Touching with the mind's hand: Tactile and proprioceptive stimulation facilitates conceptual size judgements

Louise Connell (louise.connell@manchester.ac.uk)
School of Psychological Sciences,
University of Manchester,
M13 9PL, UK

Dermot Lynott (dermot.lynott@manchester.ac.uk)
Decision and Cognitive Sciences Research Centre,
Manchester Business School, University of Manchester,
M15 6PB, UK

Felix Dreyer (felix.dreyer@studserv.uni-leipzig.de)
Institute for Psychology, University of Leipzig, Seeburgstraße 14-20
04103 Leipzig, Germany

Abstract

Is a grapefruit bigger than an apple? How do you know? People have little difficulty in comparing objects in this way, but the nature of the underlying size representations remains opaque. While visual information is clearly important in conceptualizing size, it is not the full story: object representations may also rely on how the hands feed back touch and proprioceptive information during physical interaction. In a series of novel studies, we asked people to make conceptual size comparison judgements while receiving tactile or proprioceptive stimulation to the hands or feet. Results show that hand stimulation facilitates size judgements, but, critically, only for objects that are small enough to be manipulated by the hands. These findings confirm that size representations automatically involve touch and proprioceptive information, independent of motor planning, and validate embodied assumptions that concepts are grounded in the same neural systems that govern perception and action.

Keywords: touch; proprioception; embodied cognition; size; modality specific; representation; affordances.

Introduction

Which is bigger: a grapefruit or an apple? A toaster or a cup? A planet or a moon? People have little difficulty in making these kinds of object comparisons but, even after decades of research, the nature of the underlying mechanisms and representations is still in some doubt. There is, at least, consensus that size representations have a strong visual component, distinct from propositional representations such as [size:5cm] or [size:huge] (Kosslyn, 1980; Paivio, 1986). Evidence for visual representations of size comes from numerous behavioural (Kosslyn, Murphy, Bemesderfer & Feinstein, 1977; Paivio, 1971; 1975) and neuroimaging (Newman, Klatzky, Lederman & Just, 2005; Oliver & Thompson-Schill, 2003) studies.

However, this concentration on visual appearance has come at the expense of other perceptual modalities. Another source of information about object size comes from physical interaction; the arms, hands and fingers feed back touch and proprioceptive information when contact is made with an object. Embodied cognition research argues that this kind of body-specific information plays an important role in conceptually representing objects because cognition is grounded in the same neural systems that govern perception and action (Barsalou, 1999, 2008; Glenberg, 1997; Wilson, 2002). For example, in order to decide whether a toaster or a cup is bigger, a strong interpretation of such theories would assume that past experiences across various modalities – visual, motor, tactile, proprioceptive, etc. – will be re-enacted (or simulated), and the resulting simulations of cup and toaster will then be compared. Simulating non-visual information, however, depends on being able to interact physically with the object in question. While an apple or cup can be picked up and spanned by the hands, a planet offers no such opportunity for haptic interaction.

In the following studies, we investigated whether tactile and proprioceptive representations are involved in conceptual evaluations of size. Previous work has shown that bodily feedback can facilitate cognitive processing by directing attentional resources to relevant neural systems. For example, when the mouth is pulled into a smiling expression by holding a pen between the teeth, people find cartoons funnier (Strack, Martin & Stepper, 1988) and are quicker to understand sentences that describe pleasant or happy situations (e.g., You and your lover embrace after a long separation: Havas, Glenberg & Rinck, 2007). Similarly, slumping in a chair makes it easier for people to retrieve sad or negative memories (Riskind, 1983), while lying down speeds up people's recall of visiting the dentist (Dijkstra, Kaschak & Zwaan, 2007). Based on such work, we expected bodily feedback from touch and arm/hand positioning to direct attention to the modality in question and hence facilitate the speed of simulating conceptual information in those modalities.

Current Studies

In two experiments, we asked people to compare the size of named objects while receiving tactile or proprioceptive stimulation to the hands or feet. Critically, objects were either of small size (i.e., can be held in one hand, such as apple) or large size (i.e. greater than arms' width, such as elephant). For each study, testing took place in two blocks (order counterbalanced): in one block the hands were stimulated (critical condition), while in another block the feet were stimulated (i.e., providing a control of equivalent sensory distraction).

