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RESEARCH ARTICLE

Using the hands to learn about the brain: Testing action-based instruction in brain anatomy

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Abstract

Brain anatomy is typically taught using static images. We asked participants to use their own hands to represent the brain and perform gestures during learning. We measured learning via a pretest/postest design. We compared five video trainings in which participants heard similar audio and repeated terminology aloud. Conditions were: (1) Image: Participants saw images of a physical model of the brain. (2) Physical model: Participants saw hands pointing to the physical model. (3) Physical model + action: Participants performed actions on the physical model. (4) Hand model: Participants saw images of hands being used to represent the brain. (5) Hand model + action: Participants performed gestures seen in the video. All trainings improved post-test performance. Performance in the hand model condition was worse compared to conditions with action. We connect these findings to the larger claim that gesture benefits learning.

KEYWORDS
action, brain anatomy, embodiment, gesture, learning, multimedia

1 | INTRODUCTION

Although the brain is a three-dimensional object, brain anatomy is typically taught using two-dimensional images (Estevez et al., 2010). Here, we explore a novel method of teaching basic brain anatomy that uses one's own hands as a three-dimensional representation of the brain. We ask participants to use their own hands to represent the brain and to perform actions with their hands while watching video instruction in brain anatomy and investigate the effects on learning (see Oh et al., 2011 and Siegel, 2010 for similar approaches to teaching anatomy). We compare our hand model instruction to other multimedia instructional practices that have empirical support. Specifically, we compare training that requires participants to both observe and perform actions to training that only requires observation. Our study is grounded in findings from two bodies of literature: (1) multimedia learning and video instruction, and (2) the use of enactment, action, and gesture in teaching and learning.

1.1 | Multimedia learning and video instruction

Presenting learners with visual-plus-auditory information can facilitate learning (Mayer, 2020). However, it is also clear that simply combining modes during instruction is not enough to enhance learning. Because auditory and visual streams are processed separately in working memory (Baddeley, 1998), learning through multimedia videos requires the integration of information across modalities. In addition, because both attention and working memory have limited capacity, instructional videos must be designed carefully to avoid generating excessive cognitive load (a situation in which processing demand exceeds capacity). Information overload can occur in one or both channels of multimodal instruction (Mayer & Moreno, 2003).

Mayer's cognitive theory of multimedia learning (CTML, Mayer, 2020) lays out the details of how visual and auditory information are integrated and makes recommendations for how to construct instructional videos in order to promote integration and avoid overloading learners

(Mayer & Moreno, 2003). For example, essential information can be moved to an auditory channel rather than being presented as visual text, thereby freeing up capacity in visual working memory for processing images, and information from verbal and visual channels can be presented simultaneously in order to support integration (see also Mayer et al., 2020). This body of work argues that multimedia instruction must follow certain principles in order to be effective.

An additional factor to be considered is the inherent complexity of the material being learned, referred to as intrinsic cognitive load (Sweller, 1994). Intrinsic cognitive load is independent of how information is presented and is determined in part by the extent to which the concepts, terms, and relationships can stand alone during learning (element interactivity, see Sweller, 1994; Sweller, 2010). Sweller argues that low element interactivity (material can be learned one element at a time rather, than requiring a great deal of information to be held in working memory) results in low intrinsic cognitive load. When intrinsic cognitive load is low, it may be unprofitable to use instructional design to further reduce extraneous cognitive load (that is, load caused by factors not related to the difficulty of the content itself). In the case of brain anatomy, element interactivity can be relatively low because the content to be learned is terminology paired with a spatial relationship. But there is also a cumulative effect of needing to build a cognitive representation of the brain as a whole. These lines of research are germane to our project because our instruction is multimodal, and because our training has the potential to increase extraneous cognitive load by incorporating the use of models, action, and gesture. Why design a training that might increase extraneous cognitive load? A large body of research suggests that action and gesture may also *reduce* cognitive load and, in addition, may create motor traces that help learners retrieve information. Because of these capacities, instruction that uses action and gesture may be worth any cost.

1.2 | Action and gesture in teaching and learning

Broadly speaking, performing actions and observing actions appear to be independently beneficial for language comprehension (see Dargue et al., 2019) and learning (Goldin-Meadow et al., 2012). However, quite a bit of complexity is buried beneath this generalization. Without going too far beyond the scope of the background needed to explain our training, we will attempt to disentangle the some key terms before describing relevant findings in these bodies of literature. First, *action* is often used to mean only movements of the hands on real world objects (e.g., moving the parts of a model), but is sometimes used synonymously with gesture. Gestures, “spontaneous movements of the hands and arms accompanying speech” (McNeill, 1992, p. 37) typically do not involve movements on physically present objects, and are categorized into different types based on hypothesized differences in their relationships to speech and their functions. One frequently used taxonomy is McNeill's four-category system, in which gestures are divided into iconic, metaphoric, deictic, and beat gestures. However, these categories are not mutually exclusive, and contain internal complexity (Parrill & Sweetser, 2004). This means that studies attempting to explain whether all four of these types of gestures are equally beneficial for comprehension or learning (such as the Dargue et al., 2019 meta-analysis) may conflate conceptual principles relevant for learning. For example, the category of iconic gestures (in which the gesture's form resembles something in accompanying speech; McNeill, 1992), can be subdivided into character viewpoint gestures and observer viewpoint gestures.

Character viewpoint gestures are those where the speaker uses their body as though they are a character. Character viewpoint gestures are sometimes referred to in other studies as *enactment* (e.g., Cohen, 1989; Roberts et al., 2022). Examples include moving the hands as though acting on a model in the absence of the model, miming drinking from a cup, or repeating paper-folding gestures observed in a training. This latter case would also be considered mimicry, because another set of gestures is being imitated.

