.

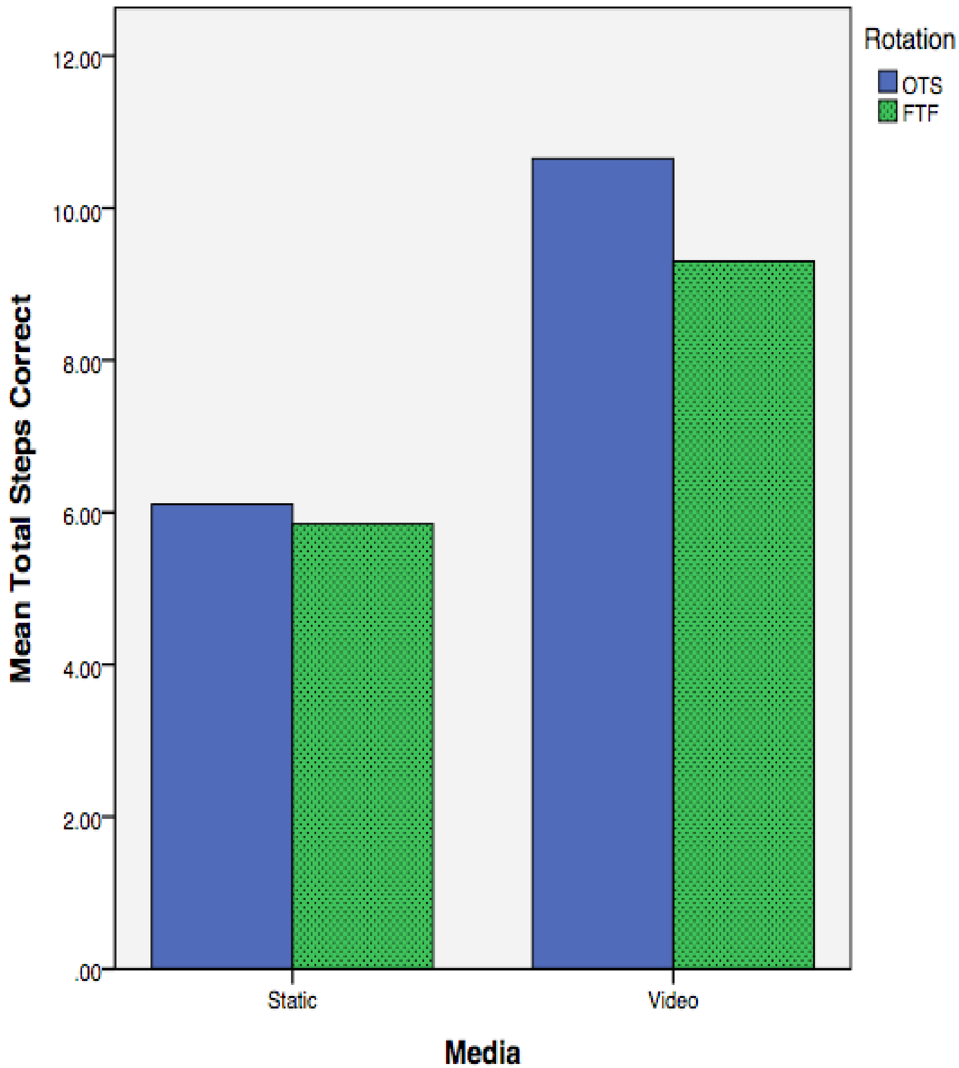

Figure 8. Mean values of total steps correct across each category. A significant difference for media was observed with video resulting in more correct steps produced across rotation conditions.