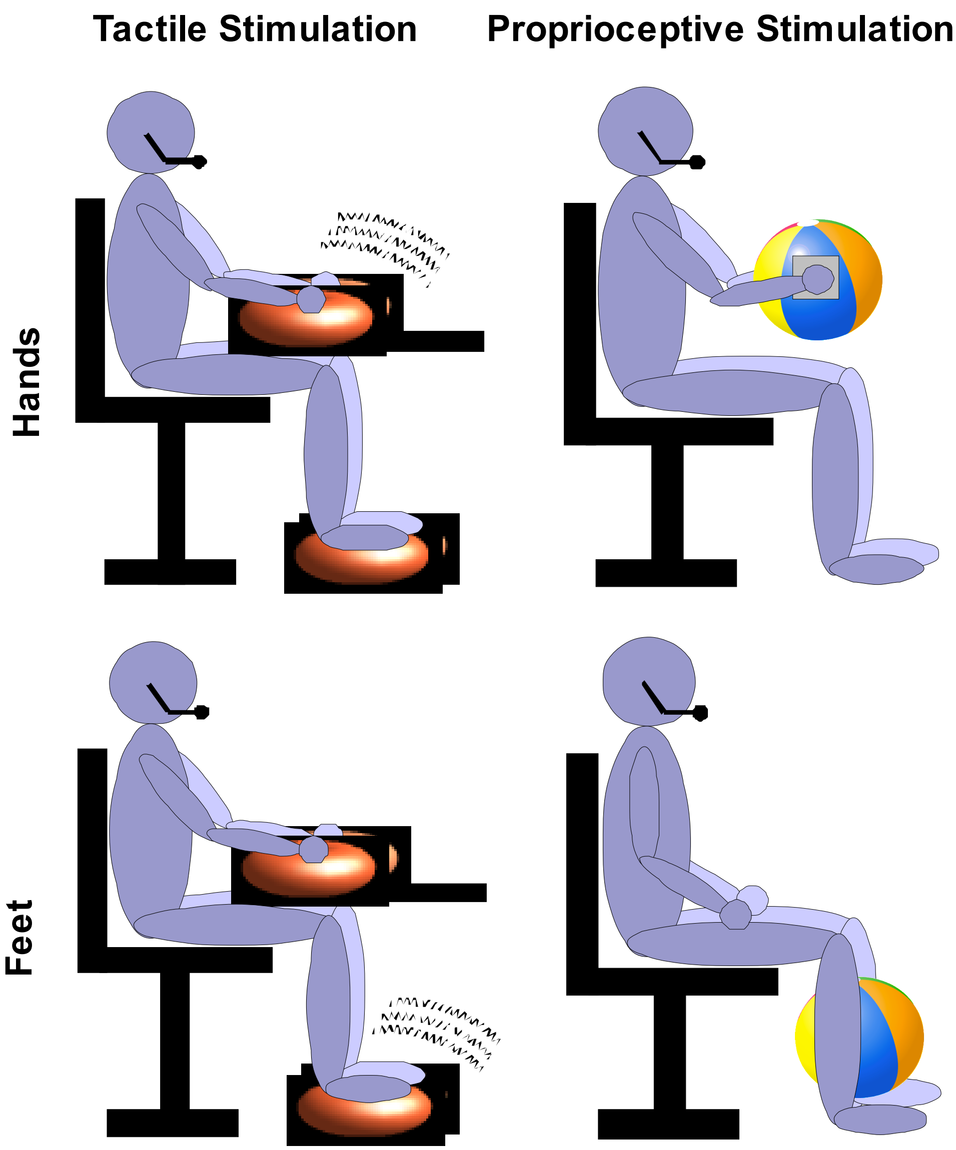

Figure 1. Schematic of perceptual stimulation to the hands (critical condition) or feet (control condition), showing participant receiving tactile stimulation from vibrating cushions, or proprioceptive stimulation from a 30cm diameter beachball.

