Shared Spatial Skills in Time Perception and Number Processing

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Senior Honors Thesis
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London, Ontario, CANADA
April, 2011

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Abstract

The present study analyzed whether individual differences in spatial skill are correlated with event timing and number processing ability. Participants (25 UWO undergraduates) completed a measure of spatial skill, a mental event timing task, and performance on a task known as mental number line bisection. It was hypothesized that superior spatial skill (high scores on part three of the Multidimensional Aptitude Battery) would be associated with more accurate timing of mental events, and with more accurate number line processing. The results indicate that scores on the Multidimensional Aptitude Battery were correlated with both number line bisection accuracy and mental event timing accuracy; however, bisection accuracy and timing accuracy were not correlated. Theoretical implications of the results and directions for future research are discussed.

Keywords: embodied cognition, number line bisection, time perception, spatial skill

Shared Spatial Skills in Time Perception and Number Processing

The mechanism by which humans work with and store knowledge of concepts has long been an important topic in psychology. As research into concepts has developed, two main positions on the representation of concepts have emerged: one position posits abstract amodal representations, and the other argues for embodied modal representations. Amodal theories of conceptual representation (e.g. semantic memory models, exemplar models, feed-forward nets) propose that concepts are represented abstractly, and that the specific physical instantiation of the conceptual system is irrelevant. Contrarily, modal theories of representation such as the *situated simulation theory* (Barsalou, 1999; 2003), or the *emulation theory of representation* (Grush, 2004), propose that concepts are represented with bodily schemas (i.e. relative to a representation of the body as a 3-dimensional object in space), and are grounded in modality-specific brain systems (i.e. systems specific to sensory modalities).

These modal views of conceptual representation fit within the *embodied cognition* framework, which (generally speaking) states that knowledge is grounded and represented in modality-specific systems (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009). Evidence supporting a modal view of conceptual representation has been demonstrated in a variety of tasks. Studies have shown that spatial and motor resources are used in such disparate tasks as the mental rotation of objects (Amorim, Isableu, and Jarraya, 2006), language comprehension (Taylor & Zwaan, 2008), and visual searches (Wykowska, Schubo, & Hommel, 2009). Extending this past body of research, I analyzed whether individual differences in spatial skill are correlated with performance on mental number line bisection and mental event timing tasks. This served two purposes: first, to test the hypothesis that these tasks are spatially-grounded, meaning that they draw on neural resources used for spatial processing; secondly, to investigate whether different spatially-grounded tasks rely on the same spatial and motor resources, or on disparate resources within the same system.

In his 2003 paper, Barsalou explicated three earlier amodal theories of the conceptual system: semantic memory, exemplar models, and feed-forward nets. Barsalou analyzed these theories along five dimensions: modularity (whether or not there are separate modules underlying conception and perception), method of representing knowledge (whether amodal or modal – that is, the same representations in the representational system underlie both perception and conception), level of abstraction (abstract meaning units of knowledge are removed from their corresponding sensory representations), stability of knowledge (stable meaning any individual unit of knowledge remains virtually unchanged over time), and organization of knowledge.

The semantic memory theory was described as modular, amodal, decontextualised, stable, and taxonomically organized. In this model, the stored representation is a distillation of what is common across all of one's experiences with a concept. In contrast, in the exemplar model, a concept is stored as representations of all the experiences you have with exemplars of the concept. Barsalou described the exemplar model theory as modular, amodal, taxonomic and stable, however he indicated that it is situated, in that the storage of exemplar memories can include experiential detail. The feed-forward net model is described as similarly modular and amodal. It is taxonomically organized, with situated information (storing more idiosyncratic knowledge about exemplars). Feed-forward nets are highly dynamic, however, in that they represent categories within a space of representations that is activated as a function of the network's current state, input, and learning history.

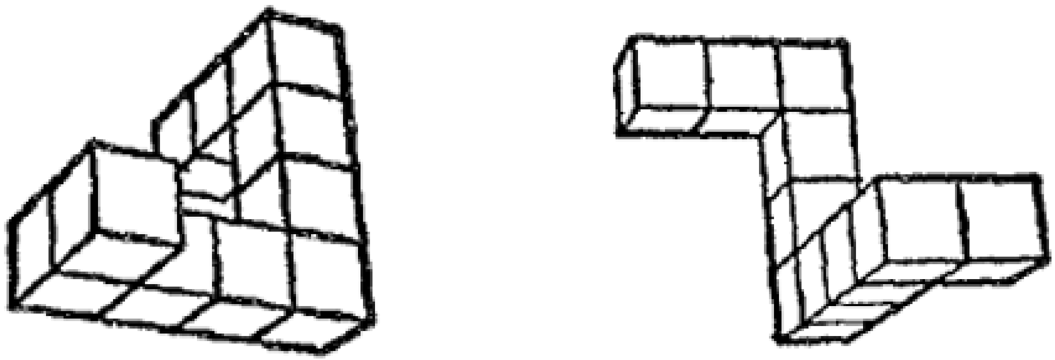
In answer to these three amodal theories, Barsalou (2003) proposed the *Situated*

Simulation theory of the conceptual system. He defined it along the same five dimensions he used to analyze the other theories; he presented the situated simulation theory as non-modular, modal, and situated in that the system produces many different conceptualizations for any concept, each designed to facilitate behaviour in a particular situation. He also described it as dynamic, in that the simulator can construct many different simulations of the same concept, for different purposes and from different perspectives, organized around situated action. That is, instead of encyclopaedia-style entries, concepts are stored to emphasize connections among things encountered in the same situations (such as things encountered in classrooms). In essence, Barsalou's Situated Simulation theory states that the conceptual system develops to serve situated action. It does this through "simulators" that create a conceptualization of an object that is contextually relevant to a current goal. In other words, when we need to think about a concept, we develop that concept as a simulation of "what it would be like" on the basis of experience.