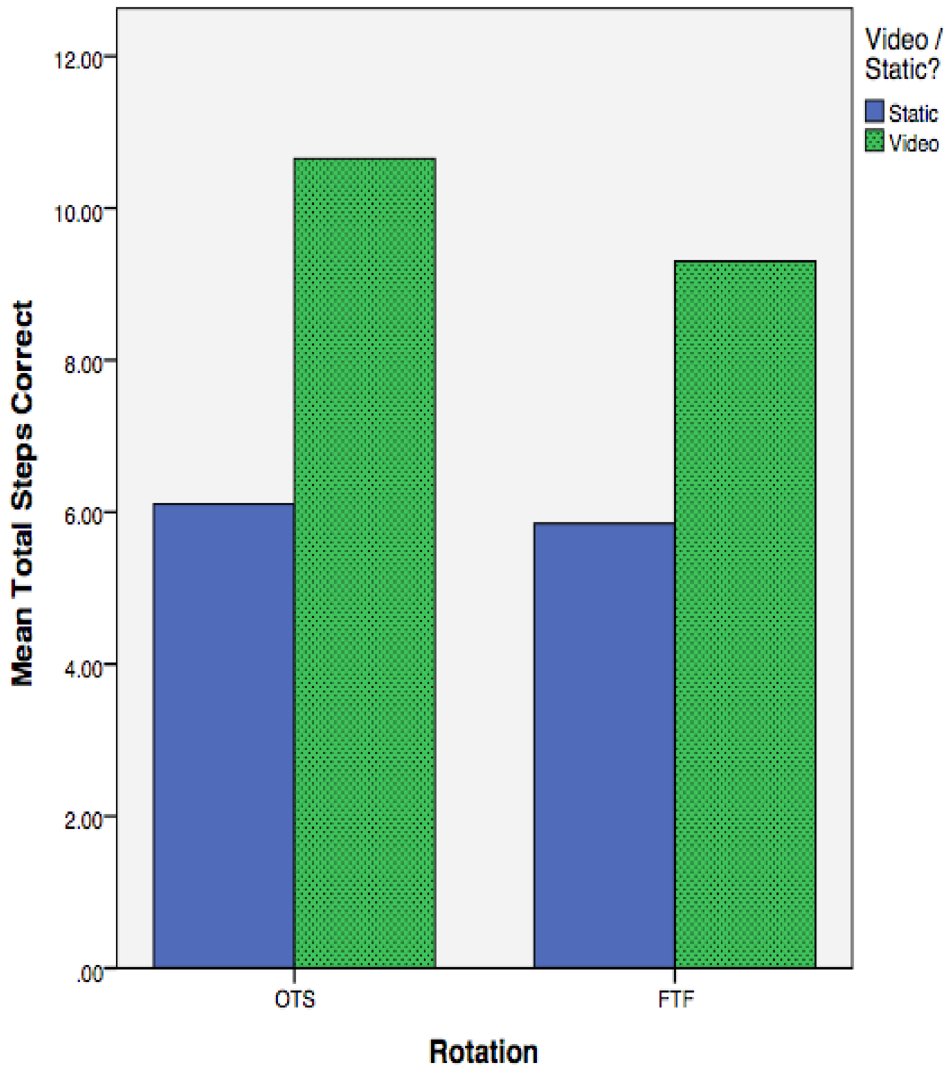

Figure 9. Mean values of total steps correct across each category. A significant difference for Rotation was observed with OTS resulting in more correct steps produced across media conditions.

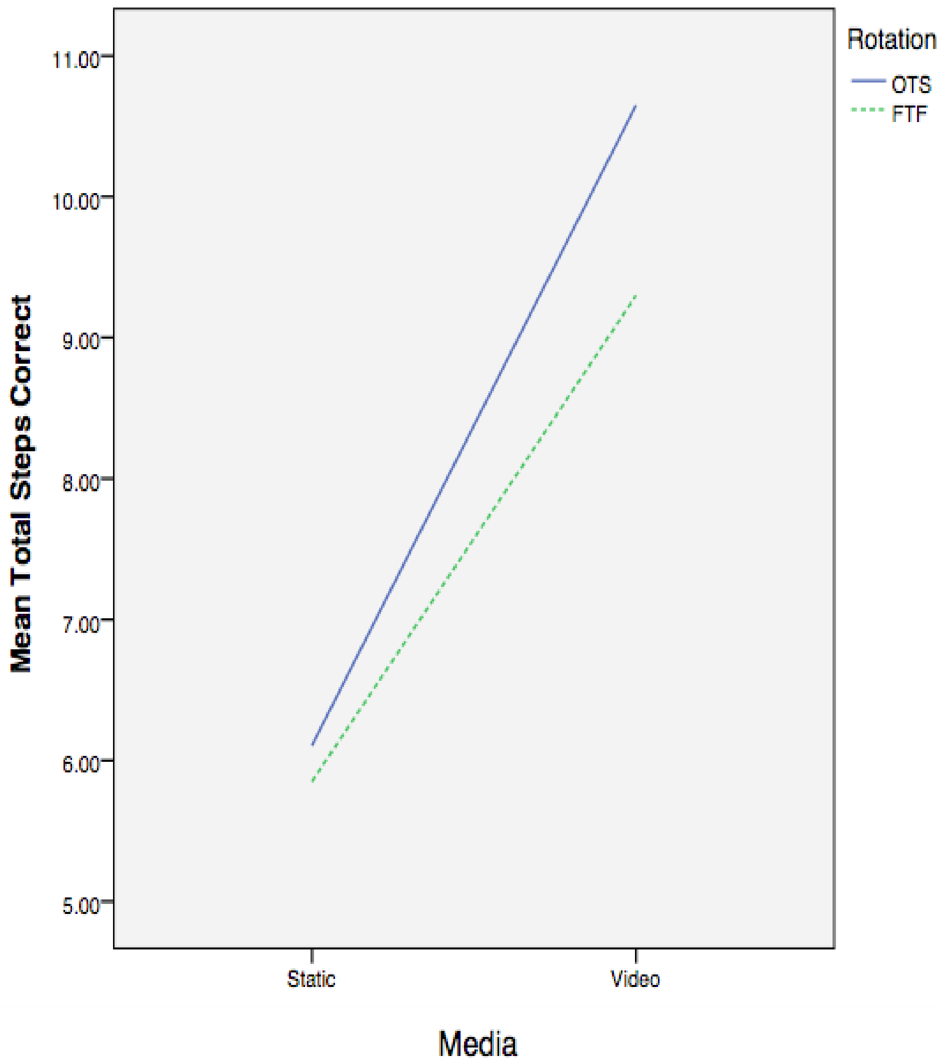

Figure 10. Mean total steps correct that were subsequently centered, representing total steps correct made across categories. A non significant interaction between Media x Rotation was observed, in contrast to the significant interactions observed between Media x Rotation for total errors and overall time to completion.