Since the simulations formed during conceptual processing should be based on experience in all relevant modalities, and since directing attention towards a particular perceptual modality facilitates simulation in that modality (e.g., van Dantzig, Pecher, Zeelenberg & Barsalou, 2009), we predicted that people would be faster to make conceptual size judgements during tactile and proprioceptive stimulation, but that such facilitation would be limited to (a) stimulation of the hands, and (b) objects of a physically manipulable size.

Importantly, our current approach seeks to extend previous work on size affordances by separating tactile and proprioceptive representations from action planning. Several studies have shown that people are faster to respond to named objects when their hand posture on an experimental prop matches the grasp aperture afforded by the object size (e.g., power grip for an apple, precision grip for a grape: Glover, Rosenbaum, Graham & Dixon, 2004; see also Gentilucci, Benuzzi, Bertolani, Daprati & Gangitano, 2000; Smith, Franz, Joy & Whitehead, 2005; Taylor & Zwaan, 2010; Tucker & Ellis, 2001). However, such studies required participants to execute a grasping action as part of their response, which conflated tactile and proprioceptive effects and, crucially, left open the possibility that the observed size effects were action-dependent. In other words, it is possible that size representations involving touch and proprioception form part of the dynamic simulation of an object only when the current situation demands making an appropriate grasping action (i.e., where the dependent measure is time to grasp, or time to execute an action with a relevant effector). A second possibility that we test in the present paper is that touch and proprioceptive information are represented as part of the dynamic object simulation across a range of conceptual tasks, including size judgements, independent of motor action planning. Thus, in the experiments below, we measured the speed of participant voice responses (where the mouth is a non-relevant effector), obviating the need for responses requiring overt actions using object-relevant effectors.

Experiment 1: Tactile Stimulation

In our first study, people performed the size comparison task while receiving tactile stimulation from vibrating cushions. By resting hands on cushions, participants received proprioceptive stimulation to the hands in both critical and control conditions. However, in the critical condition, where the hand cushions were vibrating, participants experienced vibrotactile feedback to the skin on palm and fingers which was absent during the control condition (see for example Pavani, Spence & Driver, 2000, for use of vibrotactile stimulation)1. Since touch information from the hands should form part of a multimodal conceptual representation of object size, we expected size judgements to be faster during tactile hand stimulation than during tactile foot stimulation. Furthermore, we expected such facilitation for small objects only, because the sense of touch can only inform size representations for objects that afford physical manipulation.

Method

Participants Forty-one volunteers from the University of Manchester (bigger judgements N = 20, smaller judgements N = 21; see procedure for details) took part for course credit or a £3 reward. All participants were naïve to the experiment, had normal or corrected-to-normal vision, were fluent in English, and had no mobility or reading impairments.

Materials Stimuli for the size comparison task consisted of 100 pairs of object names: 50 pairs of small-size objects (e.g., ALMOND:PEAR, CRAYON:PEN) and 50 pairs of large-size objects (e.g., ELEPHANT:WHALE, IGLOO:WINDMILL). Each item in the pair was from a similar category (e.g., both buildings, both fruits, both artefacts etc.) with one object in each pair bigger than the other. In a pretest, three independent raters correctly classified the larger/smaller item of each pair in 100% of cases. There were no differences in word length between bigger and smaller items in each pair, nor between big and small items in general (t's<1). Four counterbalanced lists of stimuli were created (each with 25 small and 25 large pairs), to ensure that all items would appear in both the hand- and foot-stimulation blocks, as well as appearing on both the left and right-hand positions onscreen. Importantly, this counterbalancing ensures that all items appear in all conditions.

Procedure Participants removed their shoes and sat in a chair in front of a computer screen. The experimenter then placed a massage cushion under each hand and foot (see Figure 1) and participants remained in this position for the duration of the experiment. The hand cushions vibrated at 67Hz to provide tactile stimulation in the critical block, while the foot cushions vibrated to provide equivalent sensory distraction in the control block.

