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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.

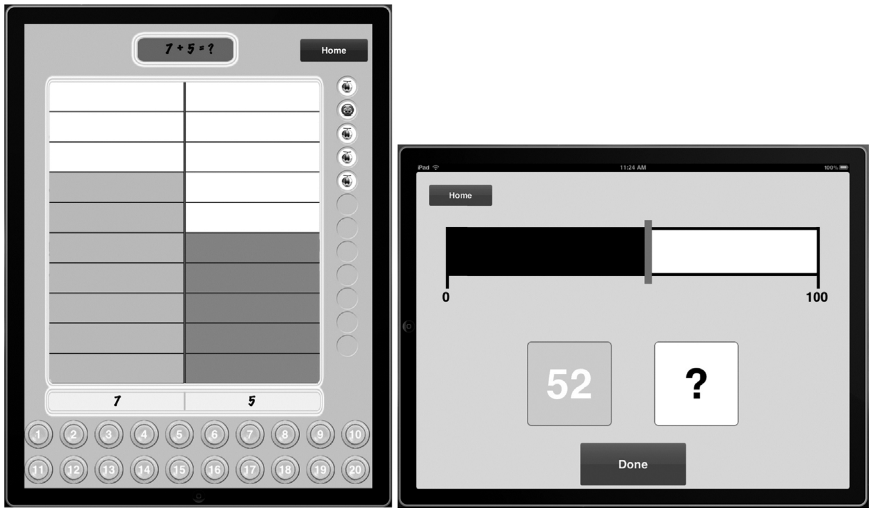

Fig. 1. On the left, the counting and addition task; on the right, the number line estimation task.

2.2. Materials

There were two platforms: a 10″ multi-touch Apple iPad, allowing direct interaction by actions on objects on the screen, and a Macintosh MacBook Pro laptop, allowing indirect interaction by a mouse that drove a cursor on the screen. Software presented the addition and number line estimation task and recorded children's answers and times to complete each task.

2.3. Design

There were four between-subject conditions, obtained by crossing congruent vs. less congruent actions and direct (iPad) vs. indirect (laptop) platforms, and two within-subject tasks, addition and number line estimation. Children were given a paper and pencil pre-test that assessed three basic math skills; number comparison (i.e. which number is bigger 25 or 13), addition, and number-line estimation (Siegler & Booth, 2005). They were randomly assigned to conditions adjusted to equate groups on pre-test scores (25 mouse/congruent, 30 touch/congruent, 24 mouse/less congruent, 28 touch/less congruent). Each child solved 10 addition and 23 number line estimation problems. Problem types were blocked and blocks were presented in counterbalanced order across conditions. The problems within each task were presented in the same order for all children. The addition problems were: 9 + 3 = ?, 2 + 8 = ?, 5 + 2 = ?, 7 + 5 = ?, 1 + 10 = ?, 6 + 3 = ?, 9 + 5 = ?, 4 + 6 = ?, 8 + 7 = ?, 10 + 10 = ?. The number line estimation problems were: 25, 52, 87, 5, 40, 64, 45, 71, 33, 14, 85, 68, 55, 15, 30, 75, 92, 7, 27, 10, 51, 66, 70. The displays for the two tasks are depicted in Fig. 1.

3. Experimenters

Eight experimenters were recruited from graduate programs at Columbia Teachers College and paid by the hour. The experimenters had had previous experience testing children and underwent a two-hour training session. They were given a script for each condition and platform and practiced the interactions needed for practice and actual trials. The experimenters were told that this was a study of technology and math but were not informed of the details of the research hypotheses.

3.1. Procedure

The experiment took about 20 min. The experimenter introduced the experiment by saying: "Hi, my name is...what's your name? Today we will play some number games together on the computer/ipad. I will show you one question and then you can try one. Are you ready? Great, Let's start." For each task, experimenters first showed the child how to solve the problem, and then let the child practice solving one problem alone. Throughout, the experimenters recorded any strategies used by the children by checking them off on a page listing possible strategies based on previous work.

