Prototypical actions with objects are more easily imagined than atypical actions

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Abstract

Tool use is an important facet of everyday life, though sometimes it is necessary to use tools in ways that do not fit within their typical functions. Here we asked participants to imagine characters using objects based on instructions that fit the prototypical actions for the object or were atypical in a novel object-action imagery task. Atypical action instructions either described sensible, substitute uses of the object, or actions that were bizarre but possible. Participants were better able to imagine the prototypical than atypical actions, but no effect of bizarreness was found. We additionally assessed inter-individual differences in movement imagery ability using two objective tests. Performance in the object-action imagery task correlated with the movement imagery tests, providing a link between motor simulations and mental imagery ability.

Keywords:

mental imagery; motor imagery; tool use; motor simulations; praxic knowledge

Introduction

Everyday we use objects to facilitate our ability to accomplish goal-directed actions, spanning everything from eating and writing, to cooking and playing sports. Though the use of man-made artifacts, i.e., tools, to accomplish everyday tasks may appear to be a modern advancement, there is evidence that hominins have been using tools for several million years (Harmand et al., 2015). Indeed, the use of man-made tools and their associated sequences of goal-directed actions have been suggested as having a direct relationship with the development of human cognition (Davidson, 2010; Stout, 2011). Here we investigated how the typicality of instructed actions involving tools can influence mental imagery performance. Further, we examined how this measure of tool-related imagery performance would relate to questionnaire measures of inter-individual differences in motor imagery ability.

Generally, objects can be used to accomplish multiple goal-directed actions; some actions fit the prototypical use of the object, others may be possible as a substitute use of the object when a more suitable option is not available. Other actions may also be accomplished, but do not necessarily make sense. Considering a baseball bat as the object, the prototypical action would be to swing it with two hands (*prototypical*), but it can also be used as a walking support if a cane is not available (*substitute*; cf. variable affordances[1] [Borghi & Riggio, 2015]). A person could also bite into a baseball bat;

[1] While the use of an object for a substitute function constitutes a variable affordance (Borghi & Riggio, 2015), we also think that the term 'affordance' should be used in reference to physical objects and is generally not suitable for images of objects (see Madan et al., 2016, for a detailed discussion).

though possible, this would be a *bizarre* action. This approach of dissociating objects from their prototypical action manipulation has been a focus of recent research (e.g., Matheson et al., 2017; Mizelle & Wheaton, 2010a, 2010b; Mizelle et al., 2013; Tobia & Madan, 2017) and converges with work demonstrating dissociations between functional and manipulation knowledge of objects (e.g., Boronat et al., 2005; Buxbaum et al., 2000; Buxbaum & Saffran, 2002; Garcea & Mahon, 2012; Guérard et al., 2015). We expected that people should perform better at imagining goal-directed actions that are prototypical than atypical. Predictions for a comparison between atypical types of actions, i.e., substitute vs. bizarre, were not as clear. While atypical, substitute actions are still plausible and thus may be more easily imagined than bizarre actions. However, bizarre visual imagery is known to be more distinctive and can be more vivid, known as the *bizarreness effect* (Anderson & Buyer, 1994; McDaniel & Einstein, 1986). As a result, bizarre actions may be imagined better than substitute actions. However, it has been also shown that bizarre imagery is more difficult and can only be effective if sufficient time is given (Mercer, 1996; Toyota, 2002), which may also result in worse performance on these trials.

We additionally were interested if performance in this object-action imagery task related to inter-individual ability in movement imagery. In other words, would participants who were generally better at movement imagery perform better at imagining these goal-oriented actions? To investigate this, we administered the Test of Ability in Movement Imagery (TAMI; Madan & Singhal, 2013, 2014) and the Florida Praxis Imagery Questionnaire (FPIQ; Ochipa et al., 1997). The TAMI involves imagining moving limbs and involves a comparable scale of movement imagery as the object-action imagery task that was primarily of interest. However, actions in the TAMI are not goal-oriented (i.e., intransitive). Thus, any shared processes between the two tasks are related to the movement imagery features, rather than the goal-directed properties. The FPIQ was designed for patients with apraxia (Ochipa et al., 1997), and only recently has been shown to be useful as a measure of movement imagery ability (Donoff et al., 2018; Madan & Singhal, 2013, 2014). Unlike the TAMI, the FPIQ indexes both transitive (i.e., goal-directed) and intransitive movement imagery processes, through four subscales. However, the FPIQ has not yet been used to examine inter-individual differences in a cognitive task (McAvinue & Robertson, 2008).

