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RESEARCH ARTICLE

Introducing TAMI: An Objective Test of Ability in Movement Imagery

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ABSTRACT. Individual ability in mental imagery varies widely across individuals, leading to the development of questionnaires to evaluate mental imagery. Within the domain of movement imagery, questionnaires have previously relied on subjective ratings of vividness, which may be influenced by additional factors such as motor skill confidence, success of imagined actions, and social desirability. These additional factors are of particular importance when making comparisons between samples from different populations, such as athletes versus nonathletes and patients versus healthy individuals. The authors present a novel test of ability in movement imagery (Test of Ability in Movement Imagery [TAMI]) that relies on objective measures and requires participants to make explicit imagined movements from an external perspective. In Study 1, the authors present evidence that young adults perform at a mid-level on the TAMI. In Study 2, they further compare performance on the TAMI with a battery of other measures to better characterize the TAMI by determining its similarities and differences with existing measures. The findings of both studies indicate the TAMI to be a valid and reliable measure of movement imagery ability. The authors additionally discuss future applications of the TAMI to athletic and clinical research.

Keywords: imagery ability, mental imagery, motor imagery, movement imagery

It has long been known that individual ability in mental imagery varies (Betts, 1909; Fechner, 1860; Galton, 1883). For example, consider the following passage, from the beginning of J. R. R. Tolkien's *The Hobbit* (1937, p. 1):

> [The hole] had a perfectly round door like a porthole, painted green, with a shiny yellow brass knob in the exact middle. The door opened on to a tube-shaped hall like a tunnel: a very comfortable tunnel without smoke, with paneled walls, and floors tiled and carpeted, provided with polished chairs, and lots and lots of pegs for hats and coats - the hobbit was fond of visitors.

The scene that an individual imagines when reading this passage likely will not be identical to the scene imagined by another. These differences may be present in the specific details of the imagined scene, such as the imagined colors and textures of the floor and carpet, but also in the overall vividness of the imagination itself. However, the consequences of interindividual variability in mental imagery ability are not limited to mere discrepancies in the vividness of imagined scenes; these differences can also have important real-world implications. Certain populations of individuals have demonstrated enhanced mental imagery abilities, such as athletes (Cumming & Ramsey, 2009; Jons & Stuth, 1997; Mahoney & Avener, 1977; Nakata, Yoshie, Miura, & Kudo, 2009), while some clinical populations have shown deficits in mental imagery ability (e.g., stroke: Sharma, Pomeroy, & Baron, 2006; Parkinson's disease: Filippi et al., 2000).

Mental imagery can be separated into many types of imagery, including visual, motor, tactile, auditory, and gustatory (Betts, 1909; Olivetti Belardinelli et al., 2004; Sheehan, 1967). In the present study we present a novel objective Test of Ability in Movement Imagery (TAMI); while motor imagery involves an individual imagining him- or herself acting out a motor action, movement imagery is imagined from either an internal (first person) or an external (third person) perspective (Madan & Singhal, 2012a). One important aspect of the TAMI is that it is an objective measure of motor imagery ability (i.e., there are correct and incorrect responses), while nearly all existing questionnaires are based on subjective measures (i.e., rate the vividness of an imagined action).

Prior studies of motor imagery ability often relied on either the Vividness of Movement Imagery Questionnaire (VMIQ; Isaac, Marks, & Russell, 1986; most recently the revised version [VMIQ2]: Roberts, Callow, Hardy, Markland, & Bringer, 2008) or the Movement Imagery Questionnaire (MIQ; Hall & Pongrac, 1983; most recently the MIQ-R [Movement Imagery Questionnaire - Revised, second version]; Gregg, Hall, & Butler, 2010). In the MIQ, participants are asked to act out a sequence of movements and later imagine the same sequence and rate how easy the imagined movements were to see (visual imagery) or feel (kinesthetic imagery). The VMIQ takes a similar self-report approach, but instead asks participants to rate how vividly they can imagine seeing an action (e.g., kicking a ball in the air) being performed by someone else (external visual imagery) or the participant alone (internal visual imagery and kinesthetic imagery subscales; for further discussions of these two questionnaires, see McAvinue and Robertson, 2008). While several studies have tested the validity of these two questionnaires,[1] other studies have found that self-report questionnaires may not correlate with more objective questionnaires (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2010; described subsequently). When comparing movement imagery across populations, such as athletes with nonathletes, young adults with older adults, or healthy controls with clinical populations, subjective report measures of movement

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imagery may be further confounded by population-level differences to a greater degree than has been previously acknowledged. For instance, while many athletes may have better movement imagery abilities than nonathletes, these differences maybe overestimated in self-report measures of movement imagery.

Specific to the comparison of athletes versus nonathletes, several other factors may contaminate subjective measures of imagery ability. Athletes are generally more self-confident in their motor abilities than nonathletes (Rattanakoses et al., 2009; Taylor & Shaw, 2002). Similarly, the outcome of imagined actions can be either successful or unsuccessful, and has been shown to influence the performance of subsequent actions (Beilock, Afremow, Rabe, & Carr, 2001; Nordin & Cumming, 2005; Ramsey, Cumming, & Edwards, 2008; Taylor & Shaw, 2002; Woolfolk, Parrish, & Murphy, 1985) and relate to skill confidence (Evan, Jones, & Mullen, 2004; Guillot & Collet, 2008; Taylor & Shaw, 2002). Subjective measures may also be influenced by social desirability (Allbutt, Ling, Rowley, & Shafiullah, 2011). For example, athletes may find it socially more favorable to respond that they can imagine movements more vividly than nonathletes. These population-level differences may make athletes more likely than nonathletes to report their movement imagery as either more or less vivid than actually experienced, but would not differentially affect performance on an objective test of movement imagery. Similarly, in the case of older adults and clinical patients who may have impaired physical abilities, individuals may misestimate their movement imagery ability in self-report questionnaires in ways that would not affect performance on an objective test. In some cases, these individual may be overconfident of their physical abilities (e.g., older adults in the early decline of physical function; Brach, VanSwearingen, Newman, & Kriska, 2002). Additionally, populations may differ on other cognitive and social factors, such as depression and anxiety (Chou & Macfarlane, 2009; Cress et al., 1995: Louie & Ward, 2010), that may in turn influence movement imagery efficacy. In sum, population-level differences in motor skill confidence in their motor skills and imagining of overly successful/unsuccessful outcomes may be present. While these factors have been shown to influence self-report measures of movement imagery, they should not influence objective measures to the same degree.