Another main researcher in representation of concepts is Rick Grush. Departing from Barsalou's (2003) situated simulation theory Grush (2004) proposed a different modal view of conceptual representation, which he called the *theory of representation.* In his account, the brain constructs neural circuits that act as models of the body and environment, which are used in parallel with sensory information. These models enhance the processing of sensory information by providing expectations of sensory feedback (i.e. what sensory information is expected during the performance of a given action). Importantly, these neural circuits can be 'run offline' to produce imagery, estimate outcomes of actions, as well as evaluate and develop different motor plans. In concordance with Barsalou's situated simulation theory, Grush believed that the framework of parallel neural circuits can be extended to use the offline functioning of the visual-motor system to generate visual imagery in the absence of actual stimuli. Finally, Grush argued that based on his theory of representation, cognitive elements which are as evolutionarily novel as theory of mind phenomena and situated robotics could fit within an embodied cognition framework.

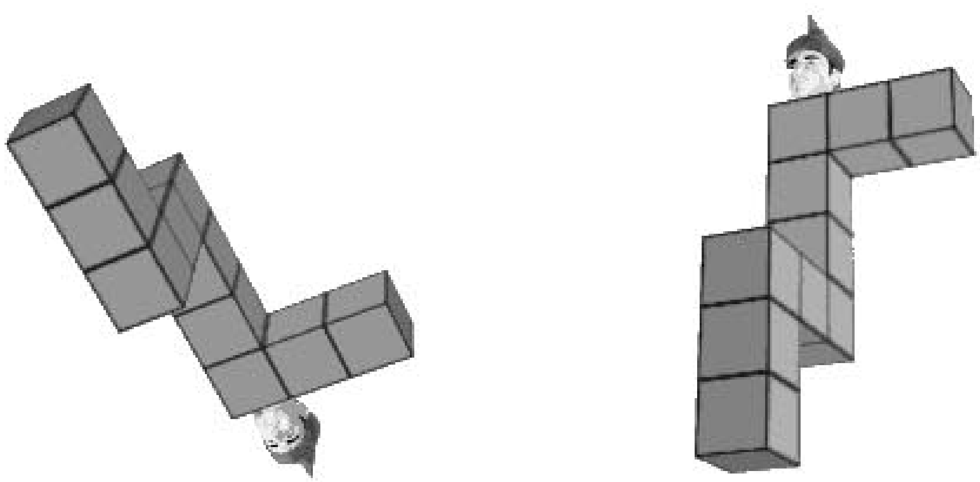
Accepting an embodied modal account of the human conceptual system, it is prudent to provide evidence indicating that concepts are, in fact, grounded in modality specific systems. One of the most prominent demonstrations of this account of conceptual representation was offered by Amorim, Isableu, and Jarraya (2006), who analyzed the advantage in speed of processing of imagined spatial transformations of the human body over imagined transformations of less familiar objects such as Shepard-Metzler cubes (Figure 1; Shepard, & Metzler, 1971). Over the course of six experiments, the researchers demonstrated that supplying Shepard-Metzler cubes with bodily characteristics (i.e. by adding a head and arranging the cubes in a posture that humans can adopt, see Figure 2) enabled participants to complete mental rotations significantly faster than if the Shepard-Metzler cubes lacked those bodily characteristics. They attributed this difference to the idea that imagined transformations of the body occur in less of a piecemeal fashion compared to imagined transformations of objects of a similar arrangement, and that difference is reflected in faster reaction times. This finding is in accord with embodied cognition, demonstrating that we have dedicated and efficient resources for manipulating our bodily schema. It is important to note that even with a head added to a Shepard-Metzler cube, if the ‘pose’ of the cubes is not a position that can be adopted by a human being, the effect disappears (i.e. there is no task facilitation by wholesale mental rotation).

Demonstrating the use of embodied modal resources for language comprehension, Taylor and Zwaan (2008) suggested that action words, read or heard, activate brain areas for corresponding motor responses. They expected that the motor system would become active



Before Rotation After Rotation

Figure 1. Identical Shepard-Metzler cubes before and after rotation (Shepard, & Metzler, 1971).