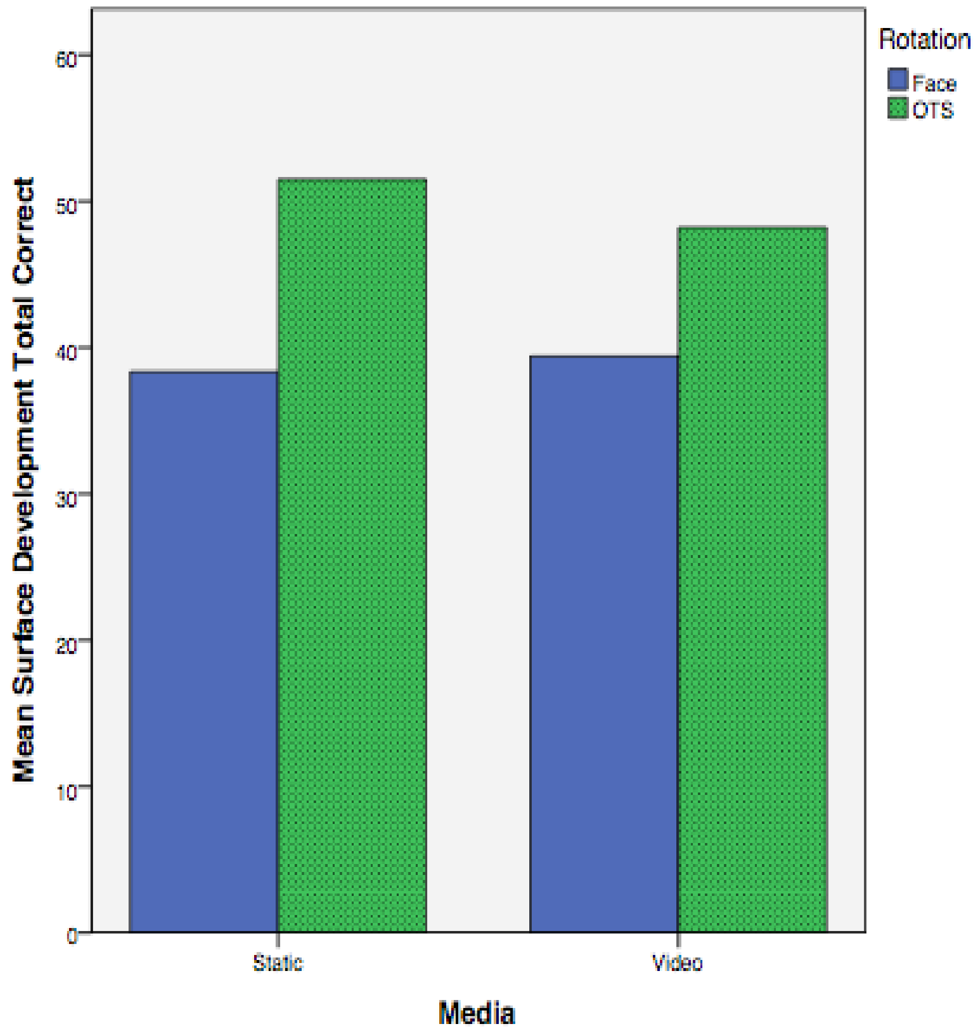

Figure 11. Mean values for the Surface Development Task representing spatial abilities for each target category. No significant difference was found in any dependent variable assessed.