Observer viewpoint gestures are those where the speaker shows a character's location or trajectory or action as though seen at a distance. Observer viewpoint gestures have multiple subcategories as well (see Parrill & Sweetser, 2004), including shape-for-shape gestures (the shape of the hands maps onto the shape of an object), path-for-path gestures (a speaker traces a character's path), and path-for-shape gestures (a speaker traces the shape of an object). These latter two categories of gestures are also sometimes used in studies that ask whether tracing gestures benefits learners (more on tracing below). And one might ask, if a learner is mimicking observer viewpoint gestures seen in a training (such as tracing the outline of a heart), isn't this also enactment, given that they are imitating the gestures another set of hands performed? In short, a study asking if iconic gestures benefit learners may be collapsing over enactment, tracing, and mimicry of both. McNeill's categories of metaphoric and deictic gestures are not less complex. Deictic, or pointing gestures, have a complex semantic relationship to speech explained by theories of reference (Clark et al., 1983), and deictic gestures can be metaphoric if the referent pointed to is abstract (an idea rather than an object). The problem is not resolved by using a different taxonomy, such as one that relies on form instead of semantic relationship or function (e.g., NEUROGES, Lausberg & Sloetjes, 2015), because ultimately meaning-making is necessary, and meaning-making is a subjective process (Parrill & Sweetser, 2004).

A second set of issues arises when disentangling the benefits of observing gesture from those of performing gesture, and separating these from benefits of both observing and performing gesture. Many studies do not compare the full set of conditions necessary to fully separate these effects. The Dargue et al. (2019) meta-analysis makes an excellent effort to do so by carefully including only studies meeting certain criteria. They are able to show that both performing and observing gestures are beneficial for comprehension, but are not able to say what happens when participants are told to perform specific kinds of gestures (as in our study).

In our study, we compare training that asks participants to observe pointing and tracing gestures, and observe and perform (mimic) pointing and tracing gestures. What is the evidence that such trainings might be beneficial? When participants perform gestures for words, phrases, or concepts, memory for the material is enhanced (Cohen, 1981; Cutica et al., 2014; Engelkamp & Krumnacker, 1980; Glenberg et al., 2004; Kaschak et al., 2017; McKim, 2015; Noice & Noice, 2007; Saltz & Donnenwerth-Nolan, 1981; Schatz et al., 2011; Steffens et al., 2015; Zimmer, 2001). These gestures may boost learning because they create a link between semantic representations and motor representations in premotor parts of the brain (Glenberg et al., 2004; Macedonia et al., 2011; Macedonia & Knosche, 2011; Macedonia & von Kriegstein, 2012). Such gestures may also enhance memory because actions are incorporated into a mental model, facilitating comprehension (Cutica et al., 2014; Sekine & Kita, 2017), and because they externalize content in working memory, thus reducing cognitive load (Goldin-Meadow et al., 2001). And such gestures may be beneficial because they add a kinesthetic or haptic component to learning, making the experience multimodal (Schatz et al., 2011). Benefits of such gestures emerge even when the actions performed are not semantically equivalent to the accompanying speech (Noice & Noice, 2007). Performing gestures can also enhance learning when directed at a model. For example, students appear to learn more when they are asked to do things with models in comparison with when they merely observe models being used (Stull & Hegarty, 2016). These kinds of gestures blur the line between action and gesture, but for the sake of simplicity we will refer to them as gesture. Numerous studies have found that instructing people to gesture in particular ways can enhance learning (Broaders et al., 2007; Carlson et al., 2014; Cherdieu et al., 2017; Cutica & Bucciarelli, 2008; Dargue et al., 2019; Kelly et al., 2009; Macedonia et al., 2011; Macedonia & Knosche, 2011; Macedonia & von Kriegstein, 2012; Macken & Ginns, 2014; Novack et al., 2014; Oh et al., 2011; Ping & Goldin-Meadow, 2008; Stevanoni & Salmon, 2005; Sweller et al., 2020). Some of this work also argues that gestures benefit learners more when they represent a concept in a more abstract way (e.g., representing rotation with two fingers and a flipping action, rather than a character viewpoint gesture showing picking up an object and rotating it). That is, when gesture makes conceptual content more abstract it makes it more generalizable, while also reducing cognitive load (Novack et al., 2014). This capacity is invoked to explain why more complex concepts, such as mathematical equivalence (e.g. Cook et al., 2013), symmetry (Valenzeno et al., 2003), and aspects of organic chemistry (Ping et al., 2021; Stieff et al., 2016) may be learned better when gesture is performed, compared to action on an object.

Gestures also have the potential to reduce cognitive load by directing attention, particularly pointing and tracing gestures (Ginns et al., 2020; Moreno et al., 2010). In this regard they are similar to arrows, color cues, animations, and so on, (de Koning et al., 2009), but when the learner produces gestures, they also add haptic and motor components to representations (Ginns et al., 2020). Further, pointing and tracing emphasize relationships among elements, allowing learners to create more complex mental models (Ginns et al., 2020; Macken & Ginns, 2014). For all these reasons, pointing and tracing appear to support recall and comprehension in ways similar to character viewpoint/enactment, or other kinds of iconic gestures that do not involve tracing.

While performing gestures appears to be beneficial, simply observing gesture can also lead to improved learning (see Dargue et al., 2019 for a recent summary of this research). The gestures produced by teachers have been shown to be an important factor in how well students learn (Alibali, Flevares et al., 1997; Alibali, Young et al., 2013; Cook et al., 2013; Valenzeno et al., 2003). Observing gesture in instructional videos can be helpful for learners (Moreno et al., 2010; Ouwehand et al., 2015; Rueckert et al., 2017; Wakefield et al., 2018), perhaps because gestures incorporate many characteristics that have been shown to facilitate learning from multimedia. Observed gestures are similar to dynamic drawings in that they unfold over time, and, as noted above, seeing gesture helps learners direct their attention.

In summary, the idea that action and gesture—whether only observed, performed, or both observed and performed—can boost learning has intuitive appeal and considerable support. Challenges arise when attempting to test this idea, and across studies that do and do not show benefits of action and gesture, there is considerable variation in methodological details. There are also confounding factors that may explain some patterns of performance (Steffens et al., 2015). Benefits depend on the characteristics of particular to-be-learned material, the nature of the instructional materials used, the encoding and recall protocols (Steffens et al., 2015), the type of gesture employed (Dargue & Sweller, 2018), the measures used to assess learning, and the characteristics of individual learners (Aldugom et al., 2021; Özer & Göksun, 2020). Furthermore, best practices for instructional videos that incorporate gestures or other motor behaviors have not been clearly established. Our study focuses on testing a relatively unexplored area of research, brain anatomy, and attempts to compare action/gesture observation to observation-plus-performance.