Before Rotation After Rotation

Figure 2. Different Shepard-Metzler cubes with bodily characteristic (head) before and after rotation (Amorim, Isableu, & Jarraya, 2006).

during comprehension of language that describes actions. They referred to this phenomenon as *motor resonance*. They based this hypothesis on previous research that had shown sentences describing simple motor actions facilitate compatible motor responses (Glenberg & Kaschak, 2002) and activate brain regions used in the performance of similar motor actions (de Vega, Robertson, Glenberg, Kaschak, & Rinck, 2004). Extending their previous work (Zwaan & Taylor, 2006), in which they found that motor resonance both occurs immediately and is short lived (in the time-scale of language comprehension), Taylor and Zwaan (2008) investigated whether attentional shifts brought on by language could extinguish motor resonance. They suggested adverbs that maintain the reader's focus on action should facilitate motor resonance in the reader's brain, whereas adverbs that shift focus to the actor should extinguish it. In two experiments, they found that this was the case, and that attentional focus as modified by adverbs could affect motor resonance depending on whether the adverbs were actor-oriented, or action-oriented. In the conclusion of their paper, Taylor and Zwaan claimed that semantic and motor systems rely on the same neurophysiological substrates, providing another piece of evidence for the claim that modal cognitive resources are used for concept representation.

Following the work of Taylor and Zwaan (2008) that indicated a shared brain region for linguistic comprehension and performance of actions, Wykowska, Schubo, and Hommel (2009) suggested that action planning (preparing grasping or pointing movements) biases visual search tasks. They posited that the cognitive system weighs stimulus information relevant to key target dimensions above stimulus information irrelevant to the target; stimuli are prioritized based on their physical dimensions so that target-relevant stimuli have a higher chance of receiving the brain's attention. The researchers argued that preparing for a particular type of action prepares the actor to correspondingly process different types of perceptual information, which they tested in three experiments. Using both pointing and grasping experiments, Wykowska et al. found that preparing to take a particular type of action primes the perception of information related to that action. To account for these results, they proposed a combination of Hommel et al.'s (2001) intentional weighting mechanism, and Wolfe's guided search model (Wolfe, 1994). That is, Wykowska et al. proposed that the actor weighs perceptual dimensions according to current intentions, and these weightings modulate bottom-up perceptual signals.

In another study using bottom-up perceptual effects on higher level cognitive processes, Rossetti et al. (2004) demonstrated the spatial basis for number line bisection based on previous work with prism adaptation. They first replicated past studies, finding that with as little as ten degrees of visual field distortion, there were "visual and proprioceptive aftereffects, as well as performance effects on pointing tasks without visual feedback" (Rossetti et al., 2004, p. 426). This is to say that after adaptation to a ten degree leftward visual field shift, both patients and healthy participants who were then instructed to 'point forward blindly' pointed significantly to the right of controls. The researchers then applied prism adaptation to number line bisection, a task where participants are asked to provide the midpoint between two numbers. Asking left unilateral neglect patients to bisect spans in the number line, they found that prism adaptation improved the patients' performance on a mental number line bisection task which was previously shown to be impaired in neglect patients (see Rode, Pisella, Rossetti, Farnè, & Boisson, 2003). It can be concluded from their data that prism adaptation also influences performance on number line bisection, which is evidence that thinking about the number line uses spatial resources.

Göbel, Calabria, Farnè, and Rossetti (2006) also investigated the bisection of the mental number line using verbally presented numbers. Their study used repetitive Transcranial Magnetic Stimulation (rTMS) over participants' posterior parietal lobes to temporarily induce neglect-like symptoms. The researchers found that prior to rTMS, participants underestimated the midpoint of numerical intervals. After rTMS, however, perceived midpoints were shifted significantly to the right. These results support of an embodied, modal view of conceptual representation by demonstrating that number representation is based partially in the posterior parietal cortex (a known spatial centre).

Casasanto and Boroditsky (2008) investigated whether mental representations of more abstract concepts (e.g. mathematics, time) are also grounded in mental representations that result from physical experience. They began with the idea that people talk about time using spatial language; they wondered, however, whether people also think about time using spatial representations. Using six 'growing line' experiments, Casasanto and Boroditsky showed that participants' estimations of the duration of an event were affected by the spatial distance covered by the growing line. Interestingly, they did not find that the converse was true; participants' estimates of the lengths of the growing lines were not affected by the duration of the event. The researchers concluded that their findings provided evidence that, as suggested by modal theories of concept representation and the theory of embodied cognition, "mental representations of things we never see or touch may be built, in part, out of representations of physical experiences in perception and motor action" (Casasanto, & Boroditsky, 2008, p. 579).

As has been demonstrated in the previous review, and in concordance with modal conceptual representation and the embodied cognition perspective, abstract tasks such as number line bisection and mental timing of events are spatially grounded (Casasanto, & Boroditsky, 2008; Göbel et al., 2006; Rossetti et al.,2004). The present study sought to extend previous research by determining if spatial skill predicts performance on spatially-grounded tasks, and by extension whether different spatially-grounded tasks rely on the same spatial and motor resources.

Spatial skill was operationalized by part three of the Multidimensional Aptitude Battery (Jackson, 1984), which provides a valid measure of spatial skill. The first spatially-grounded task used was a mental timing task; a replication of the first growing line experiment of Casasanto and Boroditsky (2008, p. 582). The second spatially-grounded task used was a number line bisection task; absent rTMS, a replication of the number line bisection task described by Göbel et al. (2006, p. 861-862).

I hypothesized that superior spatial skill would be associated with more accurate timing of mental events, and with more accurate number line bisection. Furthermore, I hypothesized that accurate timing of mental events would be associated with more accurate number bisection. These results would indicate spatial skill does predict performance on spatially-grounded tasks, and that different spatially-grounded tasks rely on the same spatial and motor resources.