Clearly, one way to improve the assessment of movement imagery ability is to create a more objective measure, where participants must explicitly select the correct answer, rather than give a rating of self-perceived vividness on a Likert-type scale. However, researchers have previously acknowledged that it is difficult to objectively assess an individual's ability to imagine physical movements (Collet, Guillot, Lebon, MacIntyre, & Moran, 2011). Nonetheless, several objective tests of movement imagery exist, but only have limited applications. The most popular objective test of movements and rotations is the Mental Rotations Test (MRT; Vandenberg & Kuse, 1978), which is based on the three-dimensional block object images first developed by Shepard and Metzler (1971). However, later research suggests that the MRT may rely more on visual imagery than movement imagery, potentially due to its use of abstract stimuli (Annett, 1995; Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Madan & Singhal, 2012a; McAvinue & Robertson, 2006, 2007; Munzert, Lorey, & Zentgraf, 2009). Other more body-related stimuli such as hands have also been used in objective tests of imagery, though they are still limited to imagery related to only a single body effector, usually the hand (e.g., Cooper & Shepard, 1975; Gemignani et al., 2004; Kosslyn et al., 1998; Parsons, 2001). Another such questionnaire is the Movement Imagery Specific Test (MIST; Moreau et al., 2010); however, it can only be used with athletes in specific sports (e.g., MIST-Wrestling: "I am performing an ankle lace to my opponent's left. Which of his ankles is on the top of the other?"). The Florida Praxis Imagery Questionnaire (FPIQ; Ochipa et al., 1997) is another objective movement imagery questionnaire. The FPIQ asks participants to answer specific tool-related questions (e.g., "Imagine you are using a handsaw. Does your hand move up and down or front to back?"). Intended for patients with apraxia, its applications with healthy adults are more limited and it has yet to be used outside of the clinical domain.

Other objective measures of movement imagery also exist, however, rather than pencil-and-paper responses they rely on physiological measures, such as the Motor Imagery Index (MII) developed by Collet et al. (2011). The MII incorporates psychophysiological measures by measuring skin conductance and heart rate while participants are engaged in the motor imagery task and combines this data with self-report and chronometric measures to create an objective measure of motor imagery ability. Additionally, motor imagery can also be objectively measured using neuroimaging methods (e.g., activation of motor-related cortices when imagining hand or body movements; for a review, see Madan & Singhal, 2012a). While these are objective measure of motor imagery ability, they may be too demanding for older adults and patient populations.

In the extant literature, one questionnaire meets the requirements of being an objective measure of movement imagery ability without these limitations: the Controllability of Motor Imagery test (CMI; Naito, 1994; Nishida et al., 1986). In the CMI, participants are given a sequence of motor instructions and then presented with several body positioning images. After reading the instructions and imagining the corresponding movements, participants are asked to select the image that matches their imagined body positioning. However, the CMI has been used in a handful of studies and is not available from the original authors and was only used in Japanese. Additionally, portions of the CMI were not used in subsequent studies, as some questions "could not be answered by performing with one's own body" (Naito, 1994). Thus, the CMI cannot serve as a fully viable objective measure for future movement imagery research.

Inspired by the CMI, we developed the TAMI. Similar to the CMI, we provide participants with a sequence of body movement instructions and ask them to choose the correct body-positioning image from five candidate images and the additional options of "none of the above" and "unclear." To improve on the CMI, we ensured that all of the questions in the TAMI were reasonably easy to imagine and were only composed of simple motor movements (e.g., stepping one foot forward, turning torso to the side, raising an arm upward). Furthermore, to provide ample opportunity for researchers to utilize the TAMI in future research, we include here a print-ready version of the TAMI as supplemental material along with this article.

To further characterize the TAMI, it is a test of ability in movement imagery that requires participants to make explicit imagined movements. Briefly, all of the questionnaires discussed in the article thus far require participants to consciously and intentionally imagine motor actions. In contrast, it is possible to have participants unconsciously and automatically imagine motor actions, as we passively do everyday when we participate in any type of physical activity, ranging from running for the bus to playing basketball.

In the present article, we propose a novel objective TAMI. In the first study, we present descriptive statistics on the questions that compose the TAMI. In our second study, we report an administration of the TAMI along with a battery of other questionnaires and test for correlations and common factors driving performance in the TAMI and the other measures. We further evaluate the TAMI's test–retest reliability and reproducibility.

STUDY 1

Method

Participants

Participants were 140 introductory psychology students (M age $= 19.3 \pm 1.7$ years; 96 women; 129 right-handed) at the University of Alberta who participated for partial fulfillment of course credit. All participants were required to have learned English before the age of 6 years. Participants gave written informed consent prior to beginning the study, which was approved by a University of Alberta Research Ethics Board.

Measure

The TAMI consists of 10 questions (preceded by one practice question) in which participants are asked to imagine a series of motor movements. Participants are then presented with several images and are asked to select the image that corresponds to their final body positioning.

Questions were produced by randomly combining sequences of four movements involving manipulations of the head, arm–hand, torso, and leg–foot. One example of a movement instruction used in the TAMI is, "Step your left foot 30 cm backward." All questions began with the instruction to "Stand up straight with your feet together and your hands at your sides." Participants were also provided with an image demonstrating this body position (see Figure 1). Each set of movement instructions was followed by a set of five images demonstrating possible body positions, along with the choices of "none of the above" and "unclear." For each question, a body-positioning image was created to include the body positioning that would result if all of the movement instructions were followed correctly (except for questions 4 and 7, where the correct answer was "none of the above"). Each question also included a body-positioning image that was nearly correct and included at least two likely errors (e.g., moving the right foot instead of the left foot). Additional body position images were created to serve as lure images and to lower the probability of choosing the correct image by chance. Most images were also included in more than one question to serve as additional lure images. Body-positioning images were created with the Victoria 4.2 model in DAZ Studio 3 (DAZ 3D Inc., Draper, UT). Three-dimensional rendered images were further processed in Adobe Illustrator CS5 (Adobe Systems Inc., San Jose, CA) to produce outline versions of the images.

Participants were first provided with a practice question. After choosing a body-positioning image as a response, participants were provided with the correct answer and given a chance to flip back and reread the instructions and ask the experimenter for clarification. For the remaining questions, participants were explicitly told that they could not flip back to the previous page.