1.3 | Current study

To learn brain anatomy, learners must acquire semantic content (labels for structures, functions), spatial content (relative locations of structures), and a mental model based on mapping between function, semantic label, and spatial location. For example, to have a useful mental model of the corpus callosum one needs the label (corpus callosum), the location (between the two hemispheres) and function (connecting left and right hemispheres).

Prior work suggests that gesture can help learners with all three of these tasks. Gesture seems to help people learn spatial relationships (e.g., in chemistry, Stieff et al., 2016; Ping et al., 2021) and acquire semantic content (e.g., in foreign word learning, Kelly et al., 2009; Macedonia & von Kriegstein, 2012). Gesture also helps learners build mental models (Cutica et al., 2014). However, anatomy is a relatively unexplored area of study. Macken and Ginns (2014) found that participants who pointed at and traced structures while learning about the heart performed better than those told not to gesture, though they did not compare this training to others involving movement. Oh et al. (2011) found that students who were asked to learn anatomy (heart, celiac trunk, etc.) via a sequence of hand movements found the training helpful, though the researchers did not assess recall/learning in this study, or compare it to traditional training. Cherdieu et al. (2017) did compare action observation and performance in learning forearm anatomy, and found that learning improved for the action performance group, but only after a delay. We extend this body of work by testing the use of the learner's hands as a model, as well as using the hands to produce actions during instruction in brain anatomy. In order to examine how using the hands as a model interacted with action production in the context of anatomy learning, we investigated the effects of five different instructional videos on student learning.

1.4 | Image

In the image condition, participants saw static images of a physical model of a brain. Static arrows were used to direct attention to certain parts of the brain. Participants were instructed to look at certain parts of the brain and to repeat terms (listen, look, and say). This condition is consistent with evidence suggesting that using arrows to direct attention can facilitate learning (Moreno et al., 2010). This condition does not include the use of the hand as a model or observing or producing actions.

1.5 | Physical model

In the physical model condition, participants saw the same physical model of a brain, but this time a moving hand, rather than a static arrow, directed attention to certain parts of the brain. Participants were again instructed to look at certain parts of the brain and repeat terms (listen, look, and say). In this condition, participants did not perform actions, but they did observe hand actions depicted in the video. This condition is consistent with evidence that hands may be powerful tools for directing attention (Wakefield et al., 2018) and that observing actions can boost learning (Dargue et al., 2019).

1.6 | Physical model + action

In the physical model + action condition, participants saw exactly the same video as in the physical model condition (a moving hand directing attention to a model brain). In this condition, participants were additionally instructed to repeat terms and imitate the actions they saw (listen, look, say, and do). Thus, in this condition they not only observed hand actions, but also performed these actions. This condition is consistent with evidence that performing actions can be beneficial for learning and memory (Kelly et al., 2009).

1.7 | Hand model

In the hand model condition, participants saw static images of a hand being used as a model of the brain, using a first-person perspective. A pointing hand (static image) was used to direct attention to aspects of the hand model. Participants were instructed to look at the indicated parts of the model and repeat terms and concepts (listen, look and say). Because piloting indicated that almost all participants in this condition imitated the images they saw, participants in this condition were explicitly told not to move their hands, and videos taken during the study were spot-checked to ensure that participants were following these instructions. Thus, in this condition, participants did not observe or perform action.

1.8 | Hand model + action

In the hand model + action condition, participants saw the hands being used as a model of the brain, and they also saw hand actions (moving hands) that directed attention. Participants were instructed to repeat the terms and imitate the pointing and tracing actions they saw (listen, look, say, and do). Participants both observed and performed actions, thus the hand model + action condition is analogous to the physical model + action condition, the difference being whether participants performed the action on a three-dimensional model of the brain or on their own hands, which were also functioning as a model. Table 1 summarizes the conditions and the dimensions of variation across the conditions. Images for the conditions are shown in Figures 1–5. The full videos are available via an Open Science Foundation repository: https://osf.io/xfaj9/.

Across conditions, the effects of using the hand as a model, and of observing and performing actions, are unconfounded with one another. However, the image condition is unique in that it uses arrows to direct attention. We used arrows because this is typical for textbooks, websites, or lecture slides, but a consequence is that the two static conditions (image, hand model) are not exactly parallel. We used a pointing hand in the hand model condition to create the strongest parallel with the other model conditions (which take advantage of our tendency to attend to human hands: Perry et al., 2016; Niimi, 2020). The decision not to include additional conditions (conditions using arrows, e.g.) was a practical one, given the number of participants required to test the observation/ performance conditions, and the fact that this study is a starting point for understanding how action can be used in brain anatomy instruction.

Why use a hand model of the brain at all, given that the hands have relatively few analogical correspondences to a brain? First, because the hand model is three-dimensional, once mappings between the hand and the brain have been created, they do not need to be transformed between two- and three-dimensional space (Estevez et al., 2010). While this is also true of a physical model, the hand model has an additional advantage. For most people, the hands are readily available to be used as a model and they can be used at any time, including during acquisition, study, and recall. The hand model + action condition is also unique in one regard. It not only involves self-produced action, but also self-touch, thereby creating a motor-haptic representation.

Despite these potential advantages, it is also possible that a hand model will hinder learning. Using the hands as a model of the brain is

TABLE 1 Dimensions of variation across training conditions.