Method

Participants

The participants in this study were a sample of undergraduate University of Western Ontario students (6 women, 25 men, M_{age} = 18.3 years, age range: 17-20). Participants were recruited via the undergraduate research participation pool, and were compensated with course credit. Of the 30 students who participated, all completed the study. The data from three participants were excluded from the analysis because of a software error that rendered their number line bisection responses unusable. The data from a fourth participant were excluded from the analysis because a hardware malfunction rendered their event timing responses unusable.

Materials

Participants completed four different tasks/questionnaires for the study. The first measure was the Edinburgh Handedness Inventory (Oldfield, 1971). It is a simple, quantitative measure of handedness; it uses 10 items, balanced for sex, cultural, and socio-economic factors (see Appendix A). The measure was scored to provide a left or right handedness classification for each participant.

The second measure was task three of the Multidimensional Aptitude Battery (Jackson, 1984). It is a measure of spatial skill, consisting of 50 multiple-choice items requiring participants to indicate which of five given figures is identical to a target figure. The correct given figure is a rotated version of the target figure, whereas the incorrect given figures are flipped or otherwise modified versions of target figure (see Appendix B). It is designed so that participants cannot complete all 50 items in the 10 minutes allotted for the task. The measure was scored as the number of correct responses out of a possible 50.

The third measure was a replication of the first mental event timing task used by Casasanto and Boroditsky (2008, p. 582). In this measure, a set of 81 distinct lines is presented to participants on a computer, in pseudorandom order. These lines vary in offset from the edge of the screen (+/- up to 50 pixels), length (between 200 to 800 pixels, in 75 pixel increments) and duration (between 1000ms and 5000ms, in 500ms increments). Nine displacements and nine durations are fully crossed to produce the 81 distinct line types. In one trial, a ready screen appears, and the line ‘grows’ across the screen pixel by pixel along the vertical midline of the screen. After the line growth event, the participant clicks the mouse once to begin timing, and again to stop timing (the interval between clicks is their estimation of the duration of the event; see Appendix C). The measure was scored by the average absolute deviation of the participants’ responses from the true durations of the line growth events (both to millisecond accuracy).

The fourth measure was a replication of the task used by Göbel et al. (2006, p. 861-862).

In this measure, 60 pairs of three-digit numbers are presented over 120 trials, in pseudorandom order. The numerical distance between each pair varies from 16-64, however the pairs are always from the same ‘hundreds’ bin (e.g. 300s, 400s), and the smaller number is always presented first. In one trial, participants are presented the first and second number auditorily (with a 0.5 second interval between the numbers), and then respond verbally with their estimation of the midpoint. The measure was scored by the average absolute deviation of the participants’ responses from the true midpoints of the number pairs.

Procedure

Participants were recruited from the undergraduate research pool, and participated at varying times of day. All participants first received a letter of information and informed consent was acquired (Appendix D).

Participants were then instructed to complete the Edinburgh handedness inventory, as per the instructions on the measure. When finished, participants were provided part three of the Multidimensional Aptitude Battery and were asked to read the instructions on the measure. When ready, they were given a time limit of ten minutes to complete the measure (participants provided answers directly on the sheet).

When finished the Multidimensional Aptitude Battery task, participants began the event timing task. Verbal instructions were provided, emphasizing that they were to replicate as accurately as possible the duration of the line growth event in the interval between the two mouse clicks. Responses were self-paced. After completing two practice trials, they began the task.

Upon completion of the event timing task, participants moved away from the computer for the number line bisection task. Verbal instructions were provided, emphasizing that participants were not to calculate the midpoint between the two numbers, but instead estimate it as quickly as possible. In concordance with the procedure described by Göbel et al. (2006, p. 861-862), participants were asked to complete the task with their eyes closed.

After completing all tasks, participants were debriefed by way of a debriefing form (Appendix E). Participation in the entire study took less than 1 hour.

Results

Spatial ability was given by participants' numerical score out of a possible 50 on the Multidimensional Aptitude Battery (MDAB; Jackson, 1984), with a higher score indicating superior performance.

Mental event timing ability was given by the scaled average absolute deviation of participants' responses from the true duration of the line growth events presented in the replication of the first mental event timing task used by Casasanto and Boroditsky (2008, p. 582), with a smaller scaled absolute timing deviation (SATD) indicating more accurate performance. It was necessary to scale the absolute timing deviation for each line growth event according to its true duration to control for the proportionally greater opportunity for error associated with the mental timing of longer events. To scale one trial, the absolute deviation of a participant's response was divided by the true duration of the event.

Mental number line bisection ability was given by the average absolute deviation of participants' responses from the true midpoint of number pairs presented in the replication of the task used by Göbel et al. (2006, p. 861-862), with a smaller absolute bisection deviation (ABD) indicating more accurate performance. Three two-tailed partial Pearson correlations were used to test for the presence of correlations between all combinations of pairs of measures.