Children solved 10 addition problems by adding virtual blocks highlighted in side-by-side piles of two 10-block towers (see Fig. 1). The addition problems were presented at the top of the display, e.g., 6 + 7 = ? 2 + 9 = ? with the numbers of blocks for each tower below each tower. Children performed 23 estimations on the number line (Siegler & Booth, 2005), (see Fig. 1). In both cases, the computer spoke the questions and gave the correct answers after the children responded.

3.1.1. Addition task

The child's task was to add the number of colored blocks in the two block towers. The experimenter opened with: "This is a blocks game. You need to figure out how many blocks are in the left and right piles. For example, how much does 3 and 4 make together?" In the congruent action condition, the experimenter tapped with a finger on each of the three blocks on the left pile and each of the 4 blocks on the right pile to highlight the color, and then selected and tapped on the answer 7 below. In the less congruent action condition, the experimenter tapped with a finger on the number 3 below the left pile and on the number 4 below the right pile. The experimenter then selected and tapped on the answer 7 below, saying "3 and 4 makes 7 together, so I press the number 7 on the green button. Now it's your turn to try the next one." In the congruent condition the experimenter said: "Remember that you have to click on each block before you answer." In the less congruent condition the experimenter said: "Remember that you have to click on the numbers below each column before you answer." In the congruent condition, children tapped with a finger on each individual block for the direct interface. They clicked on each block for the mediated interface. When the child tapped or clicked, the block's color was highlighted. In the less congruent condition, children tapped or clicked on the sums of the numbers under each column of blocks, rather than on each block. This highlighted the blocks in the corresponding tower. Note that the congruent actions necessarily took more time than the less congruent actions. The congruent condition required clicks equivalent to the sum of each problem plus one for the answer, thus, 8–21 clicks, whereas the less congruent condition required three clicks for each problem. In both cases, the actions are discrete; however, in the congruent case, there is a one-to-one mapping to the number of bricks and in the less congruent case, there is a mapping, also one-to-one, to the number of columns to be summed.

3.1.2. Number line task

Prior to the number line task, the experimenter asked the child to show her where the numbers 0 and 100 were on the number line to make sure the child recognized the numbers. The experimenter explained the task by saying, "This is a guessing game. This is a number line from 0 to 100. A number line is a line with numbers across it. The numbers on the line go from the smallest number to the largest number, and the numbers go in order, so each number has its very own spot on the number line." (Siegler & Booth, 2005). The experimenter demonstrated one question and then asked the child to try another question. In the congruent (continuous) action condition, the experimenter tapped on the red line, dragged the red line with a finger or the mouse to the place for number 95 on the number line, and then tapped on the "done" button. In the less congruent (discrete) action condition, the experimenter tapped on the number line bar at the place for number 95 and then tapped the "done" button. The experimenter said, "You can go back and forth but once you press the "done" button you can't change your answer. Now you can try, where is the number 90? Good, now press the done button." As for addition, the congruent action took longer to enact than the less congruent action. After each answer, the child received animated feedback; specifically, the bar filled with green from the left to the place of the correct value. Then the number appeared above the place. Note that, as for addition, the actions for the congruent condition took longer than those for the less congruent condition.

4. Results

4.1. Overview of findings

Both predictions were realized. Congruent actions enhanced accuracy of performance and direct manipulation improved speed of performance and counting strategies. In both addition and number line tasks, children were more accurate when using conceptually congruent actions than when using less congruent actions. The direct (touch) interface was superior to the mediated (mouse) interface in time and strategy use for addition and in time for number line estimation. There were no effects of age in any of the analyses.

4.2. Addition task: errors

Errors were analyzed by a two by two between-subjects ANOVA. As evident from Fig. 2, children who used congruent actions (M = .002, SD = .008) made fewer errors for both platforms (Touch and Mouse) than children using less congruent actions (M = .012, SD = .019), $F(1, 102) = 8.42$, $p < .005$. $\eta^2\rho = 0.08$.