To summarize, in the current study we asked participants to imagine the presented character shown using a specified object for a prescribed action. As the critical manipulation, actions corresponded to either prototypical or atypical uses of the object. This influence of action typicality on mental imagery would provide insight into the functional knowledge on imagery processes, particularly those relevant to motor simulations. Furthermore, an effect of bizarreness on action-related imagery may be useful in understanding the degree by which imagined actions correspond to semantic knowledge. With the additional inclusion of mental imagery questionnaires, namely the TAMI and FPIQ, we sought to bridge this object-action imagery task with work examining inter-individual ability in movement imagery. The FPIQ was initially designed for assessing apraxia, but here we aim to evaluate its use within healthy individuals as a correlate of motor simulation processes. However, as the FPIQ has yet to be used in this way, we may find that it is not relevant or sensitive enough for these purposes. Unlike the object-imagery task and the FPIQ, the TAMI does not involve goal-oriented imagery, but does involve body-position imagery and shares processes relevant to motor simulation, extending the TAMI's use from only being relevant in assessing movement imagery ability.

Methods

Participants

A total of 45 undergraduate students (19.73 ± 1.94 [$M \pm SD$] years old; 23 female; 42 right-handed) enrolled in an introductory psychology course at the University of Alberta participated for partial course credit. Participants gave written informed consent prior to beginning the study, which was approved by a University of Alberta Research Ethics Board.

Materials

Object images were chosen from a set of normative objects from the Bank of Standardized Stimuli (BOSS) (Brodeur et al., 2010, 2014; Guérard et al., 2015). Objects were selected such that they would be relatively high in motoric properties, while also being amenable to atypical-substitute actions. We selected objects from the 560 objects where Guérard et al. (2015) obtained ratings for graspability, ease of movement, ease of pantomime, and number of actions. The first three of these scales were 7-point Likert scales, , i.e., values ranged from 1 to 7, with higher numbers corresponding to increasing object manipulability. Number of actions was the mean rating and ranged from 0.05 to 4.60, for the full database of 560 objects. For the 112 selected objects, ratings were as follows [$M \pm SD$]: graspability=6.74±0.59; ease of movement=6.74±0.46; ease of pantomime=5.77±1.05; number of actions=1.47±0.29.

Characters were made in Daz Studio 3 (DAZ 3D Inc., Draper, UT) using the Victoria 4.2 (female) and Michael 4.0 (male) base models. Each character had a unique set of clothes and hairstyle. A total of 80 characters were made, and were rendered in poses corresponding to prototypical actions for each of the 112 selected objects, as well as a pose where the character was standing straight with their arms at their sides.

Procedure

The experiment consisted of a computerized imagery task, followed by several pencil-and-paper movement imagery questionnaires.

Object-action imagery task. Participants were instructed that they would be required to imagine a scene based on the provided images and instructions, from a third-person (allocentric) perspective. On each trial, participants were presented with a character, object, and action instruction for 8000 ms. The name of the object was presented under the object image to attenuate any potential issues with identifying the object. Across the 80 trials, the character was male for 40 trials and female for the remaining 40 trials. The screen then went blank for 2000 ms. Next, participants viewed a response screen that presented them with a 3×3 grid of potential responses, showing three different characters in three distinct poses. Responses were numbered and participants selected a response by presenting the corresponding 1-9 key on the number pad portion of the computer keyboard. Participants were also instructed that they could respond ‘0’ if they were unable to form a good mental image. After making their responses, participants saw a blank screen for 500 ms before the next trial began. See Figure 1 for an overview of this procedure.