The correlation between MDAB and SATD was significant, $r(26) = -.58$, $p = .002$. That is, in accordance with the hypothesis, as spatial ability increases mental event timing accuracy also increases. The correlation between MDAB and ABD was also significant, *r*(26) = -.54, *p* = .005. Also in accordance with the hypothesis, as spatial ability increases mental number line bisection accuracy also increases. These two relationships are presented in Figure 3 and Figure 4, respectively. The correlation between SATD and ABD was not significant, however, *r*(26) = .19, *ns*. Separate analyses for left and right handed individuals were not performed because only 4 left-handed participants participated in the study; see discussion for details.

The above correlations were also computed controlling for individual participants' susceptibility to the influence of spatial cues (i.e. line length) on their timing responses. This measure of susceptibility was given by the correlation between the length of the line in a growth event and a participant's estimation of its duration (based on the manipulation described by Casasanto and Boroditsky, 2008; line growth events that cover a greater spatial distance are perceived to occur for a greater length of time). The results of this set of two-tailed partial Pearson correlations were similar to the original correlations presented above. The correlation between MDAB and SATD was again significant, *r*(26) = -.55, *p* = .005, as was the correlation between MDAB and ABD, *r*(26) = -.51, *p* = .009. The correlation between SATD and ABD remained non-significant *r*(26) = .12, *ns*.

The individual difference variation in how strongly the length of the line in a growth event affected a participant's estimation of its duration was also compared to participants' scaled absolute timing deviation. This correlation approached significance, *r*(26) = -.38, *p* = .059, indicating a trend that participants whose scaled estimations of event duration were more affected by the length of the line in the growth event had smaller scaled absolute timing deviations. In other words, participants who were more susceptible to the influence of a spatial

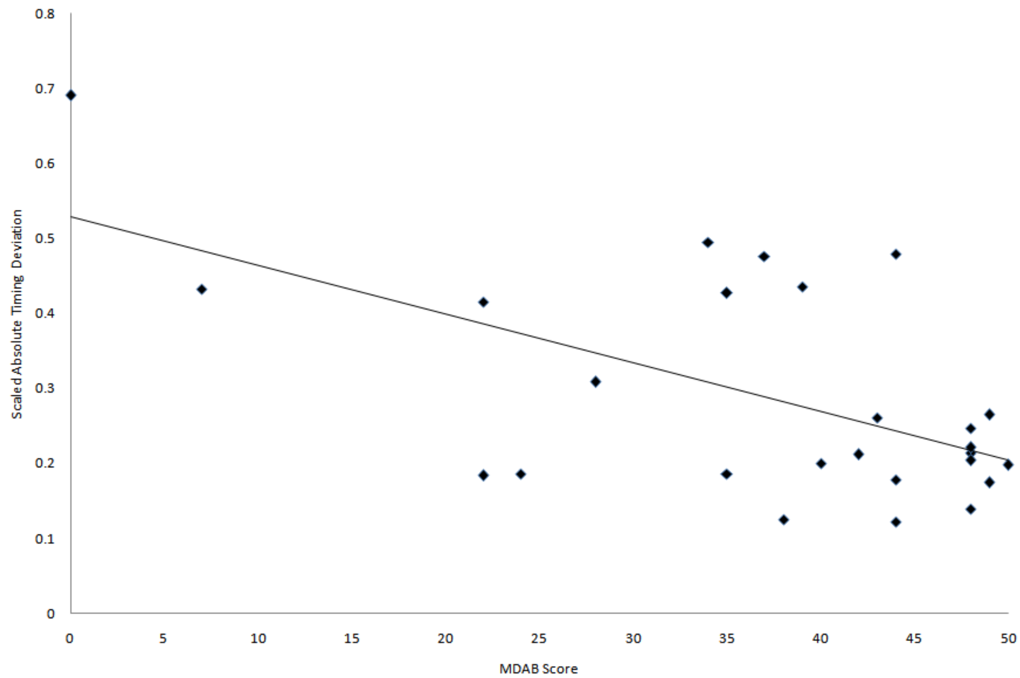


Figure 3. Scaled absolute timing deviation as a function of Multidimensional Aptitude Battery Score.