Procedure

Participants completed the questionnaire independently, though the researcher administering the questionnaire was nearby to provide clarification if requested. The questionnaire required approximately 10 min to complete.

Data from participants that flipped back to the instructions when answering a nonpractice question were excluded from analyses ($n = 7$).

Data Analysis

Responses on the TAMI were scored as correct only if the participant chose the single correct answer, with no partial grades being awarded. TAMI scores thus could be any integer value between 0 and 10.

To investigate the properties of the distribution of TAMI scores of participants in this sample, we calculated the skewness of the distribution of scores. Because skewness is a measure of symmetry, a normal distribution has a skewness equal to zero (i.e., perfect symmetry). Thus, we formally tested if the TAMI scores follow from a normal distribution using the Jarque-Bera test of normality.

Results

Participants' mean TAMI score was 7.49 ($SD = 1.62$). The skewness and was slightly negative, suggesting a bias toward higher scores on the TAMI (skewness = –0.45). Nonetheless, participants' performance on TAMI followed a normal

FIGURE 1. The body-positioning image presented to accompany the first instruction of every question in the Test of Ability in Movement Imagery: "Stand up straight with your feet together and your hands at your sides."

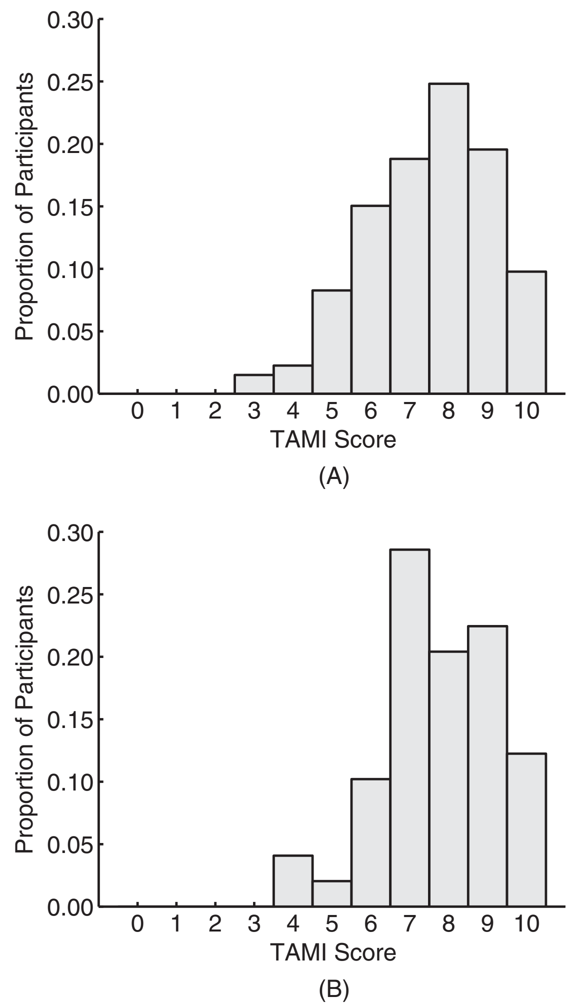

FIGURE 2. Distribution of participants' scores on the Test of Ability in Movement Imagery (TAMI) in (**A**) Study 1 and (**B**) Study 2.

distribution, $JB(132) = 4.81$, $p > .05$. Figure 2A illustrates the distribution of participants' TAMI scores.

Table 1 lists the proportion of participants that responded with each possible answer (results are combined with those from the first session of Study 2), for each question of the TAMI. Note that incorrect responses are not equally/randomly distributed across all options. This is likely due to the fact that some of the distractors are closer in terms of imagery characteristics to the correct response than others (e.g., larger limb movements relative to smaller head movements).

As the body-positioning images used in the TAMI are all based on a female form, it is possible that female participants might have performed better on the TAMI than men. Critically, we found no difference in the TAMI scores between men and women, $t(130) = 0.78$, $p > .1$.

Discussion

In Study 1, we found that the TAMI can be used with healthy young adults. Scores followed a normal distribution, though were slightly skewed toward higher scores. Nonetheless, performance was relatively far from ceiling effects to still allow for comparison populations to have relatively higher scores on average (e.g., athletes) as well as being sufficiently above floor effects to allow for populations with lower scores (e.g., older adults or patient groups). However, before the TAMI can be used as a proper test in movement imagery research, we must first explore the underlying factors that influence performance on the TAMI. For example, it is presently unclear to what extent the TAMI is influenced by visual imagery versus movement imagery. An even more

TABLE 1. Proportion of Participants' Responses to Each Question, for Each Possible Option

	Question									
Option	1	2	3	4	5	6	7	8	9	10
A	0%	2%	0%	4%	**83%**	0%	0%	0%	41%	0%
B	**90%**	1%	2%	2%	1%	**60%**	4%	0%	1%	**73%**
C	0%	7%	1%	31%	1%	0%	1%	0%	**38%**	16%
D	7%	1%	**95%**	0%	1%	13%	1%	0%	3%	1%
E	0%	**80%**	0%	4%	4%	0%	2%	**91%**	2%	0%
F	3%	10%	3%	**58%**	9%	23%	**90%**	9%	12%	8%
G	0%	1%	0%	2%	1%	3%	3%	0%	4%	2%

Note. Correct answers are shown in bold.

critical issue is the TAMI's instruction to have participants not flip back to the instructions. While this is important in ensuring that the TAMI is not too easy to perform, it also raises the possibility that working memory influence in performance in the TAMI.

STUDY 2

In the second study, we sought to compare performance on the TAMI with a battery of similar questionnaires to better understand the factors that underlie performance on the TAMI as a test of the TAMI's construct validity.

Before being able to state that the TAMI is a test of movement imagery, it is important that it be compared to existing tests of movement imagery, such as the Vividness of Movement Imagery Questionnaire, revised version (VMIQ2; Roberts et al., 2008).

VMIQ2

The VMIQ2 is a subjective test of movement imagery, first developed by Isaac et al. (1986). Participants are given a list of several actions (e.g., running up stairs, riding a bike) and asked to subjectively rate how vividly they can imagine the action through internal visual imagery, external visual imagery, and kinesthetic imagery. Subjective ratings are made on a 5-point Likert-type scale with responses ranging from 1 (*no image at all, you only "know" that you are thinking of the skill*) to 5 (*perfectly clear and as vivid as normal vision or feel of movement*). While the original version of the VMIQ did not include the kinesthetic component and its instructions were unclear (see McAvinue & Robertson, 2009), these issues were resolved in the revised version.