For the size comparison task, each pair of object names was presented in capital letters, 4cm apart in the center of the screen (left-right order counterbalanced), separated by a colon. Once a vocal response had registered, the screen blanked for 1500ms before the next trial. Participants received automatic feedback if their responses were outside the valid range (250-3000ms). Trials were randomly presented within each block. Since size comparison is bidirectional, participants were randomly allocated to make either bigger or smaller judgements. In other words, Participant A would always judge which object of a pair was bigger, while Participant B would always judge which object was smaller. Participants were told they would see the names of two objects onscreen and that they should state aloud, as quickly as possible, which item was bigger (or smaller) in size. If participants were unfamiliar with any presented words, they were asked to say so and the trial was marked as invalid. To record responses, participants wore a head-mounted unidirectional microphone. Response times were measured from the appearance of the object names to the onset of the vocal response. A practice session of ten trials preceded the main experiment to familiarize participants with the task and allow for microphone calibration.

Design and Analysis Response time data in all studies were analysed using linear mixed models, which allows simultaneous analysis with participants and items as crossed random factors (Baayen, Davidson & Bates, 2008; Locker, Hoffman & Bovaird, 2007). Object size (large, small), stimulation position (hands, feet), and judgement type (bigger, smaller) were crossed fixed factors. All condition means presented in the text are estimated marginal means in milliseconds.

Results & Discussion

Outlier responses more than 2.5SD from a participant's mean per condition (2.47% of data) were excluded before analysis. Results were as predicted: relative to foot stimulation controls, tactile stimulation to the hands facilitated size judgement times only for small objects (hand M = 1459ms, SE = 47ms; foot M = 1528ms, SE = 47ms), $F(1, 3520.1) = 18.39$, $p < .0001$, whereas it had no effect on judgements of large objects (hand M = 1576ms, SE = 47ms; foot M = 1595ms, SE = 47ms), $F(1, 3519.6) = 1.36$, $p = .243$. This critical facilitation for small objects emerged both when participants judged which object was bigger (Figure 2a), $F(1, 3509.2) = 10.88$, $p = .001$, and which object was smaller (Figure 2b), $F(1, 3528.7) = 7.65$, $p = .006$. Neither bigger nor smaller judgement types showed any difference for large objects, $F(1, 3510.2) = 1.19$, $p = .276$, and $F<1$, respectively.

Overall, people responded more quickly during stimulation to the hands than stimulation to the feet, $F(1, 3519.9) = 14.67$, $p < .001$, and small objects were judged faster than large, $F(1, 96.1) = 7.54$, $p = .007$, with a critical interaction, $F(1, 3519.7) = 4.66$, $p = .031$. Judgement type had no main effect, $F<1$, but did interact with object size, $F(1, 3510.4) = 18.67$, $p < .0001$, because "which is smaller" judgements were generally faster for small objects than large, while "which is bigger" judgements made little difference. There were no other interactions, Fs<1. Analysis of accuracy showed that size was compared more accurately for small objects than large, $F(1, 39) = 40.23$, $p < .0001$, but this varied by judgement type, $F(1, 39) = 4.68$, $p = .037$, with a greater difference for "which is bigger" judgements (small = 97%, large = 90%) than "which is smaller" judgements (small = 95%, large = 92%). There were no other accuracy effects or interactions, all Fs<1.

This study shows that stimulating the hands with tactile vibrations made it easier to represent and compare small objects like apples or cups because their size representations included modality-specific information about hand touch. Objects that were too large to be physically manipulable, like elephants and windmills, lacked tactile information in their representations and hence were unaffected by tactile stimulation. Furthermore, this modality-specific, body-specific facilitation effect was not task-dependent on judging which object was bigger, but was independent of the direction of the size comparison being made.

Experiment 2: Proprioceptive Stimulation

In this study, we manipulated proprioceptive information by asking people to hold a beachball while they performed the size comparison task. Here, participants received tactile stimulation to the hands in both critical and control conditions (i.e., skin on palm and fingers was in constant lightly-pressured contact with flat surface). Crucially, in the critical condition, holding the beachball meant that participants received isometric proprioceptive feedback (i.e., stable muscular tension during passive holding, without change in the length of muscle fibres) from the hands and arms, which is absent during the control condition. Since proprioceptive information from the hands and arms should form part of a multimodal conceptual representation of size, we expected size judgements to be faster during proprioceptive hand stimulation than during proprioceptive foot stimulation. As before, we expected such facilitation for small objects only, because hand positioning can only inform size representations of manipulable objects.

Method

As per Experiment1, with the following exceptions.