	Image	Physical model	Physical model + action	Hand model	Hand model + action
Brain = hand	n	n	n	y	y
Action observed	n	y	y	n	y
Action performed	n	n	y	n	y

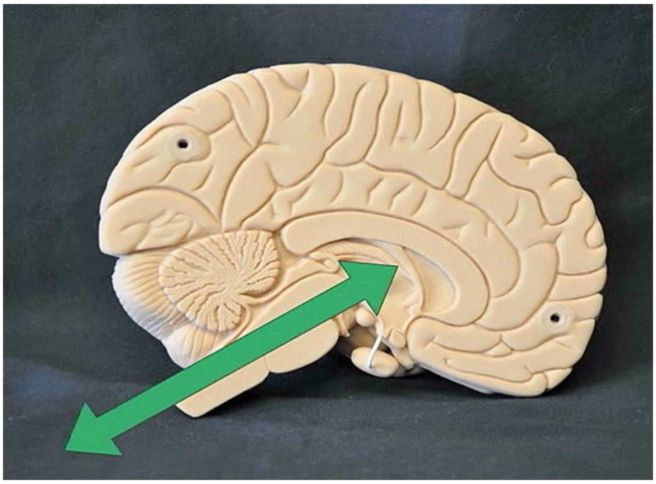

FIGURE 1 Example still from Image condition. Participants are instructed to run gaze along arrow to observe continuity of subcortical structures and spinal cord.

FIGURE 2 Example still from Model condition. Participants are instructed run gaze down subcortical structures to observe continuity with spinal cord.

novel, so students may spend cognitive resources on attending to the hand as it is being used as a model (increasing extraneous cognitive load), at the expense of encoding information into memory. Using the model may distract from information that is communicated verbally, because students need to attend to both the labels and the hand model. Finally, using the hand as a model and also performing actions on the hand model requires students to simultaneously use the hands as tools for acting and tools for representing, which may hinder learning.

Based on the research surveyed above, we predicted that (1) participants would perform better in conditions involving action observation-plus-performance (physical model + action, hand model + action) compared to those involving observation only (physical model). And, we predicted that (2) participants in conditions where action was neither observed nor performed (image and hand model) would have the lowest performance.

2 | MATERIALS AND METHODS

2.1 | Participants

The study was approved by the university IRB, which ensured confidentiality was protected with an alphanumeric code on de-identified data, that students had alternatives to participating for extra credit, and that informed consent was comprehensive. None of the researchers were instructors in a course participants were taking at the time of the study. Informed consent was obtained (written) and participants had the opportunity to ask questions and to withdraw from the study at any time.

One hundred ninety-seven students from a public university in the Midwestern USA participated in the study for course credit. To be eligible for the study, participants needed to be self-identified native speakers of English. Thirty-one participants were not included in the data analysis (Experimenter error, $n = 6$; Missing pre- or posttest data due to computer problems or failing to complete the experiment, $n = 25$). This left 166 participants (114 female and 52 male) in the analyzed sample. An additional three participants skipped one or more questions on the pretest and so were eliminated from the main analysis because we controlled for pretest performance. We did not obtain further demographic information from the participants.

Following informed consent, participants took a six-question pretest presented using Qualtrics survey software, with questions presented one at a time. Next, participants watched a training video which lasted approximately 15 min. Training videos varied by condition, as described above. Following the training, participants took a 30-question posttest, again with questions presented one at a time using Qualtrics survey software. The posttest contained the same six questions that were asked on the pretest as well as 24 additional questions. Questions were presented in random order for all participants. After a delay of 3 weeks, participants received an email asking

FIGURE 3 Example still from model + action condition. Video is identical to model condition, but audio instructs participants to run a finger down subcortical structures on the physical model to observe continuity with spinal cord.

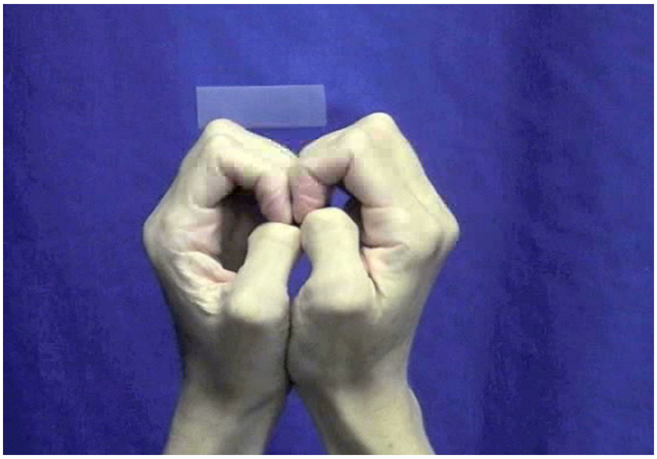

FIGURE 4 Example still from hand model condition: Participants are instructed to run gaze from thumb to arm to observe continuity of subcortical structures and spinal cord.

them to complete a follow-up posttest. Unfortunately, the response rate for the follow-up portion of the study was too low to permit any analyses (likely because of how participation credit was awarded), so data from the follow-up will not be reported here.

2.2 | Materials

2.2.1 | Pretest questions

Pretest questions are shown below. They were designed to assess a range of knowledge, including knowledge that many undergraduates have been exposed to (e.g., question 1) and knowledge fewer undergraduates have been exposed (e.g., question 6).

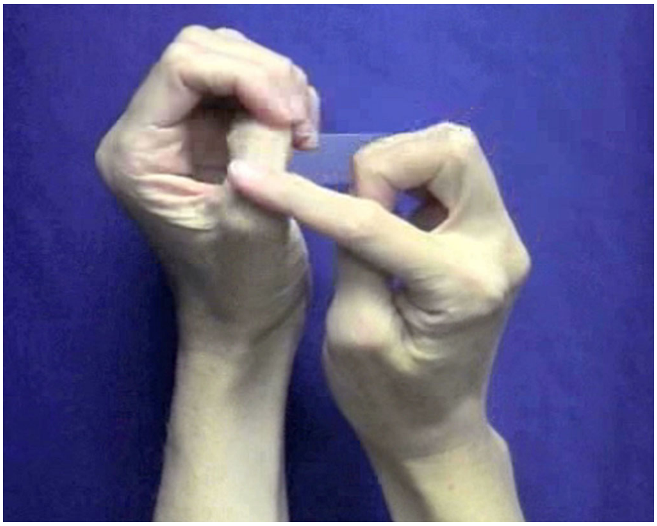

FIGURE 5 Example still from hand model + action condition: Participants are instructed run a finger from thumb to arm to observe continuity of subcortical structures and spinal cord.