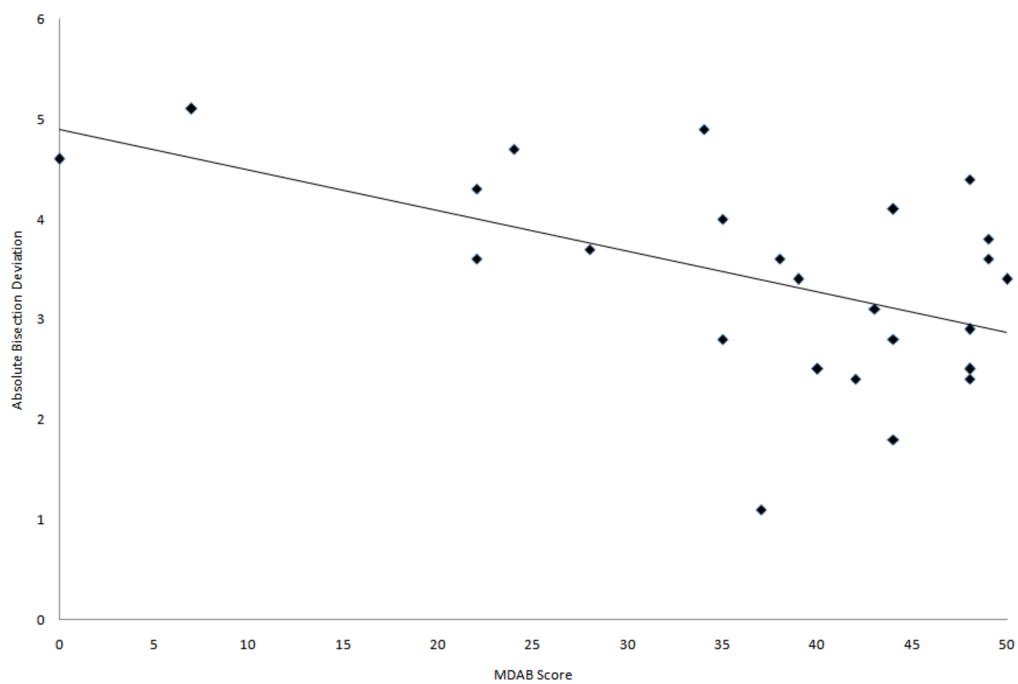


Figure 4. Absolute bisection deviation as a function of Multidimensional Aptitude Battery Score.

prime on their timing responses made more accurate responses.

In summary, there were significant correlations between Multidimensional Aptitude Battery scores and both scaled absolute timing deviation and absolute bisection deviation. Scaled absolute timing deviation and absolute bisection deviation, however, were not correlated. These results were also present when controlling for the correlation between the length of the line in a growth event and a participant’s estimation of its duration (that is, controlling for individual differences in susceptibility to the spatial prime effect). Finally, in comparing the correlation between the length of the line in a growth event and a participant’s estimation of its duration with participants’ scaled absolute timing deviation, a trend emerged indicating that participants who were more susceptible to the effect of a line’s length on its perceived growth duration had a smaller average scaled absolute timing deviation.

Discussion

I hypothesized that superior spatial skill would be associated with strong mental event timing ability, and with more accurate number line bisection. Furthermore, I hypothesized that accurate timing of mental events would be associated with more accurate number bisection.

It is uncontroversial to assume that individuals vary on many dimensions, including spatial skill, mental event timing ability, and number bisection ability. If it is shown that values of one dimension can be predicted for an individual based on values of another dimension, it can be convincingly argued that those dimensions are related. In two separate analyses, I found correlations between spatial skill and event timing, and between spatial skill and number bisection. I argue that these results provide evidence that both mental event timing and number line bisection depend on spatial skill, because individual differences in spatial skill serve as a predictor for both mental event timing and number line bisection. In addition to supporting my first hypothesis, these results also support the theory of embodied cognition, which predicts that higher-order cognitive faculties (e.g. numbers, time, mathematics) are grounded in spatial skill generally.

It is important to note, contrary to my second hypothesis, that mental event timing ability and mental number line bisection ability were not found to be correlated, indicating that they are unrelated to one another. This suggests that although they are both related to spatial skill, they draw upon different kinds of spatial processing resources. To explain these results, I posit that there is a difference in the precise embodied grounding of these two tasks.

The faculty for event timing could be scaffolded on an egocentric embodied representation, as would be used in working with one's own position in a 3-dimensional environment. For example, an egocentric embodied representation of your self could be used in representing the knowledge of being in a position two steps ahead of your previous position, and ten steps from your goal. This seems analogous to how we view time, insofar as at present we are x distance from a given past event, and y distance still away from a given future event.

The faculty for number bisection, however, could be scaffolded on an allocentric embodied representation, as would be used in working with spatial relationships between objects external to oneself on a 2-dimensional plane within our view. For example, an allocentric embodied representation would be used in representing the knowledge of an object that is six meters to the right of another object, which is three meters to the right of a third (looking right to left). This linear view of our surroundings seems analogous to how we view numbers, in that we might look at the number ten as six greater than four, which is three greater than one (moving from greatest to least).

The mental rotation task employed by the Multidimensional Aptitude Battery may draw on both egocentric and allocentric resources, as it is important to be able to compute both rotations of the self, and rotations of objects in one's environment. Egocentrically, in navigating through the world, to change direction it is necessary to compute rotations of one's body relative to its vertical axis. Allocentrically, it is important to be able to recognize the same object in the environment in many different orientations. As such, mental rotation could plausibly be grounded in both egocentric and allocentric embodied representations, as it is a necessary skill in both of these contexts.

The trend of a relation between increasing susceptibility to effects of line length on estimations of duration and increasing accuracy in timing mental events points toward the possibility that individuals who are good at mentally timing events are more likely to use (or more sensitive to) the spatial distance over which events occur when estimating their duration. This possibility has plausibility in that events which occur over a greater spatial distance (at the same rate) will have a greater duration. For this subset of susceptible individuals, it is reasonable that although there was some error introduced to their responses due to the different rates at which line growth events took place in the present study, in general they were more apt at timing events due to the overall utility of this cue.

A limitation of the present study was that an insufficient number of left-handed individuals participated to allow for the data from left and right handed participants to be analyzed separately in order to test for effects of handedness. Previous research has shown that handedness can affect hemispheric lateralization and therefore performance on line bisection tasks (for a review, see Jewell & McCourt, 2000). It would have been theoretically interesting to investigate whether the effects demonstrated in a combined group of left and right handed participants are similarly demonstrated in groups of solely left or solely right handed participants. To address this limitation, data from a pool of specifically left-handed participants could be analyzed and compared with the data of the present study to assess the influence of handedness on the relationships between spatial skill, event timing, and number bisection.