Even though the VMIQ relies on self-report measures of imagery, it nonetheless has been used in numerous studies and is a test of movement imagery. Thus, we would expect that performance on the TAMI and the VMIQ should be highly correlated despite their use of objective versus subjective measures, respectively. Unlike the MIQ, which requires participants to execute the instructed motor action just prior to imagining them, the VMIQ requires participants to only imagine the instructed action. This difference was critical when selecting which measures to include in the present study, as we wanted to measure motor imagery ability such that it could not be contaminated by interindividual variability in motor skills. For example, certain individuals may have motor execution deficits, but are not necessarily impaired in their motor imagery ability. We expected performance on the TAMI and the VMIQ2 would be reasonably correlated, as both are designed to measure ability in movement imagery.

To further test the validity of the TAMI, we also included the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), which we expect to be also correlated with the TAMI as they both involve visual imagery, but this relationship should be weaker than that with the VMIQ.

VVIQ

The VVIQ was developed prior to the VMIQ and generally follows the same procedure: Participants are given a description of a scene or object to imagine and are asked to rate the vividness of the imagined scene or object on a 5-point Likert-type scale. Here we chose to use the VVIQ rather than the revised version (VVIQ2) due to its greater similarities with the VMIQ2 and shorter length.

Correlating performance on the VVIQ with TAMI scores will give us an indication regarding TAMI's reliance on visual imagery processes. However, it was likely that we would find significant correlations between these two measures, as the VVIQ has been found to be highly correlated with the VMIQ (Eton, Gilner, & Munz, 1998; Isaac et al., 1986). In addition, due to the multiple-choice body positioning images used in the TAMI, it is likely that the TAMI involves a substantial visual imagery component.

In addition to testing for correlations between the TAMI and subjective measures of mental imagery, it is also important, if not more important, to compare it with other objective tests of mental imagery.

FPIQ

The FPIQ (Ochipa et al., 1997) is an objective test of explicit movement imagery, similar to the TAMI, and consists of four subscales: kinesthetic, position, action, and object. In the kinesthetic subscale, participants are asked questions about joint movement when interacting with a specified tool (e.g., "Imagine you are using a handsaw. Which joint moves more, your shoulder or your wrist?"). The position subscale tests an individual's ability to imagine body positions required when interacting with specific objects, while the action subscale tests for imagery of the object-related actions. Finally, the object subscale directly tests participants' ability to imagine objects, without requiring any imagination of body–object interactions. To ensure that the FPIQ is not overly difficult for its intended patient group to complete, each question only has two possible responses.

As the name suggests, the FPIQ was constructed as a test of apraxia and its questions primarily focus on tool use. The FPIQ shares commonalities with the TAMI, and we expected performance on the two measures would be positively correlated, especially with the position subscale of the FPIQ. However, the FPIQ may not be sensitive enough to interindividual differences in a sample of healthy controls, thus weakening the strength of our correlations (i.e., mean accuracy in the control group in Ochipa et al. [1997] was near 11/12 for all four subscales).

As an additional objective test of mental imagery, we also included the MRT (Vandenberg & Kuse, 1978).

MRT

The mental rotations test was first developed by Shepard and Metzler (1971); participants are presented with two three-dimensional block object images and are asked to mentally rotate the blocks to determine if both images are of the same block object or of different objects. The test was later adapted into pencil-and-paper form by Vandenberg and Kuse (1978). This version of the MRT presents participants with five block images on each trial: one target and four samples. Participants are asked to identify which two of the sample images can be produced by rotating the block object depicted in the target image. The MRT was subsequently redrawn and further developed by Peters et al. (1995). However, as noted previously, it is suggested that the MRT is more a test of visual imagery than of movement imagery. Thus, by including the MRT, we can determine whether participants perform TAMI with visual imagery processes.

In the TAMI, participants were not allowed to flip back to the instructions, as this would be too easy to respond correctly and participants would perform at ceiling. However, it is possible that this property of the TAMI may make it more reliant on working memory ability than other tests of movement imagery. To test this empirically, we included a variant of the Corsi block-tapping task, which has widely been used as a test of visuospatial working memory (e.g., Berch, Krikorian, & Huha, 1998; Kessels, Kappelle, de Haan, & Postma, 2002; Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000; Morris et al., 1988; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006; Rowe, Hasher, & Turcotte, 2008; Vecchi & Richardson, 2001).

The (original) Corsi block-tapping task was developed by Corsi (1972) as a clinical test of visuospatial working memory and was first described in Milner (1971; for detailed discussions of the Corsi task, see Berch et al., 1998; Kessels et al., 2000). In the original task, participants are presented with an arrangement of cubes on a desk (see Figure 1 of Kessels et al., 2000). The experimenter taps blocks in a sequence, starting with just two, and then asks the participant (or patient) to tap the blocks in the same order. If the participant taps the blocks in the correct order, the experiment continues with the next trial. The number of blocks in the sequence (i.e., span) gradually increases. The task ends when a participant fails to reproduce two sequences of equal length. A participant's span is defined as the length of the last correctly repeated sequence.

Modified Corsi Block-Tapping Task

In our modified version of the Corsi task, we presented the block arrangement from a two-dimensional, top-down view, using the same positions as illustrated in Appendix A of Kessels et al. (2000). This modification of the Corsi task to a two-dimensional viewpoint has been used in numerous prior studies (e.g., Aldenkamp, Alpherts, Moerland, Ottevanger, & van Parys, 1987; Malhotra et al., 2005; Morris et al., 1988; Rowe et al., 2008) as well being a further modified version used in the Cambridge Neuropsychological Test Automated Battery (CANTAB; see Owen et al., 1990). Here a low correlation between the TAMI and the modified Corsi task would indicate that performance on the TAMI only marginally relies on processes that are shared with working memory.

In addition to conducting correlations between TAMI and the aforementioned measures, we also conducted an exploratory factor analysis using participants' scores across all measures. Through this factor analysis, we were additionally able to identify common factors that drove performance across the multiple measures.