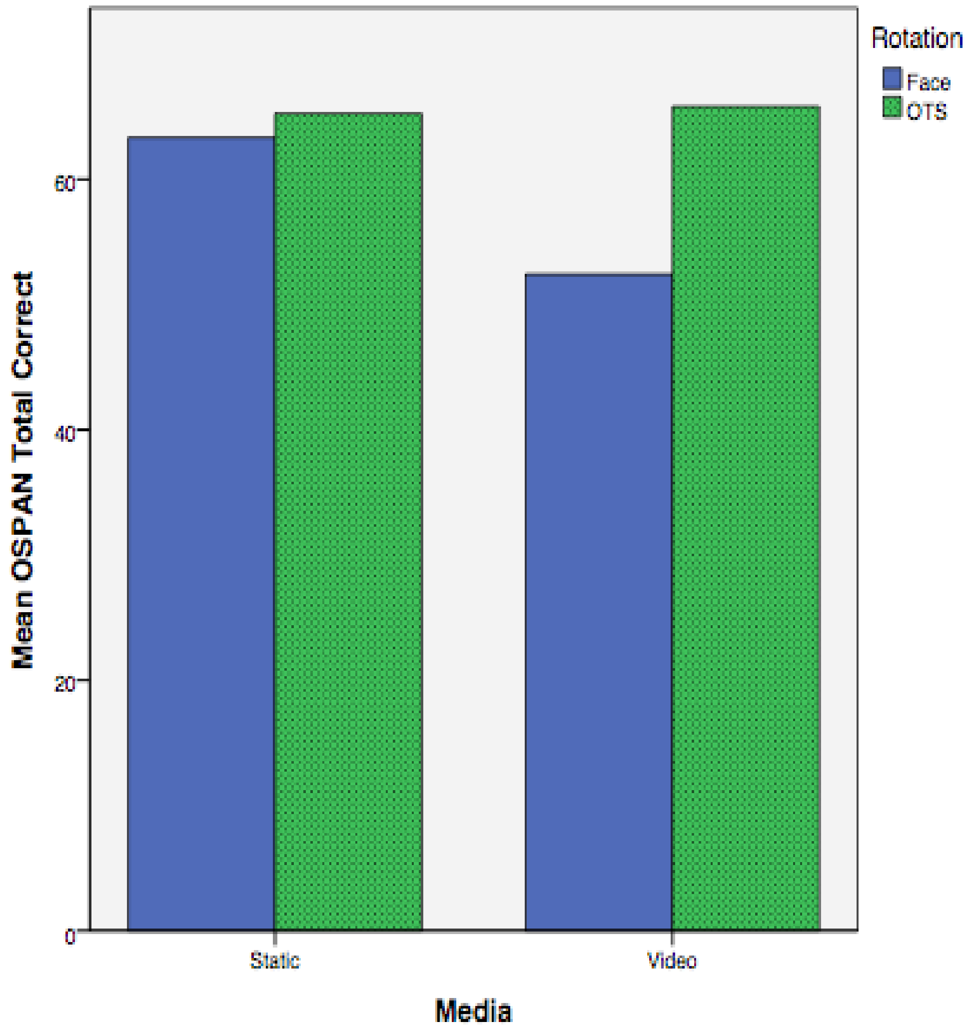

Figure 12. Mean values for the OSPAN working memory capacity score representing WMC for each target category. No significant difference was found in any dependent variable assessed.

