

Action and Space-Related Information Enriches Conceptual Knowledge in STEM Disciplines

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U.S. students' science proficiency markedly lags behind students' proficiency in other nations at the secondary level. This is particularly true in physics, where students encounter challenging concepts such as torque and angular momentum (Grigg et al., 2006). We explored whether direct experience with physics concepts (e.g., feeling forces – as opposed to reading about force, seeing forces being exerted on someone else, or even measuring forces with instruments) can enhance student understanding. Lab experiences where students feel physics quantities directly may lead to the recruitment of brain areas devoted to sensory and motor (sensorimotor) processing when students later think and reason about the physics concepts they experienced. Previous research suggests that when these sensorimotor areas are involved in thinking and reasoning tasks, people's understanding of the concepts in question can improve (Beilock et al. 2008).

In the current experiment, we compared seeing a demonstration of angular momentum and torque with feeling the effects of a spatial change to angular momentum on students' understanding of force quantities. College-age participants (N=44) completed the experiment in randomly assigned pairs.

First, participants read a short qualitative description of angular momentum and the factors that affect it. In this description, angular momentum was also connected to the familiar concept of linear momentum. The description went so far as to include the following explicit instruction: *Tilting a spinning wheel from vertical to horizontal changes the direction in which the wheel is spinning in the world, so completing this "tilt" leads to forces that would not occur if the wheel was still – and these forces are the result of the wheel's angular momentum.*

Students then completed a baseline assessment of their understanding of the relation between (a) the size/weight of spinning wheels (defined an object's moment of inertia) and the speed of the spinning wheels and (b) the amount of torque (i.e., rotational force) that is exerted when tilting the wheels. Understanding these relations is an integral part of understanding the concepts of angular momentum and torque. In this **Baseline Force Judgment Task (FJT)**, two figures are presented on the screen (Figure 1). The avatar on the left (identified to the participants as the "template") was always holding an apparatus with one larger wheel and one smaller wheel. Both wheels spun at 1 revolution per second. On the right, an avatar (identified as "Woody") was holding an apparatus in which one or more of three potential wheel factors (i.e., either the wheels' spin direction, spin speed, or size) might differ from the template's apparatus. The participant could view animations of the two figures for up to 30 seconds. The goal was to understand how the figures differed.

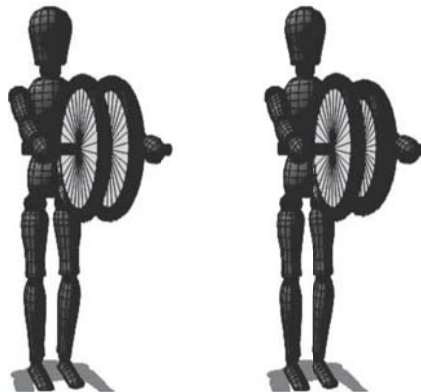


Figure 1. The template (left) does not change from trial-to-trial, and always portrays both wheels spinning in the same direction and at the same speed. On the right, is a second virtual actor ("Woody"). Woody

differs from the template in terms of one or more of three potential factors (the wheels' spin direction, spin speed, or size). Participants indicate if the person on the right is experiencing (1) more or (2) less force than the template on the left.

Each video clip was followed by the question, "Did Woody experience more or less force than the template?" Participants responded by pressing a "more" or "less" key on the keyboard in front of them. The participant then pressed a key to begin the next trial. This design allowed us to record participants' ability to understand the relations between factors of a multi-dimensional physical system. Increases in response accuracy indicate participants have learned the qualitative relations between the size, speed, and directions of wheel spin, as well as how these relations impact the amount of rotational force that is exerted when tilting the wheels. Participants performed 52 video clip trials in the **Baseline FJT**.

Following the completion of the **Baseline FJT**, some participants (randomly assigned to the *sensorimotor group*) were told they would be completing a task similar to the one on the video clips. Other participants (randomly assigned to the *observation group*) were told they would watch another participant complete the task. During this *Training Experience*, the experimenter told the observer what the other person was about to experience (e.g., wheel spin directions and speeds, with the size of the wheels apparent prior to the start of each trial). Importantly, we equated the visual feedback both groups received. To do this, a laser pointer was mounted along the axis around which the wheels spun. The *sensorimotor group* was told to tilt the wheels so that the red dot of the laser followed a straight target line on the wall. They were told to tilt the wheels from vertical to horizontal and back to vertical, 5 times in 5 seconds. Errors, which were directly related to the forces exerted by the apparatus when it was tilted, were visible to both participants (via the laser pointer deviation from the target line). Nine combinations of wheel spin direction, speed, and size were completed to demonstrate the relevance of these factors in influencing angular momentum magnitude and direction.

After completion of the *Training Experience*, each participant completed the **Test FJT**. This task was identical to the one completed prior to training.

As seen in Figure 2, the results of this experiment suggest that experiencing forces leads to greater learning about the qualitative relationships that underlie angular momentum than the observation of someone else experiencing them. An Analysis of Variance (ANOVA) revealed a significant effect of Session ($F(1,42)=4.25$, $p=0.05$), that was qualified by a significant Group \times Session interaction, $F(1,42)=4.33$, $p=0.04$.

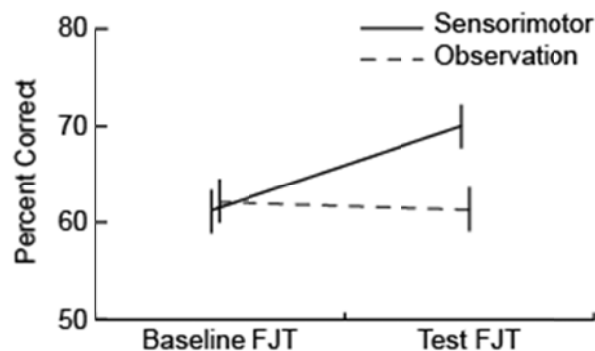


Figure 2. Results of the experiment indicate that participants in both groups performed similarly prior to the Training Experience, but showed markedly different performance after training. Since participants were tested in pairs, training experiences were matched for content, with the exception that observers never felt the effects of the spinning wheels.

Both groups exhibited limited knowledge (approximately 61% correct for each group – where random guessing should yield 50% correct) on the **Baseline FJT**. However, after the *Training Experience*, stark differences emerged. The *sensorimotor groups'* accuracy improved by about 10%. The *observational groups'* accuracy remained around 61% correct. Importantly, both sensorimotor experience and observation yielded information about the forces. This is because force-induced errors were visible in

terms of the wheel apparatus's laser pointer deviating from the target line when the participant anticipated the need for more or less force than was actually required to tilt the axle. The *observation group* was instructed to pay attention to the laser pointer during training. An experimental debriefing session revealed that they did in fact do this.

Simply put, participants that had the opportunity to feel the effects of spatially changing angular momentum demonstrated better understanding of the qualitative relationships between factors which influence angular momentum and torque. We are currently conducting both behavioral and fMRI follow-up experiments to explore whether the sensorimotor group's increased understanding of angular momentum is specifically due to the recruitment of sensorimotor systems when merely thinking and reasoning about the concept.

References

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