Participants Participants from the University of Manchester (bigger judgements N = 23; smaller judgements N = 22) took part with the same criteria as before.

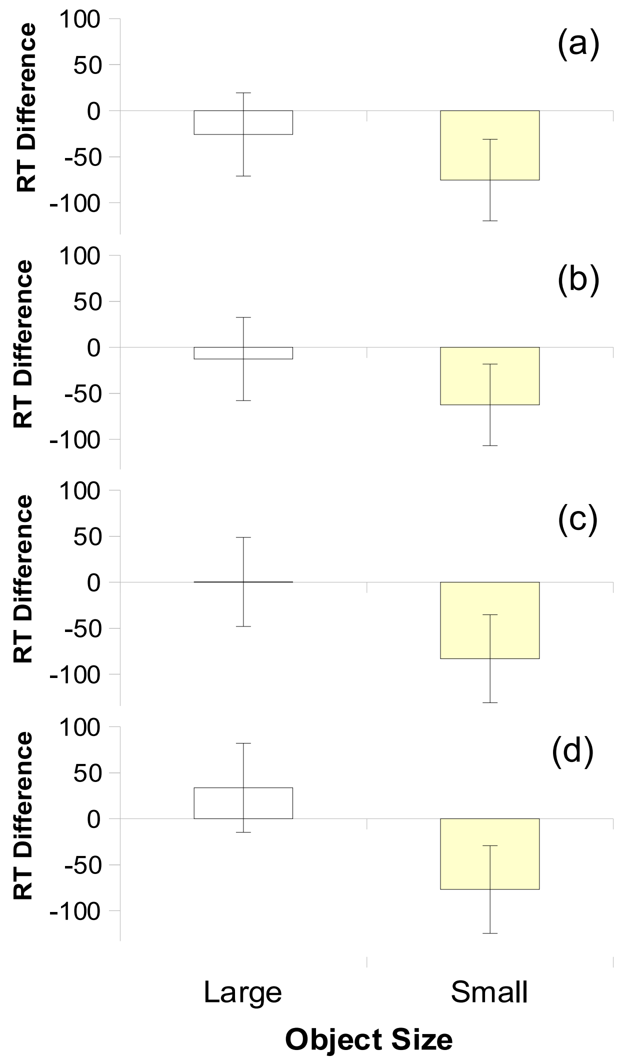

Figure 2. Size judgement effects (in ms) for tactile stimulation (a: bigger judgements, b: smaller judgements) and proprioceptive stimulation (c: bigger judgements, d: smaller judgements), showing consistent facilitation for small objects but not for large objects. RT difference was calculated by subtracting judgement times in the control foot-stimulation condition from judgement times in the critical hand-stimulation condition. Error bars show 95% confidence intervals of the difference between means.

Procedure Participants sat in a chair in front of a computer screen. In the hand stimulation block, participants held a beachball of 30cm diameter in front of their bodies at chest height, without letting the ball touch their knees or the table in front, which actively positioned their hands a constant distance apart (see Figure 1). Squares of stiff card were attached to both sides of the beachball, and participants placed their hands flat on the card, secured by rubber finger loops, to prevent the curvature of the ball providing unwanted shape information. The feet were kept flat on the ground for the duration of the block. In the foot stimulation (control) block, participants held the beachball between their lower legs, as far down as possible without letting the ball touch the ground. The hands were placed flat on the thighs for the duration of this block. Holding the beachball, rather than simply holding hands/feet apart in isolation, ensured that participants kept their hands/feet at a stable distance apart for the duration of the experiment. Participants completed the size-comparison judgements as before.

Results & Discussion

Following removal of outliers (2.72% of data), effects emerged as predicted. Relative to foot stimulation controls, proprioceptive stimulation to the hands facilitated size judgements of small objects (hand M = 1533ms, SE = 48ms; foot M = 1612ms, SE = 48ms), $F(1, 3795.2) = 22.06$, $p < .0001$, but made negligible difference to judgements of large objects (hand M = 1641ms, SE = 48ms; foot M = 1624ms, SE = 47ms), $F<1$. As in the previous experiment, size judgements for small objects were facilitated for both "which is bigger" (Figure 2c), $F(1, 3791.9) = 12.27$, $p < .001$, and "which is smaller" comparisons (Figure 2d), $F(1, 3794.0) = 9.94$, $p = .002$. There was no facilitation for large objects with either judgement type, $F<1$ and $F(1, 3796.1) = 1.87$, $p = .172$., respectively.