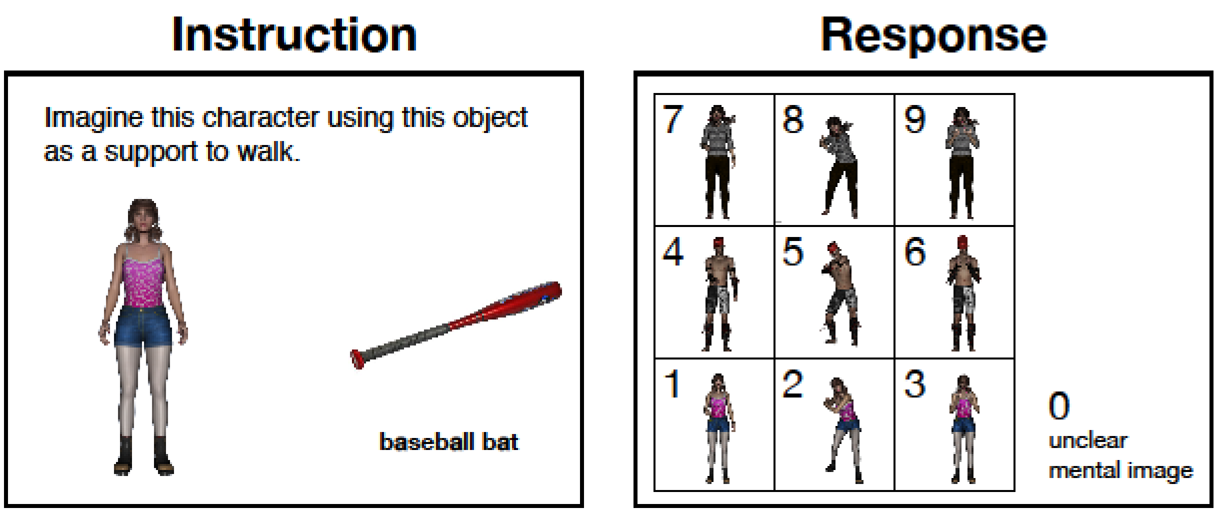

Figure 1. Illustration of the instruction and response screens.

Across 80 trials, on 40 trials the action instruction was ‘prototypical’ for the presented object, and was ‘atypical’ for the remaining 40 trials. When the action instruction was atypical, it was either ‘substitute or ‘bizarre,’ 20 trials of each. Trial order was randomized across conditions. As an example of these instructions, consider the participant was presented with a baseball bat as the object. The *prototypical* instruction was: “Imagine this character swinging this object with two hands.” The *atypical-substitute* instruction was: “Imagine this character using this object as a support to walk.” The *atypical-bizarre* instruction was: “Imagine this character biting into this object.”

The nine responses were presented such that each column showed a different character and each row showed a different manipulation pose (e.g., pantomiming swinging a bat, using a cane, and randomly selected pose from the other objects' generated poses). Thus, only three options presented the correct character and only three options presented the correct pose. On the atypical trials, the pose corresponding to the prototypical instruction was always included as one of the poses. Two of the authors (CRM and AN) went through the poses to exclude ones that may appear correct from being selected as the random pose. The different characters were included to increase task difficulty and increase the likelihood that participants were imagining the object-character-action scenes, rather than just remembering the object image and action instructions and matching them to the potential response images.

Four practice trials preceded the 80 trials of this imagery task (two prototypical, one atypical-substitute, one atypical-bizarre).

Questionnaires. After the computerized object-action imagery task, participants were given two pencil-and-paper questionnaires: the Test of Ability in Movement Imagery (TAMI; Madan & Singhal, 2013, 2014) and the Florida Praxis Imagery Questionnaire (FPIQ; Ochipa et al., 1997).