1. The front and back of the brain are symmetrical.
2. The brain has four hemispheres.
3. The occipital lobes are in the back of the brain.
4. The central sulcus is a bulge in the brain.
5. Signals traveling from the spinal cord go to the _____ first.
6. The part of the primary motor cortex that moves the feet is closer to the _____ than the ______.

2.2.2 | Posttest questions

Post-test questions are available via our repository. They were also designed to include easier (e.g., spatial relationships plus semantic labels, such as the location of the temporal lobes) and harder material (holding multiple labels and spatial relationships in mind, such as knowing the relationship between sub-areas of the primary motor and somatosensory areas).

The experimental manipulation consisted of which training video participants watched. Participants were randomly assigned to one of five instructional conditions. In all conditions, the video introduced participants to the same terms and concepts in basic brain anatomy, and participants were asked to practice these terms and concepts either by repeating verbal instructions, or by repeating while performing actions. Based on the findings from research on multimodal learning, we used non-redundant audio and text, and used coordinated visual and auditory (intonational) cues to direct attention (Xie et al., 2019).

The perspective of the training was confounded with the model that was depicted in the video. Participants in the hand model and hand model + action saw a first-person view of an actor's hand performing actions, while participants in the physical model and physical model + action conditions saw a view of the hand that either statically (physical model) or dynamically (physical model + action) directed attention from a third-person perspective. Perspective was neutral in the image condition. Given the length of the video, we did not include any breaks.

2.2.3 | Training content

The training script and videos area available via our Open Science repository. Briefly, the training introduced leaners to the two hemispheres, the asymmetry between front and back of the brain, the relationship between spinal cord and brain, the concepts of gyrus and sulcus, the lobes of the hemisphere, and the topographic organization of the primary motor and somatosensory areas.

2.2.4 | Video construction

Stimulus videos were created using Final Cut Pro so that audio and video could be adjusted precisely. An original audio track was recorded for the hand model + action condition. To create audio tracks for the other conditions, audio segments from the original were deleted and new audio segments were recorded and inserted as necessary. For example, the audio instructing participants to touch in the hand model + action condition was replaced with audio instructing participants to look at for the physical model, image, and hand model conditions. By performing these smaller edits, we ensured that prosodic features such as emphasis and pitch contours were identical across all conditions for the part of the video describing the anatomical content, but the instructions to participants varied across conditions.

Video tracks

For the image condition video track, still images of a plastic model brain were recorded, and arrows were inserted as needed. For the physical model condition video track, video was recorded of a hand pointing at or tracing parts of the same model brain. For the physical model + action condition video track, video from the physical model condition was used (the only difference being that new audio instructing participants to “touch” rather than “look at” was inserted into the audio track). For the hand model + action condition, video was recorded of hands demonstrating the configurations and actions of previous videos, but this time using our novel “hand model.” Video for the hand model condition was created by taking still frames from the hand model + action video.

Timing of action and instruction

For conditions in which action was either observed or performed (physical model, physical model + action, and hand model + action), the verbal instruction (e.g., “touch the left hemisphere”) began 500 ms after the action began. This sequencing is based on research indicating that learners benefit from seeing the onset of an action before the accompanying speech begins (Pruner & Cook, n.d.).

Delay for participant response

In the image, physical model, and hand model conditions, the duration of the delay provided for participants to repeat terms was equal to the duration of that audio in the stimulus. For example, if the audio duration for “left hemisphere” was 2 s, the interval provided for participants to say “left hemisphere” was 2 s. During this interval, the screen showed a still image. In the action-performed conditions, we increased the delay by 500 ms to allow for coordination of words and actions. In addition, any instruction to reconfigure the model or the hands was followed by a delay of 3–5 s that varied depending on the complexity of the instruction.

Repetition sequences

All instructions to say or to say and do were followed by a repetition sequence. Participants saw a screen reading “repeat after me,” followed by a repetition of the image or action along with audio of the accompanying terminology. For conditions where participants were performing an action, the action began slightly before the speech as with the initial presentation. In repetition sequences in the action conditions, the action that participants observed also preceded the speech (as described in the action/instruction timing section).

Action matching

We attempted to ensure that actions matched as closely as possible across all conditions. Participants in the physical model + action condition were instructed to perform the same actions that were observed by participants in the physical model condition, and these were the same actions that were both observed and performed in the hand model + action condition (though on the hand model rather than the model brain). For example, if participants were instructed to trace a segment in the hand model + action condition, they saw a hand trace that segment of the model in the physical model condition, and both saw and were instructed to trace that segment in the physical model + action condition. In the image condition, the arrows mimicked the pointing / tracing actions in the model condition. When the hand pointed to a location in the model condition, a single arrow was used in the image condition. For tracing actions, a longer arrow was used that covered the same path and contour. For long tracing paths, dynamic arrows were used that appeared over time.

The computer webcam recorded video of the participants throughout the procedure. This was done so we could explore any differences in their behavior and to encourage them to carefully follow the videos. For this latter reason, they were also told that their eye movements were being monitored via a webcam, and that the experimenter would review their video to make sure that they had followed the instructions. Spot checking of the videos and reports from the experimenters revealed that participants followed instructions in this experiment.

3 | RESULTS

We used R to analyze the data (version 4.3.0, R Core Development Team, 2020). We used the tidyverse (version 2.0.0, Wickham et al., 2020), broom (version 1.0.4, Robinson, 2014), and cowplot (version 1.1.1, Wilke, 2020) packages for data manipulation, cleaning, and visualization. Statistical analysis was completed with lme4 (version 1.1.33, Bates et al., 2015) and emmeans (version 1.8.6, Lenth, 2020). We used generalized linear mixed models (GLMMs) with a logistic link function to analyze performance across tests and across conditions. We fit models using the *glmer* function from the lme4 package. We compared experimental conditions using the *emmeans* function from the emmeans package to obtain estimated marginal means (EMMs) and then computing pairwise contrasts across all conditions using the Tukey adjustment for multiple comparisons to calculate *p* values. We estimated effect sizes using the *eff_size* function from the emmeans package, using the sigma and the edf estimated from every each GLMM model. Data (including pretest and postest questions) and R analysis script are available via our Open Science Foundation repository: https://osf.io/xfaj9/.