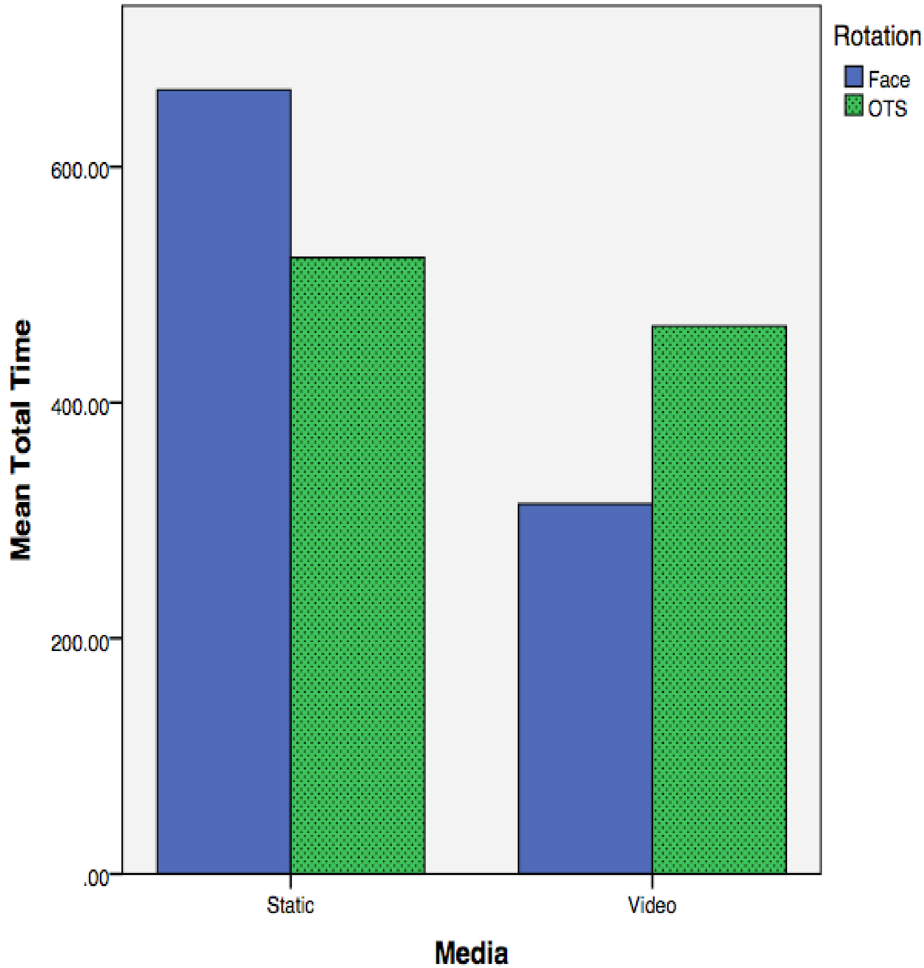

Figure 13. Mean total time values (seconds) for overall task completion across target conditions. A significant difference was found for type of media, with video resulting in faster performance than static across conditions.

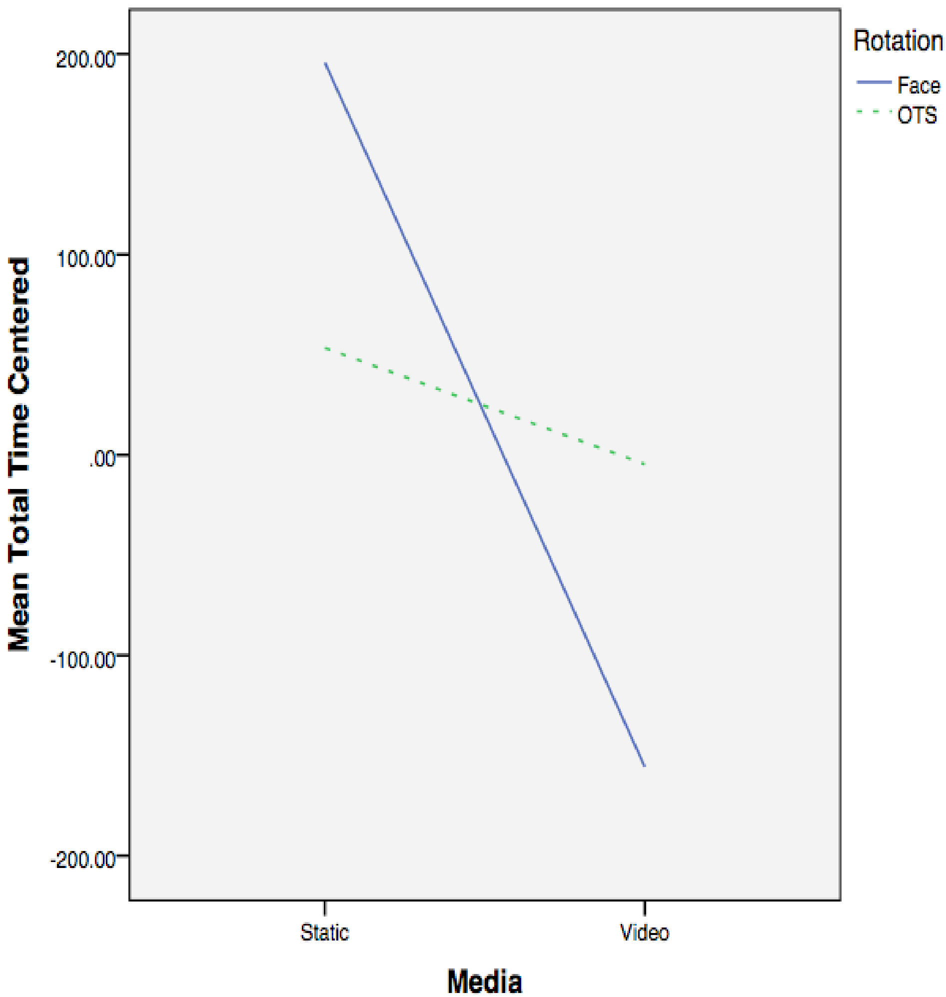

Figure 14. Mean total time value (seconds) that were subsequently centered, representing total time to completion across categories and the influence of Media on Rotation. A significant interaction between Media x Rotation was observed, where video results in better performance across rotation conditions. Interestingly unlike the first condition the FTF condition was superior to the OTS.

