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Conceptually congruent actions can promote thought

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ABSTRACT

Can action support thought? Previous work suggests that it can. Here, we examined whether actions that are conceptually congruent with thinking facilitate thinking and whether direct action facilitates performance. We found that young children performed addition, a discrete one-to-one math task, better when using discrete one-to-one actions that matched the number of objects than when using discrete actions that matched the number of sums to be added. They performed number line estimation, a continuous math task, better when using a continuous action in which the time and distance of the action were commensurate with the quantity to be estimated, than when using a discrete action that marked a proportional distance. Action congruence facilitated performance beyond spatial congruence. Furthermore, direct manipulation led to better performance than mediated manipulation. Finding advantages of congruent mappings of thought to action supports the *Spraction Theory*, which asserts that thought is internalized action, and that re-externalizing thought through congruent actions facilitates thought.

1. Introduction

Every day, it seems there is yet another demonstration of yet another surprising way that sensations or actions of the body affect thinking, phenomena broadly known as embodied cognition (e.g., Barsalou, 1999; Fischer & Zwaan, 2008; Glenberg & Gallese, 2011; Kirsh, 1995; Meier, Schnall, Schwarz, & Bargh, 2012; Semin & Smith, 2008; Wilson, 2002). When holding a hot cup of coffee, people rate others as warmer (Williams & Bargh, 2008). After social rejection, being "given the cold shoulder," people find a room chillier (Zhong & Leonardelli, 2008). When grasping a heavy clipboard, people give weightier judgments, such as higher monetary values and greater importance to fair procedures (Jostmann, Lakens, & Schubert, 2009). These are just a few of the remarkable effects making their ways to journals and often the popular press. Some are controversial, even disputed, and there are varying interpretations of how they might work. Commonly, the explanations refer to metaphors like "cold" shoulders, "warm" people, and "weighty" decisions that are so embedded in the ways we speak and gesture that we are hardly aware that they are metaphors (e.g., Lakoff & Johnson, 1980). Presumably, experiencing real heat, cold, or weight primes the general or metaphoric meanings of heat, cold, and weight and "contaminates" the judgments.

That is the sensory side of embodiment. There is also the action side. What we *do* can influence thought as well as what we *sense*. Especially intriguing, and the focus here, are the demonstrations showing that actions of the body affect thinking, in particular, facilitation when the actions are *congruent* with the thinking. When people point to objects one by one, they count more proficiently (Carlson, Avraamides, Cary, & Strasberg, 2007). When people rotate their hands in the same direction as mental rotation, they perform better (Chu & Kita, 2008; Wexler, Kosslyn, & Berthoz, 1998). When they rotate their hands, they more readily understand how gears interact (Schwartz & Black, 1996). When they create virtual diagrams with their hands, they make more accurate inferences (Jamalian, Giardino, & Tversky, 2013). These actions are more than expressive of thought; they are instrumental to thought. When gestures are prevented, thinking suffers (e.g., Carlson et al., 2007; Chu & Kita, 2008; Krauss, Chen, & Gottesman, 2000) and as thinking becomes proficient, gesturing diminishes (e.g., Chu & Kita, 2008; Schwartz & Black, 1996). These correspondences, metaphoric and literal, appear not only in actions, gestures, and language, but also in visual-spatial representations, in graphs, charts, and diagrams produced and used across cultures and by children as well as adults (e.g., Goldstone, Landy, & Brunel, 2011; Tversky, Kugelmass, & Winter, 1991; Tversky, 2011).

That thought is internalized action is a venerable idea developed by, among others, Piaget, Vygotsky, and Bruner (e.g., Bruner, 1966; Piaget, 1928; Vygotsky, 1962) and reflected in the ways we talk about thinking. We arrange and rearrange our thoughts, pull them together or apart, order them or scramble them up. This

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venerable claim is supported not just by the behavioral evidence but also by accumulating incidental findings from brain research showing that a range of mental actions, such as putting things into memory, mental rotation, and counting, activate motor or premotor cortices and even musculature (e.g., Andres, Seron, & Olivier, 2007; Eisenegger, Herwig, & Jäncke, 2007; Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000; Kansaku et al., 2007; Manoach et al., 1997). If thought is (at least in part) internalized action, then re-externalizing thought through congruent actions should facilitate thought.

In the previous examples, the actions or gestures that facilitated thinking were generated spontaneously by the thinkers. Can actions congruent with thought that are not spontaneous but induced by a task also affect thinking? There is also evidence for that. When solving beginning algebra problems, students performed better when instructed to point to the terms that need to be grouped on one side of the equation and then to the equivalent term on the other side (Goldin-Meadow, Cook, & Mitchell, 2009). When instructed to practice swinging their arms appropriately, they solve Maier's two-string problem better (Thomas & Lleras, 2009).