Table 2 shows descriptive statistics for performance as a function of condition at pretest and posttest. Because the content we were studying is often a part of the psychology curriculum, we first investigated whether our instruction supported learning. We investigated improvement in the task by analyzing performance for the six matched pretest and posttest questions. We used a GLMM with correctly responding to each question as the outcome variable and with a fixed effect of Test (Pretest, Posttest) and random intercepts for Participant and for Question. We did not include additional slopes as they were not justified by the design. As expected, performance improved after instruction. For the matched questions, performance on the posttest (mean = 85% correct) was significantly better than performance on the pretest (mean = 64% correct, $B = -1.24$, $z = -10.48$, $p < .001$, $d = 1.24$). Figure 6 shows improvement after instruction.

To test our main hypothesis, we examined performance across the entire posttest, that is, including both repeated and non-repeated questions. We included correctly responding to each question as the outcome variable, a fixed effect of Condition, and random intercepts for Participant and for Item. Condition was coded with the image condition as the reference level. We also included the number of items answered correctly on the pretest as a fixed factor to control for prior knowledge. We did not include a random slope for Condition by Item because models including this slope did not converge.

TABLE 2 Descriptive statistics for performance (mean proportion correct) as a function of condition at each timepoint.

	Pretest		Posttest	
Condition	***M***	***SD***	***M***	***SD***
Image	0.68	0.14	0.73	0.16
Physical model	0.61	0.19	0.67	0.16
Physical model + action	0.66	0.22	0.74	0.17
Hand model	0.59	0.17	0.59	0.16
Hand model + action	0.68	0.16	0.74	0.15

Note: *M* and *SD* represent mean and standard deviation, respectively. Note that the pretest included six questions, while the posttest included 30 questions; the two tests were not matched in content or difficulty.

As expected, the number of items answered correctly on the pretest was a significant predictor of posttest performance ($B = 0.33$, $z = 5.04$, $p < .001$). There were two significant contrasts. Performance in the hand model condition was reliably worse than performance in the hand model + action condition, ($B = -0.8$, $z = -3.58$, $p = .003$, $d = .42$) and the physical model + action condition, ($B = -0.75$, $z = -3.44$, $p = .005$, $d = .85$). There was also one marginal contrast. Performance in the hand model condition was marginally worse than performance in the image condition ($B = -0.6$, $z = -2.65$, $p = .06$, $d = .75$). There were no other significant contrasts (all *ps* > .27). The right panel of Figure 7 depicts posttest performance across all questions.

We next investigated whether the amount of improvement for the repeated questions varied across experimental conditions. This analysis allows us to more directly control for prior knowledge. We used correctly responding to each question on the posttest as the outcome variable and included a fixed effect of Condition (5 levels: image, physical model, physical model + action, hand model, hand model + action), while also controlling for pretest performance (correct or incorrect) on each question. Condition was coded with the image condition as the reference level. We included random intercepts for Participant and for Question. We did not include additional slopes for Condition by Item because models including this term did not converge, likely because of the small number of items. As expected, there was a significant effect of pretest performance on posttest performance ($B = 1.27$, $z = 6.27$, $p < .001$). Improvement in the hand model condition was marginally worse than improvement in the physical model + action condition ($B = -0.86$, $z = -2.64$, $p = .06$, $d = .86$). There were no other significant or marginal contrasts (all *ps* > .15). The left pane of Figure 7 depicts performance on matched pretest and posttest questions.

4 | DISCUSSION

A short video training on basic brain anatomy led to learning in all conditions. However, contrary to our predictions, there was no evidence that participants who combined observation and performance of action learned more than those who received training that did not include action, or included only observation of actions. In addition, there was no evidence that those who received instruction that included a hand model of the brain showed better learning compared to no model or a physical model. Instead, when participants used the hand model without performing actions on the model, they learned less than participants who used a physical model with actions or a hand model with actions. Adding actions improved performance with the hand model to a considerable degree, with a large effect size in the main analysis. However, adding action did not improve learning with the physical model, and adding action was not enough to provide an overall benefit to learning with a hand model compared to the other conditions. Participants who acted on a model did not learn