The findings of the present study could be used to guide future research in several ways. First, other spatially-grounded higher cognitive characteristics, such as affective response to emotional stimuli (Williams & Bargh, 2008), approach motivation (Nash, McGregor, & Inzlicht, 2010), and empathy (Thakkar, Brugger, & Park, 2009) could be compared to spatial ability to assess the presence of correlations between other spatially-grounded faculties and spatial ability. The results of such an investigation could have implications for the effectiveness of spatial priming (e.g. priming spatial closeness or distance) on emotional regulation or explanatory theories of emotional disturbance. A second application of the present findings is in the assessment of spatial ability in general aptitude or intelligence measures. The results of the present study indicate that disparate embodied resources are used in the performance of what could generally be referred to as spatially-grounded tasks, and as such measures of spatial ability or spatial sense might benefit from a sensitivity to the distinction between allocentric and egocentric spatial abilities.

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Appendix A: Edinburg Handedness Inventory

Date of Birth: _______________
Sex: ______

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If in any case you are really indifferent *put + in both columns*.

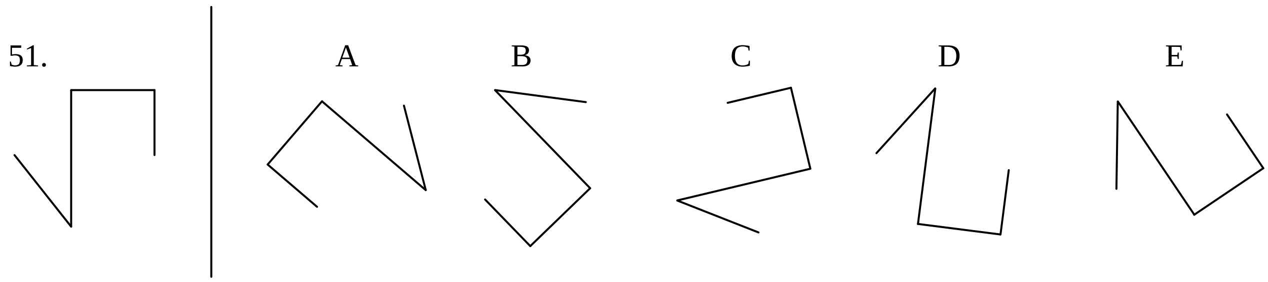
Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