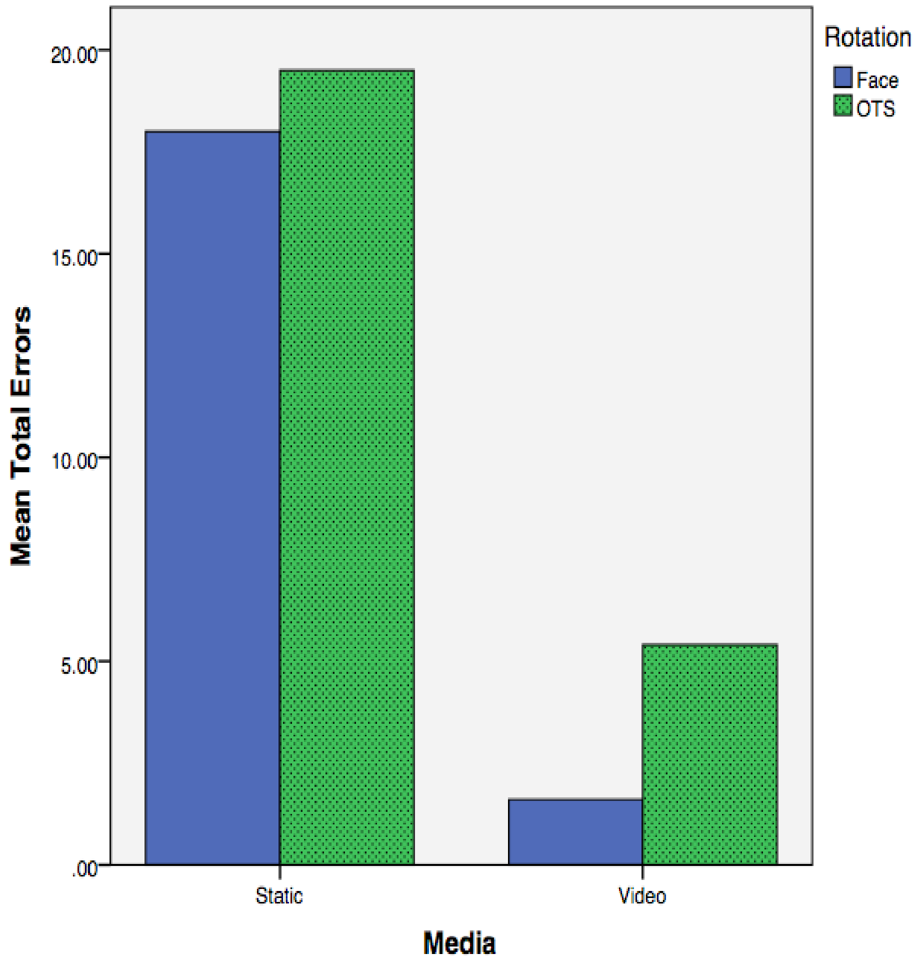

Figure 15. Mean total error values for overall number of errors participants made across target conditions. A significant difference was found for type of media, with video resulting in fewer errors than static conditions.

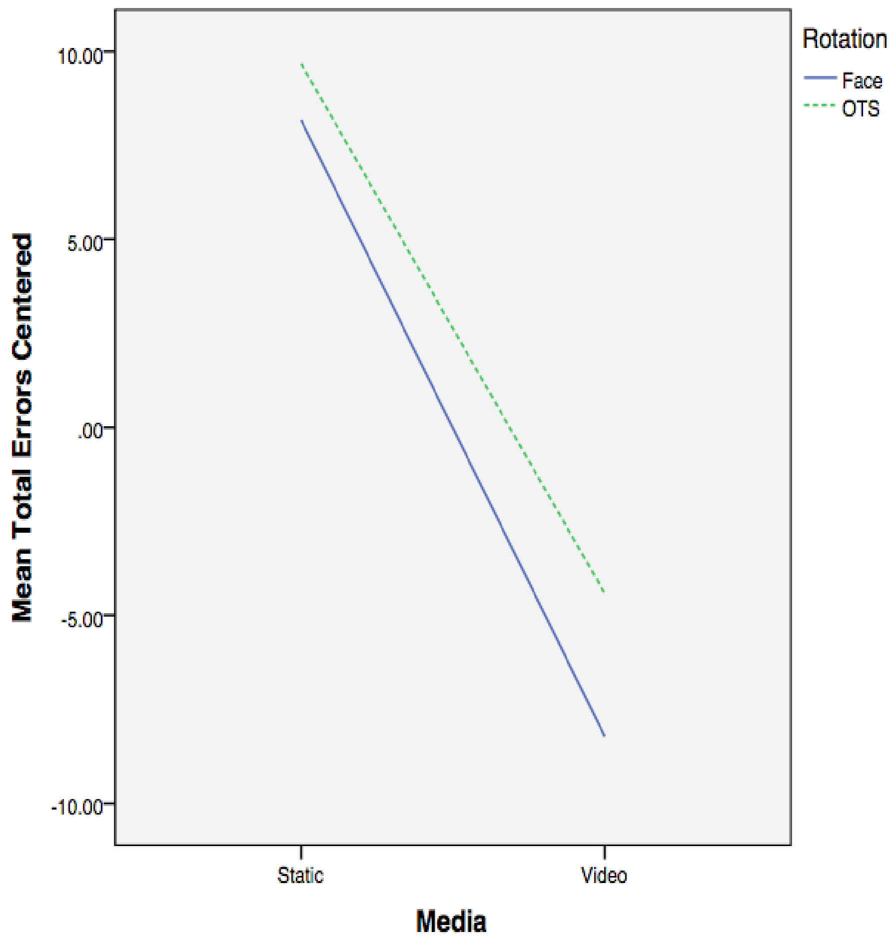

Figure 16. Mean total errors that were subsequently centered, representing total errors made across categories. A non significant interaction between Media x Rotation was observed, in contrast to the significant interaction observed between Media x Rotation in experiment 1.