Furthermore, the present study was conducted over two sessions separated by a two-week delay. This allowed us to additionally assess the test–retest reliability of the TAMI. To determine the minimum sample size needed for the test–retest correlations, we conducted a power analysis in G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). Based on the standard deviation in the TAMI scores obtained in Study 1, we determined that we would require a minimum sample size of 21 participants to minimize the likelihood of both Type I and Type II errors ($\alpha = .05$; Power $[1 - \beta] = .70$), given a difference between test and retest of 0.5 standard deviation or greater.

Finally, we combined the TAMI data from Studies 1 and 2 to measure the reproducibility of the mean TAMI scores across both samples.

Methods

Participants

Participants were 49 introductory psychology students (*M* age = 19.6 ± 1.7 years; 29 women; 47 right-handed) at the University of Alberta who participated for partial fulfillment of course credit. All participants were required to have learned English before the age of 6 years. Participants gave written informed consent prior to beginning the study, which was approved by a University of Alberta Research Ethics Board.

Measures

TAMI

The TAMI was administered following the same procedure as in Study 1.

VMIQ2

The VMIQ2 consists of 12 items, each describing a to-be-imagined movement, all of which are listed in Roberts et al. (2008). Participants are asked to imagine each of these 12 movements from using three types of imagery (i.e., subscales): external visual imagery, internal visual imagery, and kinesthetic imagery. For each movement and imagery type, participants rate the vividness of the imagined movement on a 5-point Likert-type scales with responses ranging from 1 ("perfectly clear and as vivid as normal vision or feel of movement") to 5 ("no image at all, you only 'know' that you are thinking of the skill"). See Roberts et al. for further details regarding the VMIQ2.

FPIQ

The FPIQ consists of four subscales: kinesthetic, position, action, and object. Each subscale consists of 12 questions, each of which has two possible responses. In the present study, all participants completed the subscales in the fixed order listed previously. For further details on the FPIQ, see Ochipa et al. (1997).

MRT

The MRT consisted of 24 questions, preceded by four practice questions. In each question, one three-dimensional block image as a target image, along with four similarly shaped sample images. Two of the sample images represent rotated versions of the target block image, while the remaining two represent different block images. Participants are required to choose the correct two sample images on each trial, with no partial grades being awarded for selecting only one sample image correctly. Here we used the MRT-A from Peters et al. (1995), which is redrawn from the Vandenberg and Kuse's (1978) original version.

VVIQ

The VVIQ consists of 16 questions, each instructing the participant to imagine a specific scene or object. As in the VMIQ, participants are asked to rate the vividness of imagined scene or object on a 5-point Likert-type scale, with responses ranging from 1 ("perfectly clear and vivid as normal vision") to 5 ("no image at all, you only 'know' you are thinking of an object"). In the present study we made a small modification to the VVIQ: The original VVIQ would ask participants to write their response (i.e., their rating between 1 and 5) on a blank beside the question number. However, in developing the VMIQ2, Roberts et al. (2008) suggested that participants would find it easier to circle a number as their response instead. As such, we presented each question of the VVIQ along with all possible ratings between 1 and 5, with participants instructed to circle their response. All other aspects of the VVIQ were done as described in Marks (1973).

Modified Corsi Block-Tapping Task

The modified Corsi task was presented via a computer. On each trial, participants were first presented with the arrangement of squares (as shown in Appendix A of Kessels et al., 2000) for 2 s. To present a sequence, the color of a single block was then changed (i.e., lit up) for 1 s, immediately followed by a subsequent block. At the end of each sequence, the text "End of Sequence. Write down your response." was presented for 15 s. Participants had been given blank arrangements of squares, and were asked to mark down the location or sequence that the blocks were presented by writing a number on the block corresponding to when it was lit up (e.g., write 1 on the first block to be presented). Participants were presented with the same sequences as listed in Appendix B of Kessels et al. (2000; i.e., spans 2–8, with two sequences of each span). All participants were presented with all sequences regardless of performance on earlier sequences. Prior to the actual task, participants were given two practice trials of spans 3 and 4, respectively.

We measured performance on our modified Corsi task through two measures: (a) the longest sequence correctly repeated by the participant (i.e., the span) and (b) the accuracy on each sequence multiplied by the length of the sequence or difficulty, referred to as the product. The product measure was included as we thought it would be more sensitive than the span alone and it is intended to be similar to the total score measure described in Kessels et al. (2000), but additionally accommodates for our modified procedure where participants are for presented with increasingly longer sequences regardless of performance (i.e., they may get an earlier sequence incorrect, but still respond correctly to a longer sequence).

Procedure

Questionnaire measures were separated into two sessions, such that they each contained a diverse array of questionnaires (e.g., the VMIQ and the VVIQ were intentionally not assigned to the same session). Questionnaires were divided across the two sessions in the following way:

Session A: TAMI, VMIQ2, MRT
Session B: TAMI, FPIQ, VVIQ, modCorsi (modified Corsi block-tapping task)

In their first (or only session), participants were randomly assigned to complete either the questionnaires of Session A or Session B. However, within these two sessions, participants were given the questionnaires in a fixed order. For example, in Session A, all participants did TAMI, then VMIQ2, then MRT (e.g., no participant ever completed the MRT before the TAMI). Participants completed the questionnaire independently, though the researcher administering the questionnaire was nearby to provide clarification if requested. Each session took just under 1 hr to complete.

Two weeks later a subsample of participants completed the other session (i.e., Session B if they first did Session A). This two-session design allowed us to collect a greater number of measures from the same participant, reduced effects of fatigue, as well as to allowed for the assessment of the TAMI's test–retest reliability. This subsample consisted of 24 participants who voluntarily returned for the second session. Only participants that participants who attended both sessions were included when calculating the test–retest correlation.

At the end of the first session, participants completed a demographics questionnaire. At the end of the second session, participants again completed the demographics questionnaire (to aid in cross-indexing across the two sessions) and were additionally asked if they remembered their TAMI responses from the first session. In the TAMI, none of the participants flipped back to the instructions when answering a nonpractice question.

Data Analysis

As in Study 1, we first evaluated the properties of the distribution of participants' scores on the TAMI. Test–retest reliability was measured using the Pearson's product-moment correlation coefficient (r), as was done in previous studies tests of movement imagery (e.g., Gregg et al., 2010; Isaac et al., 1986). Four participants reported remembering their responses to the TAMI from the first session and were excluded from the test–retest correlation analysis. Combining data across the two studies we also were able to test TAMI's reproducibility (ρ_c; Lin, 1989; Nickerson, 1997).