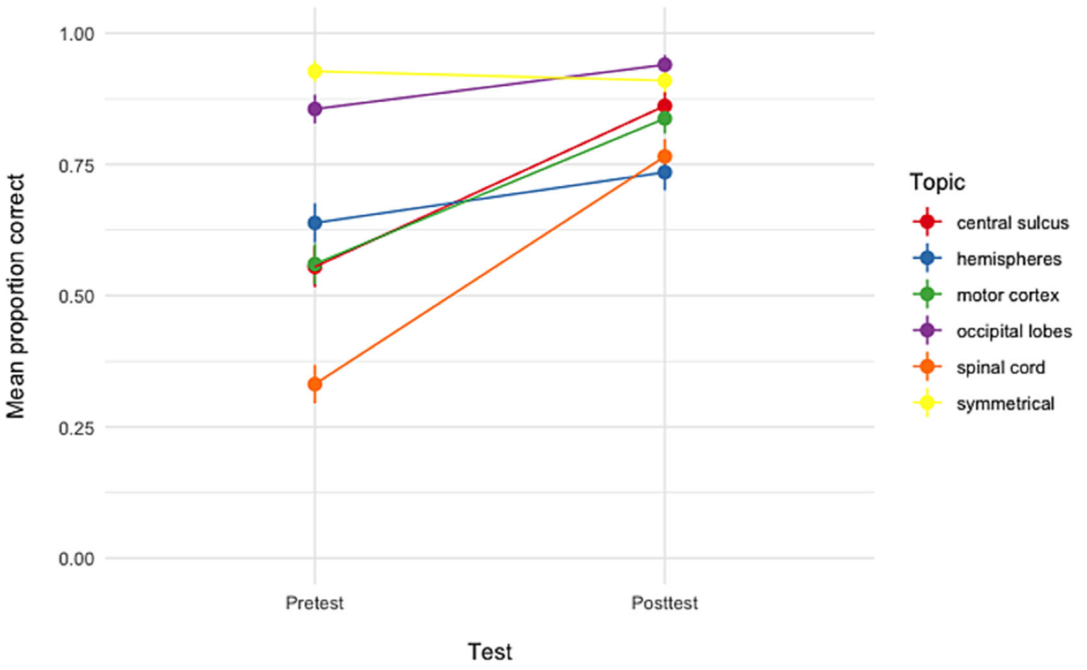

FIGURE 6 Improvement from pretest to posttest after instruction for each of the six matched questions, identified by topic. Shapes depict mean performance in each condition, and the vertical lines depict the standard error of the mean.

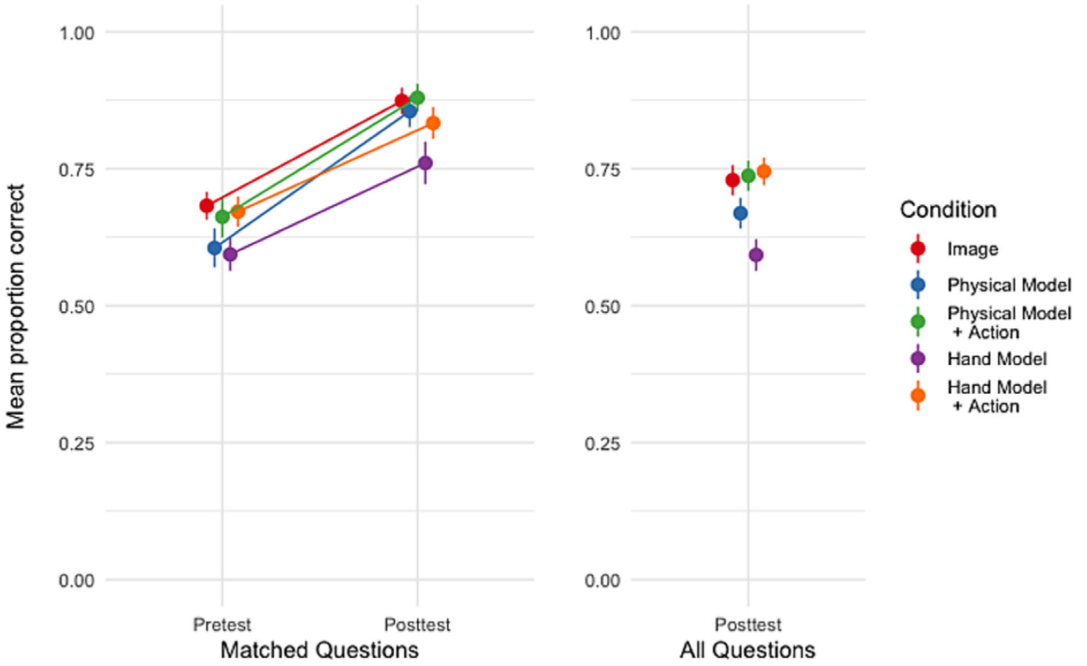

FIGURE 7 Performance on the 6 matched pretest and posttest questions (left panel) and all 30 posttest questions (right panel) for the five experimental conditions. Points depict mean performance in each condition, and the vertical lines depict the standard error of the mean. In our statistical model of all questions, which controlled for pretest performance, participants in the hand model condition performed significantly worse than participants in the hand model + action condition and the physical model + action condition and marginally worse than participants in the image condition.

more than those who observed action on a model, or those who saw static images without any actions. Thus, simply incorporating actions or bodily-based representations into instruction was not enough to support learning in this context.

These findings suggest a complicated relation between instruction and learning. It was not the case that the availability of a particular representation (image, physical model or hand), or the observation or performance of particular behavior (action) uniquely supported learning. Instead, representation and behavior combined to support learning in unexpected ways.

This study does have several limitations. First, because our factors of interest (action observed, action performed, and hand as brain) were not fully crossed, we based our analyses on condition, rather than on these factors, and so we are not able to detect factorial effects. Second, our ability to detect differences may have been hampered by the design of our pretest, which was used to control for prior knowledge in this study. In order to avoid participant fatigue and to ensure that participants had enough time to complete the study, we used a very short pretest. Furthermore, all of the pretest questions had only two answer choices (making chance 50%). As Figure 6 shows, participants performed very well on two of the six pretest questions (a possible ceiling effect). A longer pretest with a larger proportion of difficult questions may have allowed for more space to measure differences in prior knowledge and understand how characteristics of instruction influence learning of particular content.

Another limitation is that although the study was designed to test both immediate and delayed recall, the low response rate for the follow-up test meant we could only test immediate recall. It may be that differences across training would have emerged after a period of consolidation. For adults learning semantic content (as compared to children learning a conceptual principle, equivalence), the shape of the forgetting curve might have varied by training type even without effects at initial learning. Indeed, Cherdieu et al. (2017) compared action observation to observation-plus-performance in anatomy learning and found a benefit of the latter, but only after a delay.

Some characteristics of our experimental design may have decreased the potential benefit of action and gesture. We chose to have participants repeat labels and relationships in all conditions, meaning that all conditions required vocal actions, while some conditions also included added manual actions. While considerable work has been done exploring the most beneficial way to combine auditory and visual information for learners, relatively little is known about the right way to combine the production of speech and gesture or action to support learning. We also used a multiple-choice test with verbal content, rather than free recall or image-based assessments, which may have decreased the likelihood of seeing effects of action production (Steffens et al., 2015).