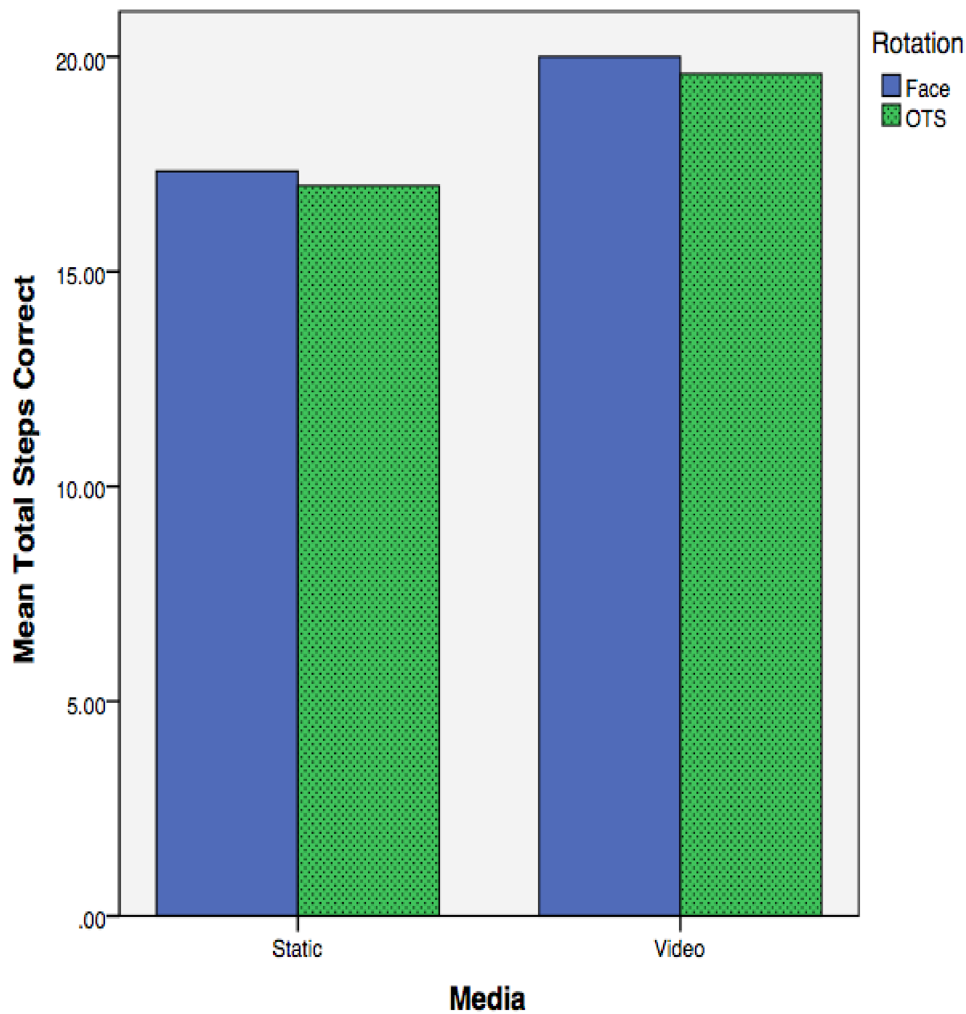

Figure 17. Mean values of total steps correct across each category. A significant difference for media was observed with video resulting in more correct steps produced across rotation conditions, as observed in experiment 1.