To test the construct validity of the TAMI, we tested for significant correlations between performance on the TAMI with each of the VMIQ2, VVIQ, FPIQ, MRT, and modified Corsi task. Mean performance and descriptive statistics were also calculated for each of these other measures, for comparison with previous studies.

Results

TAMI

Participants' mean TAMI score was 7.76 ($SD = 1.49$). The skewness (–0.46) was again slightly negative, suggesting a bias toward higher scores on the TAMI. Participants' performance on the TAMI followed a normal distribution, $JB(48) = 1.64$, $p > .1$. Figure 2B illustrates the distribution of participants' TAMI scores. Table 1 lists the proportion of participants that responded with each possible answer (results are combined with those from Study 1), for each question of the TAMI based on only the first session of the TAMI. As in Study 1, we found no difference in the TAMI scores between men and women, $t(47) = 1.26$, $p > .1$.

We found the TAMI to have a relatively high test–retest correlation, $r(19) = .71$, $p < .001$, comparable to test–retest correlations previously reported for the VMIQ and the VVIQ (Eton et al., 1998; Isaac et al., 1986). Comparing the mean performance on each question across both studies, we found the reproducibility of the TAMI to be relatively high, $\rho_c(8) = .85$, $p < .01$.

Other Measures

Descriptive statistics for each measure are listed in Table 2. In general, average scores are consistent with those previously reported.

In the VMIQ2, participants had marginally lower scores for external visual imagery than for internal visual imagery and kinesthetic imagery, as reported in Roberts et al. (2008).

In the FPIQ, participants scored near ceiling. The healthy controls in Ochipa et al. (1997) scored slightly higher than our participants, but these differences may be attributed to differences in motivation, with Ochipa et al.'s participants being age-matched healthy controls for a clinical study. Nonetheless, both here and in the controls from Ochipa et al., participants performed marginally worse on the kinesthetic subscale than on the other three subscales.

Performance on the MRT was also approximately the same as previously reported (e.g., McAvinue & Robertson, 2007; Peters et al., 1995; Vandenberg & Kuse, 1978), as was true of the VVIQ (e.g., Eton et al., 1998; Marks, 1973).

Average span on our modified Corsi task was comparable to findings reported in healthy controls in a number of studies (e.g., Aldenkamp et al., 1987; Morris et al., 1988). Note that performance in healthy individuals was lower in these studies, as well as our own, than in Kessels et al.'s (2000) normative study. However, these differences in average span across studies may be attributed to the use of the two-dimensional Corsi, with this modified version being more difficult than the original due to its less immersive design.

Correlations Between TAMI and the Other Measures

The other questionnaires were included in the present study primarily to allow us to test potential commonalities

TABLE 2. Descriptive Statistics and Correlations With the TAMI for All Measures From Study 2

	Descriptive statistics				
	M	*SD*	Possible range	Observed range	Correlation with the TAMI[a]
TAMI	7.76	1.49	0–10	4–10	.71***[b]
VMIQ2-IV[c]	23.00	8.67	60–12	52–12	.36*
VMIQ2-EV[c]	26.49	8.30	60–12	49–12	.24
VMIQ2-Kin[c]	21.38	7.85	60–12	46–12	.05
FPIQ-Pos	10.14	1.38	0–12	5–12	.45**
FPIQ-Act	10.33	1.83	0–12	6–12	.39*
FPIQ-Obj	10.67	1.37	0–12	7–12	.34*
FPIQ-Kin	8.61	1.55	0–12	5–11	.24
MRT	13.32	4.75	0–24	6–24	.15
VVIQ[c]	30.47	10.30	80–16	55–16	.43**
modCorsi-Span	5.44	1.58	0–9	2–8	–.20
modCorsi-Prod	33.44	14.41	0–88	10–72	–.09

Note. TAMI = Test of Ability in Movement Imagery; VMIQ2 = Vividness of Movement Imagery Questionnaire, revised version; VMIQ2-IV = VMIQ2 internal visual imagery subscale; VMIQ2-EV = VMIQ2 external visual imagery subscale; VMIQ2-Kin = VMIQ2 kinesthetic imagery subscale; FPIQ = Florida Praxis Imagery Questionnaire; FPIQ-Pos = FPIQ position subscale; FPIQ-Act = FPIQ action subscale; FPIQ-Obj = FPIQ object subscale; FPIQ-Kin = FPIQ kinesthetic subscale; MRT = Mental Rotations Test; VVIQ = Vividness of Visual Imagery Questionnaire; modCorsi = modified Corsi block-tapping task.
[a]Correlations between TAMI and other measures use the score from the TAMI administered in the same experimental session.
[b]Test–retest correlation across both experimental sessions.
[c]In the VMIQ2 and VVIQ, lower scores correspond to better imagery. Correlations with VMIQ2 and VVIQ are sign-adjusted such that a positive correlation indicates a better score on both measures.
†$p < .10$; *$p < .05$. **$p < .01$. ***$p < .001$.

between the TAMI and the other measures. All correlations are reported in Table 2.

Performance on the TAMI was significantly correlated with internal visual imagery component of the VMIQ2, $r(36) = .36$, $p < .05$, but was uncorrelated with both the external visual imagery and kinesthetic imagery scales (both *p*s > .1). This suggests that participants may have been using internal visual imagery when performing the TAMI.

Scores on the TAMI were significantly correlated with the position, action, and object subscales of the FPIQ (all *p*s < .05), but not the kinesthetic subscale ($p > .1$). This is particularly important as it suggests that performance on the TAMI and the FPIQ share many properties, which is reassuring considering that they are both objective tests of movement imagery. These correlations were the highest for the position subscale, $r(35) = .45$, $p < .01$, which is particularly indicative of commonalities between the imagery required in this subscale of the FPIQ and movement instructions and body-positioning images used in the TAMI. Additionally, it is unsurprising that the TAMI does not correlate with kinesthetic subscale of the FPIQ, as questions in the TAMI do not involve any kinesthetic properties. These results also indicate that the FPIQ is indeed sensitive to be used in samples of healthy individuals, and not only for comparison with clinical populations.

As tests of visual imagery, we included both the MRT and the VVIQ. Performance on the MRT appears to have no relation to performance on the TAMI ($p > .1$), suggesting that participants perform the TAMI using a different type of imagery when rotating or moving their imagined body position than when rotating abstract block images. TAMI scores were significantly correlated with performance on the VVIQ, $r(35) = .43$, $p < .01$. This is reasonable considering the higher correlations previously observed between the VVIQ and the VMIQ (Eton et al., 1998; Isaac et al., 1986), as well as between the VVIQ and the MIQ (Hall & Martin, 1997).