Our two key findings were that the hand model alone decreased learning compared to the hand model with action, and that learners did no better in conditions that combined action observation and performance compared to conditions involving no manual action. Why might the hand model have decreased learning when actions were not performed? It may be that participants were inhibiting the production of gestures in this condition, and this inhibition may have decreased learning. As noted in the description of the hand model training, our pilot work suggested that participants often spontaneously imitated the actions in the hand model condition, so they were explicitly told not to move their hands. Inhibiting action may have placed an additional burden on memory and attention. While prior work has found no difference in memory performance for participants told not to gesture versus those who simply chose not to gesture (Goldin-Meadow et al., 2001), the question of whether being told not to gesture increases cognitive load has not been directly tested in a learning context so far as we know.

Alternatively, the novelty of the hand model may have distracted learners, thus creating additional cognitive load. While neither the image nor the hand model condition involved action performance or observation, the image condition is familiar to participants as it is similar to material from textbooks, websites, and lecture slides. If there is a cost to the novelty of the hand model, it should also have decreased learning in the hand model + action condition, but in that case a benefit of action may have offset the cost of novelty of the hand model.

Given that many studies have found that learning is improved when learners perform actions/gestures, why might we have failed to find such a benefit? As noted in the introduction, there are many challenges in designing a study to test these effects. First, our design combined action (movements directed at an object) and gesture (tracing, pointing). This is not unique to our work, but in our study some participants also used their hands both as objects (brain model) and as gesturing hands. This combination of action, gesture, and hand-as-model in our trainings may not have capitalize on benefits of action or of gesture. What's more, action and gesture are thought to benefit learners in putting the parts into the whole (Cutica et al., 2014). In our study, pointing and tracing occupied relatively little of the instructional time (approximately 1 min of the 15 min time). Thus, learners may not have spent enough time gesturing to capitalize on the benefits of tracing and pointing.

Second, we did not specifically design our training and test items with regard to element interactivity and cognitive load, which have both have been linked to effects of instructional materials on learning (Sweller, 1994, 2010). While some portions of the training have low element interactivity ("The brain has two hemispheres, left and right. Look at/touch the left hemisphere and say left hemisphere. Look at/touch the right hemisphere and say right hemisphere.") others are considerably more complex, such as training on the internal structure of the primary somatosensory cortex (see training materials in our repository). Further, some test items required participants to hold multiple relationships in mind at once, but this factor was also not systematically controlled. Intrinsic cognitive load may have been low overall. Sweller has suggested (Sweller, 1994, 2010) that when this is the case, tweaking instruction to reduce extraneous cognitive load (load caused by factors not related to the difficulty of the content itself) does not necessarily improve learning. But it is also possible that intrinsic load was high because of the additive effect of building a mental model of the whole brain. Because we did not collect a measure of cognitive load, we cannot assess this factor. Furthermore, one theorized benefit of using gesture as a teaching tool is that it reduces cognitive load by allowing learners to externalize content, freeing up working memory. However, asking learners to imitate specific gestures may also increase extraneous cognitive load. The logic of using gesture despite this potential obstacle is that the cognitive-load reducing capacity of gesture is so beneficial that it outweighs the costs of an increase in extraneous cognitive load. A complex design is necessary to fully test this question. Next steps would be to conduct a study that carefully pits action observation against performance, observation-plus-performance, and at least some other kind of training. We would need to consider intrinsic cognitive load as well as measuring extraneous cognitive load. We would need to do this work in a well-tested domain, using a paradigm that has been successful in the past, given that different learning tasks are a source of variability.

Indeed, anatomy may not be a useful area to use action or gesture to support learning. While robust effects of gestures have been found in the domain of mathematical equivalence (e.g., Cook et al., 2013), and there is also evidence for effects of gesture on foreign word learning (e.g., Sweller et al., 2020), there are other cases where gesture does not appear to improve recall or performance (e.g. Guarino & Wakefield, 2020; Ping et al., 2022). Steffens et al. (2015) present a list of comparisons between action performance and observation, in which over a dozen studies show no benefit. Similarly, while Stieff et al. (2016) found that gesture helped students understand chemical molecules, a study directly comparing gesture instruction to action on a molecule and mental imagery (Ping et al., 2022) found no benefit for gesture relative to other kinds of training (see also DeSutter & Stieff, 2020; Rollinde et al., 2021). And studies failing to find an effect are harder to publish than those showing an effect. As Steffens et al. (2015) point out, while the idea that learning by doing is better than learning by watching is attractive, actual findings from the literature are less clear. Instead, methodological details such as the measure of learning (free or cued recall and percent correct), the delay between learning and test, or whether action performance and observation are intermixed appear to be related to whether benefits of gesture and action are observed. While action observation and performance are thought to be independently beneficial, many studies do not include trainings that control this dimension.

Taken together, a lack of systematic control of performance versus observation, and a lack of fine-grained distinction between action (manipulating an object), gesture (moving the hands in either concrete or abstract ways), and enactment (performing the actions of a character) may lead to a conflation of the findings from different studies, overselling the potential benefits of action and gesture on learning. Similarly, a lack of distinction between various kinds of iconic gestures (including those that point and trace, those that enact movements, and those that mimic actions performed in a training) and abstract or symbolic gestures may lead researchers and practitioners to believe that any kind of action can be employed to support learning of any kind of content. While benefits have been found both for conceptual principles (equivalence) and semantic relationships (foreign language learning), many questions remain about whether, how, and when incorporating different types of gesture and action into learning environments can support learning of various content.

5 | CONCLUSION

We found that a short video training on brain anatomy led to improved understanding of basic relationships and structures. Participants started at around 60% correct and improved to about 80%. We did not find an overall benefit of performing or observing actions during the instruction, and we did not find that using one's own hands to represent the brain generally improved understanding of brain anatomy, compared to other kinds of training. These findings may reflect the particular methodological choices of this study, the content (brain anatomy), or they may reflect the limits of using models and actions to help learners represent and understand material. There are a number of potential mechanisms by which pictures, models, and actions contribute to learning; in order to effectively capitalize on these mechanisms to promote learning across domains; we will need to better understand how and when these mechanisms support learning on their own as well as how they interact and compare with one another.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available via the Open Science framework at https://osf.io/xfaj9/.

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