Neither the effects of platform $F(1, 102) = 0.41$, $p > .05$, n.s., $\eta^2\rho = 0.00$, nor the interaction $F(1, 102) = 2.65$, $p > .05$, n.s. $\eta^2\rho = 0.03$ reached significance.

4.3. Addition: time

The analyses included both correct and incorrect responses. Children who used the direct touch interface (M = 22.7 SD = 10.69) solved the addition problems significantly faster than children who used the indirect mouse interface (M = 29.76 SD = 14.61), $F(1, 102) = 21.72$, $p < .001$, $\eta^2\rho = 0.18$. Children using less congruent actions responded faster (M = 16.73 SD = 5.82) than children using congruent actions (M = 34.63 SD = 12.01), $F(1, 102) = 163.53$,

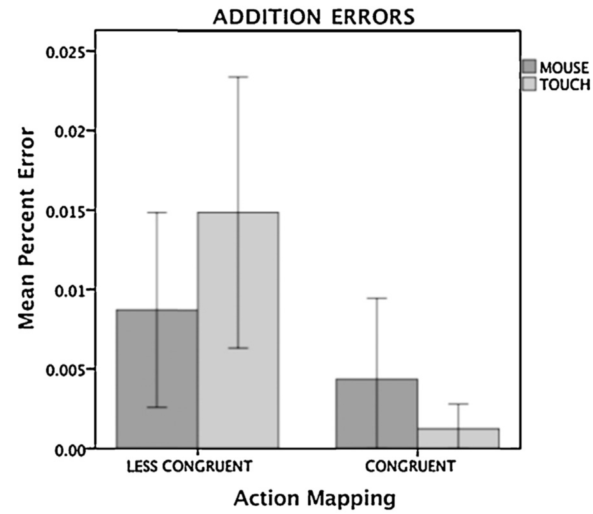

Fig. 2. Means percent error for the addition task for each interface. Error bars represent standard errors.

$p < .001$, $\eta^2\rho = 0.62$. The interaction between platform and action congruence was not significant, $F(1, 102) = 3.81$, $p > .05$, n.s, $\eta^2\rho = 0.04$.

As noted, the less congruent condition required fewer actions than the congruent condition, so it is not surprising that children in the less congruent condition were faster. The less congruent case required three actions, one for each of the two columns and one to submit the answer. The congruent case required one action per block to be counted, plus one to submit the answer, between 8 and 21 clicks total. To check whether the number of clicks could account for the difference, we divided the times for the less congruent cases by 33 (3 × 11) and the times for the congruent cases by 134 (sum of answers + 11), the average sum for the addition problems, to get a rough estimate of the time per action. These data appear in Fig. 3. When time per action is taken into account, children using congruent actions responded faster (M = .27 SD = .117) than children using less congruent actions (M = .51 SD = .177), $F(1, 102) = 81.73$, $p < .001$, $\eta^2\rho = 0.44$. The interaction between platform and congruence did not reach significance $F(1, 102) = 0.46$, $p > .05$, n.s, $\eta^2\rho = 0.00$. Similarly, the direct interface yielded faster response times $F(1, 102) = 16.96$, $p < .001$).

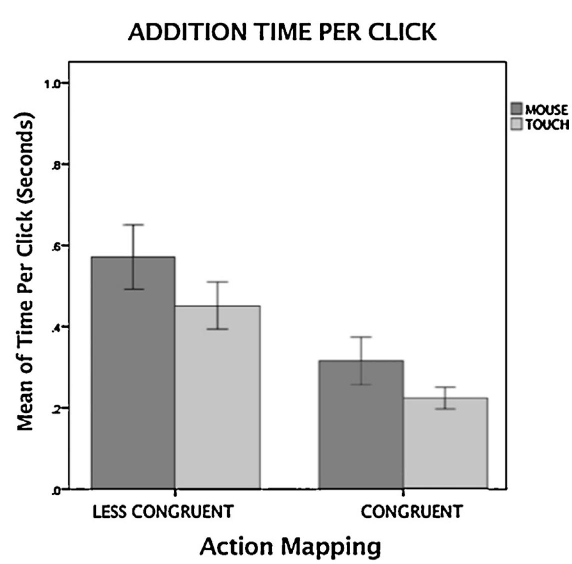

Fig. 3. Means time on task per click for addition. Error bars represent standard errors.