Performance on the TAMI did not significantly correlate with either measure from the modified Corsi task (both *p*s > .1), suggesting that TAMI is not confounded by variability in working memory ability.

Exploratory Factor Analysis

To further characterize TAMI with respect to the other measures administered in Study 2, we conducted an exploratory factor analysis. More generally, our goal was to summarize the data of all measures obtained in this study and to determine the latent factors that influenced multiple measures.

As a preliminary analysis, we first assessed the suitability of our data for factor analysis. Results of Bartlett's test of sphericity support the existence of factors within the data, $\chi^2(66, N = 49) = 137.90$, $p < .001$. Thus, we then proceeded to conduct the factor analysis using a principal component

TABLE 3. Varimax-Rotated Factor Loadings for the Measures From Study 2

	Factor					
	I	II	III	IV	V	h^2
Task measures						
VMIQ2-IV	0.93					0.89
VMIQ2-EV	0.87					0.85
VMIQ2-Kin	0.73					0.64
VVIQ	0.63		0.56			0.71
modCorsi-Span		0.95				0.68
modCorsi-Prod		0.92				0.75
MRT			0.91			0.93
FPIQ-Act			0.70			0.89
FPIQ-Obj			0.48		0.51	0.87
TAMI				0.81		0.82
FPIQ-Pos				0.93		0.92
FPIQ-Kin					0.86	0.88
Factor statistics						
Eigenvalue	2.69	2.08	1.98	1.70	1.36	9.81
Variance (%)	22.42	17.40	16.48	14.18	11.29	81.77

Note. Factor loadings less than .40 have not been printed and variables have been sorted by loadings on each factor, while maintaining conceptual groupings. Eigenvalues and percentage of variance are after rotation. h^2 = communality; VMIQ2 = Vividness of Movement Imagery Questionnaire, revised version; VMIQ2-IV = VMIQ2 internal visual imagery subscale; VMIQ2-EV = VMIQ2 external visual imagery subscale; VMIQ2-Kin = VMIQ2 kinesthetic imagery subscale; VVIQ = Vividness of Visual Imagery Questionnaire; modCorsi = modified Corsi block-tapping task; MRT = Mental Rotations Test; FPIQ-Act = FPIQ action subscale; FPIQ-Obj = FPIQ object subscale; TAMI = Test of Ability in Movement Imagery; FPIQ = Florida Praxis Imagery Questionnaire; FPIQ-Pos = FPIQ position subscale; FPIQ-Kin = FPIQ kinesthetic subscale.

analysis extraction method with an orthogonal (varimax) rotation method.

Both Kaiser's criterion and the scree test criterion indicated the presence of five latent factors in our data. This conclusion was further supported by the percentage of variance criterion (see Hair, Anderson, Tatham, & Black, 1995) that suggests that all retained factors should account for at least 60% of the total variance. This five-factor solution explained 81.77% of the variance. Communalities for all measures were reasonably high (*M* communality = .82; see Table 3) suggesting that all measures were adequately accounted for by the five-factor solution; all communalities were above .50. All measures significantly loaded on at least one factor and we observed a minimal amount of cross-loading.

As suggested by Hair et al. (1995), only factor loadings above .40 (or below –.40) were considered to meet the minimal level for interpretation of factor structure. Rotated factor loadings are reported in Table 3. Items that salient loadings on Factor I included the three scales of the VMIQ2 and the VVIQ. Both of these measures comprised the only tests of subjective mental imagery used in the study. Factor II was loaded on by two measures from the modified Corsi task, and thus corresponded to working memory. Factor III was loaded on by several measures: the VVIQ, the MRT, and two subscales of the FPIQ (action and object), all measures focused on the visual properties of imagined objects. Factor IV was loaded on by the TAMI and the position subscale of the FPIQ, the two objective measures of movement imagery. Factor V was loaded on by the object and kinesthetic subscales of the FPIQ, the two measures most focused on the physical properties of imagined objects. Thus, the five factors were named as subjective mental imagery, working memory, visual imagery of objects, objective movement imagery, and tactile imagery of objects.

Considering that several of our measures involved imagery of objects, namely the four measures comprising the FPIQ, it is unsurprising that object-specific imagery played a key role in the interpretation of the factor analysis. Nonetheless, we observed that the TAMI grouped with the position subscale of the FPIQ, but none of the VMIQ2 measures, providing evidence supporting the initial hypothesis of different latent factors influencing subjective and objective tests of movement imagery. Additionally, it is reassuring that the VMIQ2 and VVIQ grouped together, as they were administered in separate experimental sessions. Furthermore, the grouping of the VMIQ2 with the VVIQ also serves to replicate and extend prior studies finding strong correlations between the original VMIQ and the VVIQ (Eton et al., 1998; Isaac et al., 1986).

GENERAL DISCUSSION

In two studies, we presented a novel test of ability in movement imagery (TAMI) that relies on objective measures and requires participants to make explicit imagined movements. In the first study, we tested the TAMI with a sample of young adults and found them to perform at a mid-level on the TAMI. In the second study, we compared performance on the TAMI with a battery of other measures in order to better characterize the TAMI by determining its similarities and differences with existing measures. The findings of both studies provide evidence that the TAMI is a reliable test of ability in movement imagery. Additionally, the TAMI was built with applications to a variety of populations in mind, ranging from athletes to patients.

Comparing the TAMI to Extant Tests of Mental Imagery

In the second study we tested TAMI's construct validity to determine the key characteristics of the TAMI and understand what aspects of movement imagery it is influenced by. Performance on the TAMI correlated strongly with the internal visual imagery subscale of the VMIQ2, as well as the VVIQ, suggesting that the TAMI is primarily influenced by the visual aspects of movement imagery. Correlations with the kinesthetic subscales of the VMIQ2 and FPIQ were not significant, indicating that kinesthetic aspects of movement imagery did not influence performance on the TAMI.

The TAMI was significantly correlated with the remaining three subscales of the FPIQ (position, action, object), supporting the notion that the TAMI tests similar constructs as the FPIQ. The correlation with the MRT was not significant, suggesting that participants did not employ the same type of mental rotations when imagining the body movements in the TAMI, as they do when rotating the 3D abstract block configurations used in the MRT.