Briefly, the TAMI consists of 10 questions, preceded by a practice question. For each question, participants were instructed to imagine a series of five movements instructions; each involving manipulations of the head, arm/hand, torso, or leg/foot. After reading the instructions, participants flip to the response page and must select from a set of five body-positioning images, along with the options 'none of the above' and 'unclear.' Each question begins with the instruction to "Stand up straight with your feet together and hour hands at your sides. The correct answer was provided for the practice question and participants were allowed to flip back and ask the experimenter for clarifications, but for the remaining 10 questions, the correct answer was not provided and participants were explicitly instructed not to flip back to the instructions nor ask the experimenter for further clarification. For further details on the TAMI, see Madan and Singhal (2013, 2014, 2015).

The Florida Praxis Imagery Questionnaire (FPIQ; Ochipa et al., 1997) evaluates movement- and object-related imagery ability, using four subscales: kinesthetic, position, action, and object. Each subscale consists of twelve questions, with two possible responses for each. Below are example questions for each subscale.

Kinesthetic: Imagine you are using a handsaw. Which joint moves more, your shoulder or your wrist?

Position: Imagine you are shaving with a disposable razor. Which finger is higher, your index finger or your pinky?

Action: Imagine you are using a nail file to file your nails. Does your hand move in a circle or back and forth?

Object: Is the part of the key you insert into the lock longer or shorter than the part you hold?

Data Analysis

Object-action imagery task. For all conditions, we scored the proportion of trials where the participant chose the image depicting the both the correct character and pose. For the atypical conditions, we additionally scored how often participants chose the pose corresponding with the prototypical action (with the correct character).

TAMI. Responses in the TAMI were scored using the weighted scoring procedure (TAMIw) proposed in Madan and Singhal (2014) and validated in Madan and Singhal (2015). Briefly, instead of scoring the ten questions as a score out of ten, questions are weighted based on their difficulty, such that each question is worth between one and five points. This approach yields a score out of 24, and has been shown to be more sensitive to inter-individual differences (Madan & Singhal, 2014, 2015).

Results

Object-action imagery task

A repeated-measures ANOVA was conducted to compare the correct responses among the three conditions: *prototypical*, *atypical-substitute*, *atypical-bizarre*. The main effect of action typicality was significant [$F(2,88)=39.16$, $p<.001$, $\eta_p^2=.47$]. Post-hoc comparisons indicated that performance in the *prototypical* condition was significantly better than for both *atypical* conditions [both p's < .001; prototypical ($M \pm SEM$): 82.4±1.8%, atypical-substitute: 64.1±2.3%, atypical-bizarre: 64.7±2.9%]. Accuracy did not differ between the two *atypical* conditions [$p=1.00$]. Thus, typicality was relevant to the movement imagery, but it did not matter if the atypical action was bizarre or more sensible.

The type of atypical condition did not influence how often participants chose the incorrect pose corresponding to the correct character and prototypical action [$t(44)=0.04$, $p=.97$; atypical-substitute: 17.7±1.8%, atypical-bizarre: 17.1±2.1%]. Thus, it appears that our differentiation of bizarre or merely ‘substitute’ atypical actions did not bear out in the current paradigm, and will be discussed further in the Discussion section.

Questionnaires

Performance on the TAMI [$M \pm SD$], using the weighted scoring method (TAMIw), was 14.84±4.99 out of 24. This is consistent with prior studies using the TAMI (Madan & Singhal, 2014, 2015).

Performance on the FPIQ subscales was also consistent with prior work with healthy adults (Madan & Singhal, 2013) [kinesthetic: 8.98±1.67, position: 10.53±1.55, action: 10.76±1.25, object: 10.71±1.51; each subscale consisted of 12 questions]. Numerically worse performance on the kinesthetic subscale replicates prior findings (Donoff et al., 2018; Madan & Singhal, 2013; Ochipa et al., 1997 [controls]).

Correlations between object-action imagery task and questionnaires

Mean accuracy in the object-action imagery task (across conditions) significantly correlated with performance on the TAMI [$r(43)=.45$, $p=.002$], suggesting that participants' abilities in imagining the posed characters has similar properties to the imagery processes underlying body movement instructions of the TAMI. Mean accuracy in the object-action imagery task significantly correlated with the action and object subscales of the FPIQ [action: $r(43)=.35$, $p=.02$; object: $r(43)=.41$, $p=.005$]. Correlations with the remaining two subscales of the FPIQ were not significant [kinesthetic: $r(43)=.18$, $p=.24$; position: $r(43)=.25$, $p=.10$]. This pattern of results is not surprising, but is re-assuring. Given the design of the object-action task, it is apparent that performance should be related to similar imagery processes as in the action and object sub-scales of the FPIQ; however, this is nonetheless the first evidence of the FPIQ being useful in a sample of young adults, to index task-related inter-individual differences in imagery ability.