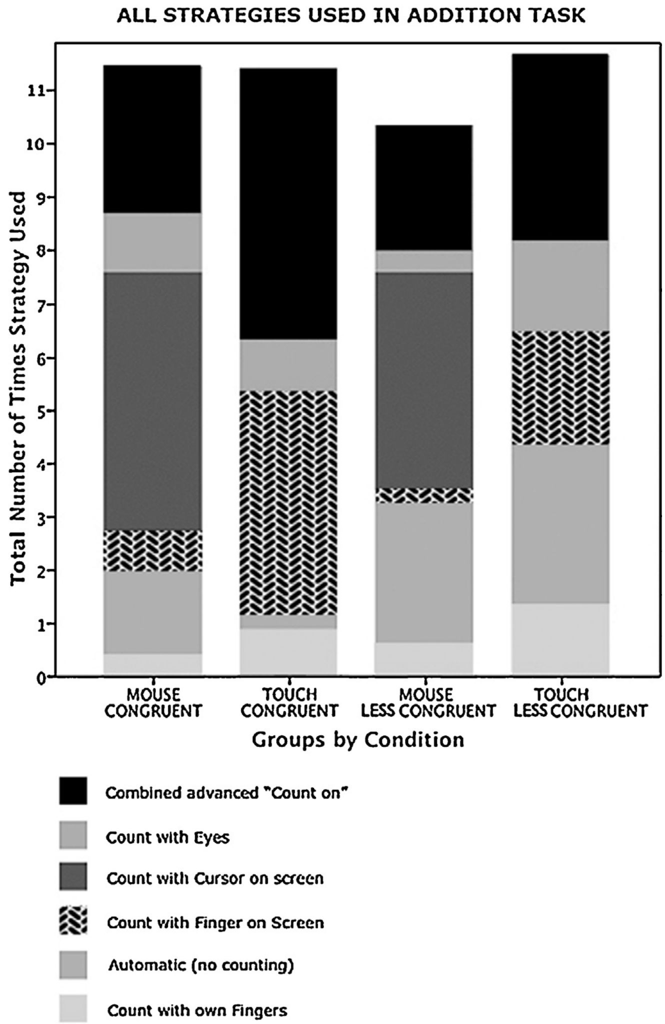

Fig. 4. Overview of all strategies used in addition task.

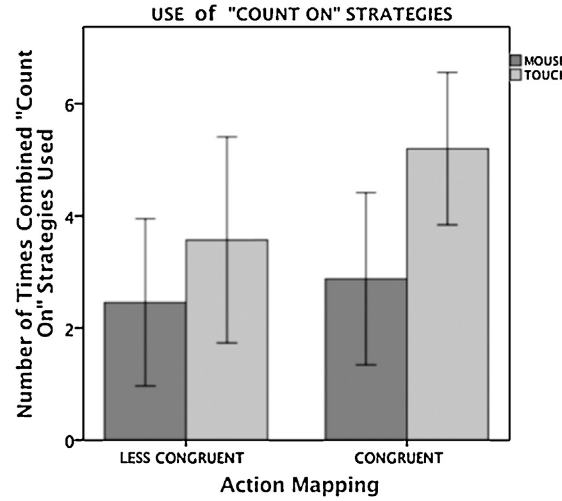

Fig. 5. Means use of "count on" strategy use in Addition Task by interface and congruence. Error bars represent standard errors.