Finally, correlations with the modified Corsi task were not significant, suggesting that working memory ability does not play a significant role in performance in the TAMI.

Using Objective and Self-Report Measures of Motor Imagery

Despite our evidence of the TAMI as a novel test of ability in movement imagery, we do not necessarily suggest that the TAMI be used as a sole measure of movement imagery. Instead, it would be ideal to use it as a complementary approach to test an individual's ability with movement imagery processes in conjunction with other objective measures (e.g., the MII [Collet et al., 2011]) and self-report measures. This notion is supported by a large body of research that suggests that objective and self-report measures of physical ability are influenced by different factors and explain different sources of variability in real life situations (e.g., Chou & Macfarlane, 2009; Cress et al., 1995; Reuben, Siu, & Kimpau, 1992). Notwithstanding the issues noted in the Introduction of this article, self-report measures of motor imagery have been successful in the past and are also able to target specific body parts (e.g., the KVIQ; Malouin et al., 2007). However, the inclusion of more objective tests when measuring movement imagery will allow us to additionally ensure that participants' measures are not being biased by their own conceptions of their movement abilities.

Future Applications to Athletics Research

Using a variety of measures, some studies have found movement imagery to be enhanced in athletes (e.g., Babiloni et al., 2010; Callow & Waters, 2005; Guillot, Nadrowska, & Collet, 2009; Moreau et al., 2010; Naito, 1994; Oishi & Maeshima, 2004; Tomasino, Guatto, Rumiati, & Fabbro, 2012), while others have found no difference between athletes and nonathletes (e.g., Chang et al., 2011; Moreau et al., 2010; O & Munroe-Chandler, 2008). While it is worth noting that some studies used subjective measures and others used objective measures. Furthermore, some tests were based on general movement imagery ability (e.g., the MIQ), whereas others focused on sport-related ability. Thus, there are not a sufficient number of studies to draw strong conclusions regarding which factors lead to these discrepancies. It is likely that enhanced movement imagery ability is crucial in some sports, while not as much in other sports.

A particularly interesting avenue of future research would be to test athletes in a wide variety of sports in both objective and subjective tests of ability in movement imagery. Through the use of both approaches, the extent to which factors such as confidence, imagery of outcomes, and social desirability could be tested directly. Additionally, this could also provide evidence of differential contributions of movement imagery ability across sports, and even serve as a potential indicator of future athletic success, particularly in sports such as gymnastics.

Future Applications to Clinical Research

While the MIQ and the VMIQ are by far the most commonly used motor imagery questionnaires, there may be difficulties when applying these questionnaires to clinical populations: The MIQ requires participants to overtly act out movements, an ability that can often be impaired in patients even if they still have intact motor imagery abilities. The VMIQ2 can be quite long to administer (consisting of a total of 36 ratings), which can challenge the cognitive abilities of many patients. While these concerns would prevent the MIQ and the VMIQ from being applicable to some clinical use, other self-report questionnaires have been developed. One such questionnaire is the KVIQ (Malouin et al., 2007). However, this tool also requires overt movements and relies on self-report measures.

When developing the TAMI, one of our primary goals was to ensure that all movement instructions were relatively easy to imagine, both in not requiring specialty knowledge (e.g., of a specific sport) as well as being easily understandable. One important reason for this was to allow for future use of the TAMI in comparing and contrasting cognitive deficits in various motor impairments. Specifically, patients with motor impairments due to damage to noncortical regions (e.g., subcortical, spinal, amputees) may still have intact motor imagery abilities, despite exhibiting impairments in motor execution (e.g., amputees: Alkadhi et al., 2005; Raffin, Giraux, & Reilly, 2012; Huntington's disease: McLennan, Georgiou, Mattingley, Bradshaw, & Chiu, 2000; Yágüez, Canavan, Lange, & Hömberg, 1999; upper limb hemiplegics: Johnson, Sprehn, & Saykin, 2002). Thus, these patients may be unimpaired in the TAMI relative to healthy controls. In contrast, patients with cortical damage may be impaired in both motor imagery and motor execution (e.g., stroke: Sharma et al., 2006; Parkinson's disease: Filippi et al., 2000; Helmich, de Lange, Bloem, & Toni, 2007; Yágüez et al., 1999; cerebral palsy: Mutsaarts, Steenbergen, & Bekkering, 2007; schizophrenia: Maruff, Wilson, & Currie, 2003). We would predict these patients to perform worse on the TAMI than healthy controls.

These comparisons may not be as readily testable using self-report measures of motor imagery, such as the MIQ and VMIQ, as patients with either cortical or subcortical damage may be biased to overestimate their motor imagery deficits in self-report measures due to their inability to overtly execute the same movements (Tanji et al., 2008) or due to confounding psychological factors, such as depression (Chou

& Macfarlane, 2009; Cress et al., 1995; Louie & Ward, 2010; Ruo, Baker, Thompson, Murray, Huber, & Sudano, 2008).

Future Applications to Cognitive Research

While the implications of movement imagery ability to athletic and clinical research are more direct, individual differences in movement and imagery ability may relate to other human cognitive processes (e.g., Madan & Singhal, 2012b). For example, it has long been known that imagery and memory are related processes (Marks, 1973; Paivio, 1971), and that imagery can enhance the learning of novel associations (e.g., Madan, Glaholt, & Caplan, 2010).

Given the perspective that cognitive functions may have developed to serve individuals' abilities to carry out movements (Gallese & Sinigaglia, 2010; Glenberg, 1997; Madan & Singhal, 2012a; Wolpert, Ghahramani, & Flanagan, 2001), it is plausible that individual differences in the ability to imagine and execute movements may also affect other cognitive abilities. This is particularly relevant given recent evidence that suggests that motor properties of objects represented by words (i.e., word manipulability) uniquely interact with intentional and automatic motor processes and their effects on memory (Madan & Singhal, 2012c). With this in mind, the TAMI could serve as a measure of individual movement imagery ability, and be correlated with performance in other cognitive tasks.

NOTE

1. Isaac et al. (1986) found the correlation between the VVIQ and VMIQ to be between .45 and .81 in different samples. Eton et al. (1998) found correlations between VMIQ score and self-reported use of mental imagery in sports performance to be significantly correlated ($r = .60$). Roberts et al. (2008) calculated correlations between the VMIQ2 and the MIQ-R to range between .34 and .74 (sign-adjusted) for the various subscales.

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