Congruence, correspondence, compatibility, affordance—these are not new concepts. Conceptions of natural correspondences between seeing and doing, between space and action, between actions and spatial consequences, between space and meaning, have appeared and reappeared in theory in psychology and linguistics as well as in practice, in the design of products, graphics, and interfaces (e.g., Fitts & Deininger, 1954; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kornblum, Hasbroucq, & Osman, 1990; Norman, 1988). Nevertheless, a complete account of congruence has been elusive. Convention, learning and familiarity play roles, but can't explain why certain relations are easier to learn than others, why certain correspondences are invented and reinvented. Stimulus-response overlap or common features have been suggested (e.g., Fitts & Deininger, 1954; Hommel et al., 2001; Kornblum et al., 1990) but leave open the question of the origins of the overlap. Metaphoric correspondences go a step farther by pointing to the natural origins of many correspondences in appearances and actions in the world (e.g., Clark, 1973; Lakoff & Johnson, 1980; Tversky, 2001). Good things do tend to go up: piles of money grow higher, as do hardier trees, healthier people, and stronger buildings. It takes money, strength, energy and time to counteract gravity. We bring things we like closer and we distance ourselves from things we do not like.

In the absence of a complete account of congruence, clues to correspondences can come from spontaneous behaviors in the wild, language, cultural artifacts such as diagrams, and behavior, notably, gestures. Math is a domain that lends itself to spatial and action correspondences. Counting is a discrete task that depends on one-to-one correspondences between objects and numbers. In contrast, estimating value on a dimension, such as approximate time, quantity, or preference, is a continuous task. When describing solutions to discrete math problems, students tended to make discrete gestures, for example, a series of discrete taps, chops, or beats, similar to counting. When describing solutions to continuous math problems, they tended to make continuous gestures, for example, smooth sweeps or slides (Alibali, Bassok, Olseth, Syc, & Goldin-Meadow, 1999). A parallel phenomenon occurs for diagrams, which, like gestures, externalize, embody, and facilitate thought (e.g., Tversky, 2011). When asked to create diagrams for discrete or continuous concepts, sets vs. dimensions, people produced discrete or continuous diagrams, as appropriate (Tversky, Corter, Lixiu, Mason, & Nickerson, 2012). Remarkably, discrete and continuous math tasks appear to use different parts of the brain (e.g., Dehaene & Cohen, 1995; Dehaene, 1997). This distinction, discrete vs. continuous, category vs. continuum, exact vs. approximate, digital vs. analog, is fundamental and pervasive.

If people spontaneously use discrete gestures for counting and for describing discrete math tasks and use continuous gestures for describing continuous math tasks, then embedding these correspondences as actions should improve performance over less congruent actions. Computer interfaces enable designing actions that are more or less congruent with thought. Could embedding congruent actions improve math performance in young children? Here, children performed two math tasks, a discrete one-to-one task, addition, and a continuous task, number line estimation. The addition task had two columns of blocks; the task was to sum the columns and add them together. The conceptually congruent mapping (discrete and one-to-one) was one tap for each block in each column so that the number of actions corresponded to the sum of the blocks. The less congruent mapping (discrete, but not one-to-one with the blocks) was a single tap for each column so that the number of actions corresponded to the number of sums to be added (two). The number line estimation task was to indicate the position of a given number on a scale from 1 to 100. The conceptually congruent continuous action was to slide a marker to the chosen position, so that both the time to slide and the distance covered were commensurate with the estimated number. The less congruent action was a single tap at the appropriate position. In this case, the marker marked the proportional distance on the line, so there was spatial congruence but no action congruence. For both interfaces, children were free to go back and forth, moving the slider or tapping again, before deciding on their answers. This allowed them to use any strategies they liked. The prediction is straightforward: if actions that are conceptually congruent with thought aid thought, then the congruent actions should improve performance.

Another line of research has shown that thinking is facilitated by direct actions on objects, in particular, manipulables or tangibles (e.g., Clements, 2000; Ishii & Ullmer, 1997; Marshall, 2007; Shneiderman, 1983; Uttal, Scudder, & DeLoache, 1997; Zuckerman, Arida, & Resnick, 2005). The present research allowed comparing direct and less direct manipulation. An iPad touch platform offered direct manipulation: children moved objects in the display with their fingers. A laptop computer allowed only indirect manipulation via a mouse that drove a cursor that "touched" and "moved" objects in the display. Direct manipulation should be more natural and better; however, it should be noted that the differences between touching and moving an object on a screen and touching and moving a mouse that grabs and moves an object on the screen are small, analogous to reaching a distant object with a hand or with a stick. In both cases, the child manipulates (computer) objects, with or without a tool.

The research addresses two related questions about the externalization and embodiment of thinking. Will actions that are congruent with thought but not spontaneously produced benefit thought more than actions that are less congruent with thought? Next, will direct manipulation of the externalized objects of thought benefit thinking more than mediated manipulation?

2. Method

2.1. Participants

One hundred and twenty eight first and second grade children were recruited from two after school programs in public schools in a low-SES area of New York City. Twelve children were eliminated because of age and nine to technical problems, leaving 107 children (60 boys). Their ages ranged from 5 years 9 months to 7 years 10 months with a mean of 6 years 10 months.