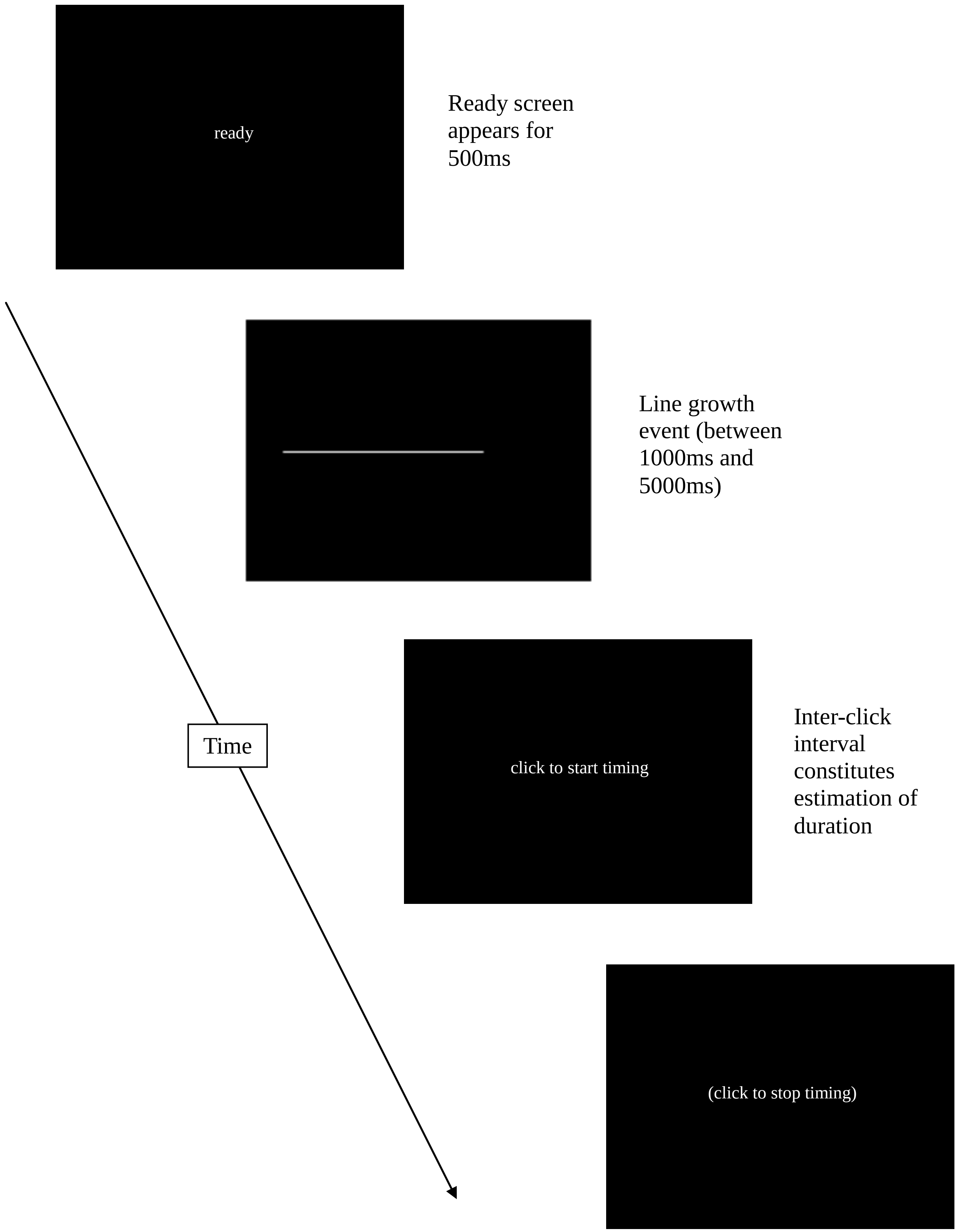
L.Q.		Leave these spaces blank	DECILE	

Appendix B: Example Item from Multidimensional Aptitude Battery, Part Three



* B is the correct answer, in this case

Appendix C: Single Trial of Event Timing Measure



Appendix D: Informed Consent Form

Title of Research: Shared Spatial Skills in Time Perception and the Number Line

Research Investigator:
Andrew Kope (Honors Thesis Student)
E-mail: akope2@uwo.ca

This study is investigating whether a common spatial ability underlies people's ability to work with the number line and perceive time. For this study you will be asked to answer a short handedness questionnaire, mentally rotate images, verbally bisect pairs of numbers while wearing a blindfold, and mentally time short events. The study should take approximately 45 minutes to complete. This research project is being conducted as part of the requirements for the Honors Thesis psychology course (4850).

For your participation in this study you will receive 1.0 research credits. Your participation in this study is voluntary and you may withdraw from participating at any time throughout the study or refuse to answer any questions that make you feel uncomfortable, at no penalty or loss of benefits. Audio tapes of your responses will be erased at any time if you desire. The information you provide will be kept completely confidential and there are no known risks to participating in this study.

All information gathered in this study is kept confidential and anonymous and is used for research purposes only. Analyses of the data will be conducted on group responses and not individual responses. Once the study is completed, the data will be kept securely stored. You will receive written feedback concerning the purposes of the study at the end of the study and will have the opportunity to ask any questions at that time.

If you have questions about this research, and/or if you want to obtain copies of the results of this research upon its completion, please contact me, Andrew Kope (email: akope2@uwo.ca) or my supervisor, Dr. Patrick Brown (office SSC 7328, phone 519-661-2111 x84680).

If you have any questions about the conduct of this study or your rights as a research participant you may contact the Director, Office of Research Ethics, The University of Western Ontario, 519-661-3036 or email at: ethics@uwo.ca.

Consent Statement

I have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

______________________	______________________	__________
Participant's Name (Please Print)	Participant's Signature	Date
______________________	______________________	__________
Researcher's Name (Please Print)	Researcher's Signature	Date

Appendix E: Debriefing Form

Title of Research: Shared Spatial Skills in Time Perception and the Number Line

Research Investigator:
Andrew Kope (Honors Thesis Student)
E-mail: akope2@uwo.ca

The purpose of the current study was to investigate whether a common spatial ability underlies people's ability to work with the number line and perceive time. This research follows previous work on number line bisection (Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Gobel, Calabria, Farne, & Rossetti, 2006) and time perception (Casasanto, & Boroditsky, 2008) that relate each ability to spatial perception. The goal of the present research was to investigate possible personal differences in spatial skill that might predict number line bisection and time perception abilities, and to assess possible correlations between these three measures.

In this study you were asked to mentally rotate shapes, mentally time line-growing events, and to describe bisect a pair of large numbers. The purpose of these tasks was to collect data on a valid measure of your spatial ability (shape rotation), and to measure your performance on two associated tasks (number bisection and event timing).

Your responses and participation are much appreciated. Without your involvement, it would not be possible to conduct this research. Thank you.

To ensure confidentiality, your responses will be assigned a coding number and your name will never be associated with your responses.

If you have any further questions about this research please contact Andrew Kope (email: akope2@uwo.ca) or my Professor, Dr. Patrick Brown (office SSC 7328, phone 519-661-2111 x84680). Thank you for helping me with this project--your time is much appreciated.

If you have questions about your rights as a research participant, you should contact the Director of the Office of Research Ethics at ethics@uwo.ca or 519-661-3036.

<u>References:</u>

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, *106*, 579-593.

Doricchi, F., Guariglia, P., Gasparini, M., & Tomaiuolo, F. (2005). Dissociation between physical and mental number line bisection in right hemisphere brain damage. *Nature Neuroscience*, *8*(12), 1663-1665.

Gobel, S. M., Calabria, M., Farne, A., & Rossetti, Y. (2006). Parietal rTMS distorts the mental number line: Simulating 'spatial' neglect in healthy subjects. *Neuropsychologia*, *44*, 860-868.