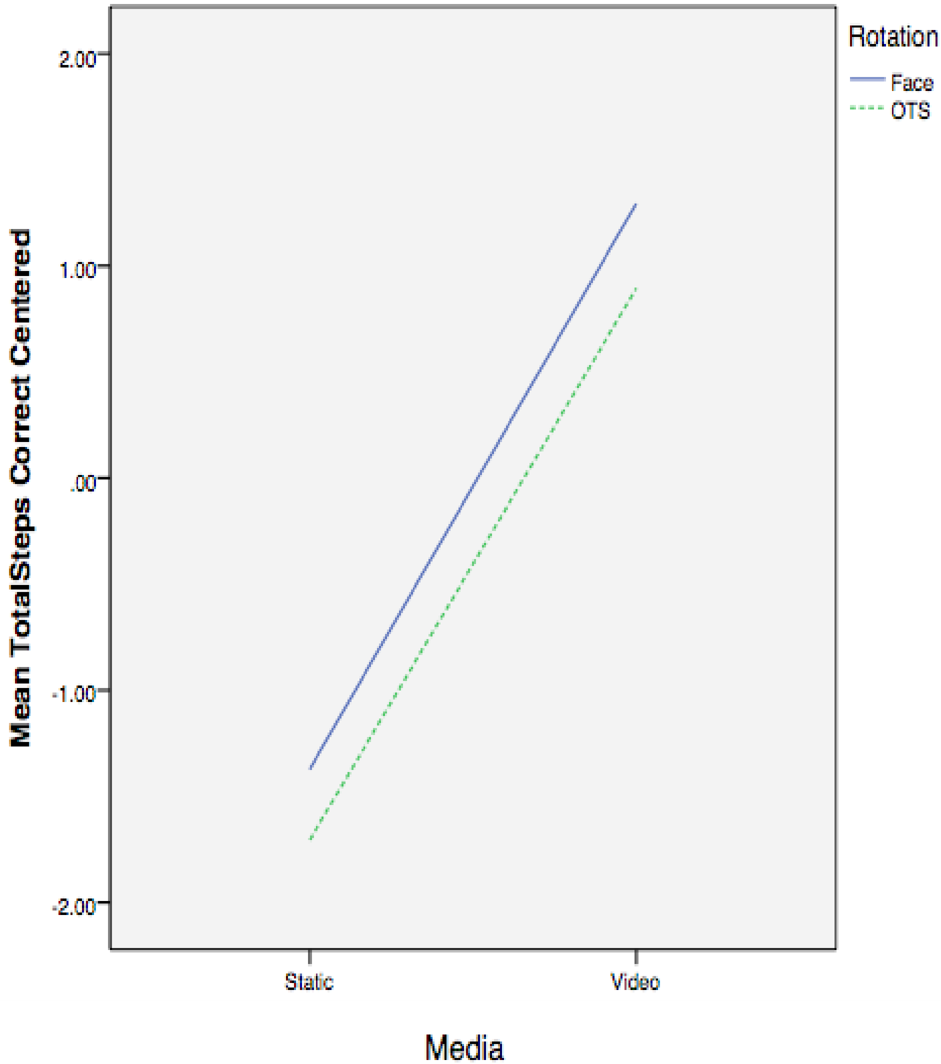

Figure 18. Mean total steps correct that were subsequently centered, representing total steps correct made across categories. A non significant interaction between Media x Rotation was observed, as in experiment 1, however no significant results were observed for Rotation and Spatial abilities in experiment 2.

APPENDIX A

EXPERIMENTAL STIMULI

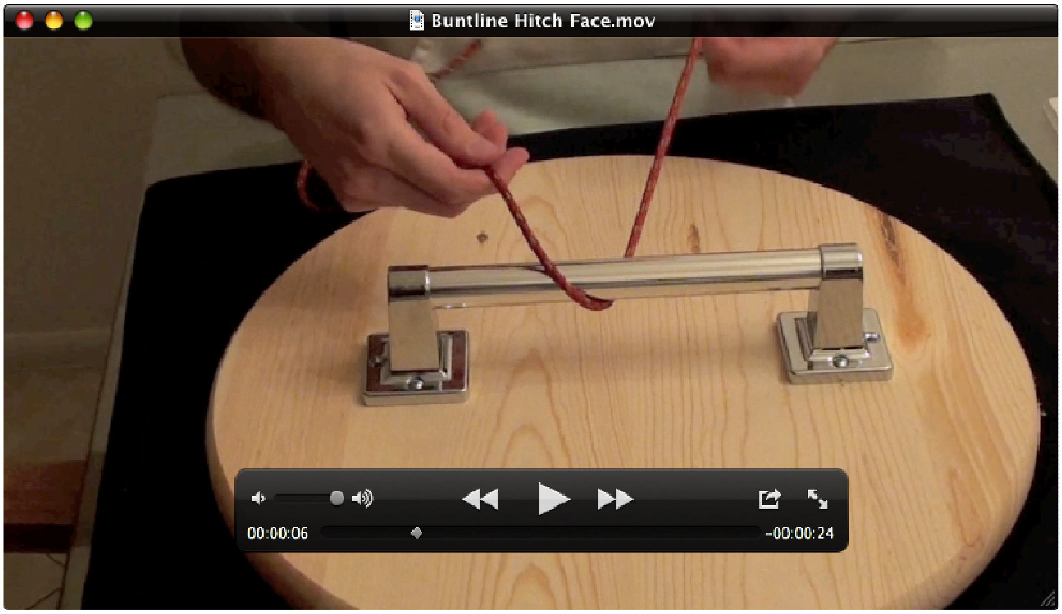

Figure 1. A screenshot of the rotated condition video in experiment 1 displaying the buntline hitch.

Figure 2. A screenshot of the non rotated condition video in experiment 1 displaying the constrictor knot.

Figure 3. A screenshot of the rotated condition video in experiment 2 displaying a step within stage 2, attaching the channel plug.

Figure 4. A screenshot of the non-rotated condition video in experiment 2 displaying a step within stage 3 attaching the suction tube.