Overall, response patterns followed the previous experiment. People responded more quickly during stimulation to the hands than stimulation to the feet, $F(1, 3795.6) = 6.71$, $p = .010$, small objects were judged marginally more quickly than large, $F(1, 97.7) = 3.03$, $p = .085$, and factors interacted, $F(1, 3795.6) = 15.95$, $p < .0001$. Judgement type had no overall effect of its own, $F(1, 42.9) = 2.20$, $p = .146$, but interacted with object size in the same way as before, $F(1, 3790.6) = 29.25$, $p < .0001$. There were no other interactions, $Fs<1$. In terms of accuracy, small object comparisons were more accurate than those of large objects, $F(1, 43) = 28.49$, $p < .0001$, but interacted with judgement type, $F(1, 43) = 7.61$, $p = .009$, such that judging "which is bigger" produced a greater accuracy difference (small = 95%, large = 90%) than did judging "which is smaller" (small = 94%, large = 92%). No other accuracy effects or interactions emerged: position by judgement interaction $F(1, 43) = 1.85$, $p = .180$; all other $Fs < 1$.

In short, the proprioceptive findings replicate those for tactile stimulation. Positioning the hands 30cm apart created proprioceptive stimulation that assisted people in representing and judging small objects, because past experience of physically manipulating pears and cups meant that their conceptual representations included information about hand/arm positioning. Even though participants could have based their judgements of both large and small objects entirely on visual information, they appeared to do so only for large objects like planets and whales, because such judgements remained unaffected by positioning (and touch) feedback from the hands.

General Discussion

In a series of novel studies, we found that tactile and proprioceptive feedback from the hands facilitated conceptual size judgements, but only for objects that were small enough to be physically manipulated. These findings of distinct tactile and proprioceptive representations of size extend previous work on action affordances. The present studies provide the first evidence that the senses of touch and proprioception uniquely and separably contribute to conceptual representations of size. Furthermore, by requiring vocal responses, they confirm that tactile and proprioceptive size representations are independent of motor planning an associated action.

While we report facilitation effects in both of the above studies, in line with existing work involving bodily feedback (e.g., Dijkstra et al., 2007; Havas et al., 2007; Riskind, 1983; Strack et al., 1988), others have shown conceptual interference effects during concurrent perception of motion, such as for visual scrolling (Kaschak et al., 2005) or auditory directional noise (Kaschak, Zwaan, Aveyard & Yaxley, 2006). In such cases, the temporal dynamics of a moving perceptual stimulus require attention to continuously monitor it for change, and hence leaves few attentional resources in the input modality free for simultaneous conceptual processing (i.e., interference). Our perceptual stimulus, on the other hand, is stationary: there is no need for continuous monitoring, and so it directs attention to the input modality while leaving resources free for concurrent conceptual processing (i.e., facilitation).

We have previously shown that modality-specific perceptual information is automatically represented in conceptual processing of words relating to touch, vision, taste, smell and hearing (Connell & Lynott, 2010; see also Lynott & Connell, 2009). Other studies have shown various modality-specific effects for the same set of five basic senses (e.g., Connell, 2007; Connell & Lynott, 2009; Goldberg, Perfetti & Schneider, 2006; Pecher, Zeelenberg & Barsalou, 2003; van Dantzig, Pecher, Zeelenberg & Barsalou, 2008; Vermeulen, Mermillod, Godefroid & Corneille, 2009). The present work is the first demonstration that proprioception can be added to the list of automatically-represented perceptual modalities in conceptual tasks, such as the size-comparison task employed here.

In conclusion, the present findings enhance our understanding of embodied conceptual representations, demonstrating that people can "hold" something in the mind's hands by simulating modality-specific information captured during perceptual experience. While vision is a useful and fundamental means of perceiving and representing objects, the importance of bodily feedback such as touch and proprioception should not be underestimated as they offer valuable means of conceptualizing the world around us.