Discussion

In the current study, we examined how well participants could imagine actions that were either prototypical or atypical uses of an object and how performance in these imaged actions related to questionnaire measures of motor imagery. As expected, people were better at imagining the prototypical than atypical actions. Importantly, rather than asking participants to subjectively evaluate their imagined actions, we used an objective task. Specifically, participants were presented with several images of different body positions, i.e., poses, and asked to choose the correct pose from the presented options. This approach was inspired by the Test of Ability in Movement Imagery (TAMI; Madan & Singhal, 2013, 2014), which similarly sought to *objectively* measure movement imagery.

While objects have many potential functional uses (i.e., prototypical actions), functional knowledge is inherently a property of semantic memory. However, an object often has additional manipulation actions where it could be used, but are rarely done (i.e., substitute actions). This distinction has become a recent topic of study within the neuroimaging literature (e.g., Mizelle & Wheaton, 2010a, 2010b; Matheson et al., 2017; Mizelle et al., 2013; Tobia & Madan, 2017). A consideration with these previous studies, however, is that accuracy is quite high, thus only successful action imagery could be examined (Mizelle & Wheaton, 2010b; Tobia & Madan, 2017). Using a novel procedure, here we were able corroborate these findings, while also increasing the difficulty of the task. As such, future neuroimaging studies using a similar paradigm may be able to additionally examine differences in brain activity related to imagery success vs. failure, rather than solely focusing on successful trials.

We also found that across individuals, mean performance correlated with questionnaires designed to assess inter-individual ability in imagery, the Test of Ability in Movement Imagery (TAMI) and the Florida Praxis Imagery Questionnaire (FPIQ). Here we found that performance correlated with imagery of whole-body movements (i.e., the TAMI), as well as the action and object subscales of the FPIQ. This is interesting because it suggests a relationship between imagery for three types of actions: functional actions, whole body actions, and hand actions. This finding supports the idea that motor imagery functions hierarchically for the production of action and may incorporate cognitive processes involved in action simulation (Jeannerod, 1995). This is the first use of the FPIQ as a cognitive psychology measure, as it was initially developed for clinical use. Our findings indicate that the FPIQ can also be useful for indexing ability to imagine tool-related interactions within samples of healthy individuals and should be considered when assessing motor imagery ability as a multidimensional ability (e.g., see McAvinue & Robertson, 2009). Moreover, the FPIQ is an objective measure, and thus cannot be confounded by traits that may result in response biases, such as motor skill confidence.

An important consideration for the results presented here is the role of perspective. In our task, participants imagined characters performing actions from a third-person, allocentric perspective. This point-of-view can be used to evoke movement imagery, however, motor and kinesthetic imagery components require a first-person perspective (Madan & Singhal, 2012). Moreover, this is in alignment with evidence suggesting that perspective plays an important role in motor simulations (e.g., Lorey et al., 2009; Marzoli et al., 2011, 2013; Ruby & Decety, 2001). Between the atypical action instructions, if the atypical action was a plausible substitute use of the object (such as using a baseball bat as a cane) or a bizarre action did not influence participants' performance. As such, it is possible that participants did not process action bizarreness per se, but rather processed the bizarre instruction only semantically and vividly, but did not engage any degree of motor simulation. This account may also relate to our FPIQ results, where the action and object subscales related to performance in the object-action imagery task, but did not relate to the kinesthetic subscale—which is likely more related to motor processing. A further limitation of our comparison of typicality is that some actions involved other body parts as the effector, such as the mouth in imaging to bite the baseball bat, while most actions involved only the hands. We had not considered this difference when designing the study, but is an important consideration for future research.

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