Acknowledgments

This research was funded by the British Academy. Thanks to Donna Lloyd, Andrew Howes, and Andrew Stewart for comments.

References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390–412.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22,* 577-660.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617-645.

Connell, L. (2007). Representing object colour in language comprehension. *Cognition, 102*, 476-485.

Connell, L., & Lynott, D. (2010). Look but don't touch: Tactile disadvantage in processing modality-specific words. *Cognition, 115*, 1-9.

Connell, L., & Lynott, D. (2009). Is a bear white in the woods? Parallel representation of implied object color during language comprehension. *Psychonomic Bulletin & Review, 16*, 573-577.

Dijkstra, K., Kaschak, M. P., & Zwaan, R. A. (2007). Body posture facilitates retrieval of autobiographical memories. *Cognition, 102*, 139–149.

Gentilucci, M., Benuzzi, F., Bertolani, L., Daprati, E., & Gangitano, M.(2000). Language and motor control. *Experimental Brain Research, 133*, 468-490.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1-55.

Glover, S., Rosenbaum, D. A., Graham, J., & Dixon, P. (2004). Grasping the meaning of words. *Experimental Brain Research, 154*, 103-108.

Goldberg, R. F., Perfetti, C. A., & Schneider, W. (2006). Perceptual knowledge retrieval activates sensory brain regions. *Journal of Neuroscience, 26*, 4917-4921.

Havas, D. A., Glenberg, A. M., & Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomic Bulletin & Review, 14*, 436–441.

Locker, L., Hoffman, L., & Bovaird, J. A. (2007). On the use of multilevel modeling as an alternative to items analysis in psycholinguistic research. *Behavior Research Methods, 39,* 723–730.

Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behavior Research Methods, 41*, 558-564.

Kaschak, M. P., Madden, C. J., Therriault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A. A., Zwaan, R. A. (2005). Perception of motion affects language processing. *Cognition, 94*, B79–B89.

Kaschak, M. P., Zwaan, R. A., Aveyard, M., & Yaxley, R. H. (2006). Perception of auditory motion affects language processing. *Cognitive Science, 30*, 733-744.

Kosslyn, S. M. (1980). *Image and mind*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M., Murphy, G. L., Bemesderfer, M. E., & Feinstein, K. J. (1977). Category and continuum in mental comparisons. *Journal of Experimental Psychology: General, 106*, 341-375.

Newman, S. D., Klatzky, R. L., Lederman, S. J., & Just, M. A. (2005). Imagining material versus geometric properties of objects: An f MRI study. *Cognitive Brain Research, 23,* 235-246.

Oliver, R. T., & Thompson-Schill, S. L. (2003). Dorsal stream activation during retrieval of object size and shape. *Cognitive, Affective, & Behavioral Neuroscience, 3*, 309-322.

Paivio, A. (1971). *Imagery and verbal processe*s. New York: Holt, Rinehart & Winston.

Paivio, A. (1975). Perceptual comparisons through the mind's eye. *Memory & Cognition, 3*, 635-648.

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford, UK: Oxford University Press.

Pavani, F., Spence, C. and Driver, J. (2000). Visual capture of touch: Out-of-the-body experiences with rubber gloves. *Psychological Science, 11*, 353–359.

Pecher, D., Zeelenberg, R., and Barsalou, L. W. (2003). Verifying properties from different modalities for concepts produces switching costs. *Psychological Science, 14*, 119–124.

Riskind, J. H. (1983). Nonverbal expressions and the accessibility of life experience memories: A congruence hypothesis. *Social Cognition, 2*, 62–86.

Smith, M., Franz, E. A., Joy, S., & Whitehead, K. (2005). Superior performance in the blind on bimanual object size estimations. *Psychological Science, 16*, 11-14.

Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology, 54*, 768-777.

Taylor, L. J., & Zwaan, R. A. (2010). Grasping spheres, not planets. *Cognition, 115*, 39-45.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8,* 769-800.

van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cognitive Science, 32*, 579-590.

Vermeulen, N., Mermillod, M., Godefroid, J., & Corneille, O. (2009). Unintended embodiment of concepts into percepts: Sensory activation boosts attention for same-modality concepts in the attentional blink paradigm. *Cognition, 112*, 467-472.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*, 625-636.