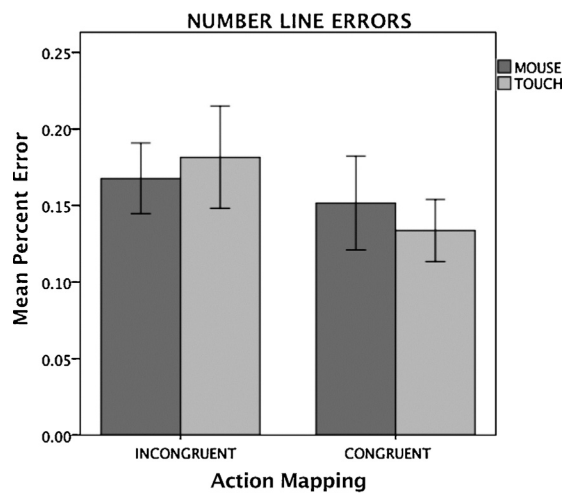

Fig. 6. Mean error for number line estimation by action congruence and interface. Only the effects of action congruence were significant ($p < .001$). Error bars represent standard errors.

4.4. Addition strategies

Children used many different strategies, recorded by the experimenters (see Fig. 4). When children used more than one strategy, for example, "count with fingers on screen" strategy and counting with fingers, both were recorded. Some interfaces prompted using one strategy vs. another. The mouse interface conditions encouraged more "counting with cursor on screen" than "counting with fingers on screen." Children who used the automatic strategy, and did not count in any way, had the poorest performance.

4.5. Count-on strategy

Children who used the direct touch interface ($M = 4.41$ $SD = 4.24$) used an advanced counting strategy, the "count on" strategy, significantly more often than children who used the mouse-mediated interface. A post hoc analysis confirmed the significance of the effect ($M = 2.67$ $SD = 3.59$) $F(1, 102) = 4.96$, $p < .028$, $\eta^2\rho = 0{\cdot}05$ (see Fig. 4). A *t*-test between platform groups (mouse vs. touch) for use of the advanced "count-on" strategy confirmed that conclusion; $t = 2.296$ $p < .024$. The "count on" strategy entails counting the number of blocks in the first column and continuing to count the blocks in the second column, rather than counting each column separately and then adding the numbers. For example, for the equation "5 + 7″ the child would count the first column, "1, 2, 3, 4, 5," and continue counting "6, 7, 8, 9, 10, 11, 12" on the second column, reaching the sum in one set of operations. The less efficient and more taxing strategy would be to count each column separately and add the sums. Congruence had no effect on use of advanced strategies $F(1, 102) = 1.71$, $p > .05$, $\eta^2\rho = 0{\cdot}02$ n.s. and there was no interaction between platform and congruence in strategy use $F(1, 102) = .61$, $p > .05$, $\eta^2\rho = 0{\cdot}01$ n.s.

4.6. Number line: errors

Errors were analyzed by a two by two between-subjects ANOVA. As evident from Figs. 5 and 6, children who used congruent actions ($M = .14$, $SD = .06$) made significantly fewer errors for both interfaces than children using less congruent actions ($M = .17$, $SD = .07$). $F(1, 102) = 4.31$, $p < .04$, $\eta^2\rho = 0{\cdot}04$. Neither the effects of platform $F(1, 102) = 0.006$, $p > .05$, n. s, $\eta^2\rho = 0{\cdot}00$, nor the interaction $F(1, 102) = 1.37$, $p > .05$, n. s, $\eta^2\rho = 0{\cdot}01$ reached significance.

4.7. Number line: time on task

Children who used a direct touch interface ($M = 8.12$ $SD = 2.93$) solved the number line problems faster than children who used an indirect mouse interface ($M = 11.88$ $SD = 5.14$), $F(1, 102) = 24.67$, $p < .001$, $\eta^2\rho = 0{\cdot}19$. Children who used congruent actions ($M = 10.97$

SD = 4.76) took longer to solve number line problems than children who used less congruent actions (M = 8.65 SD = 3.88), $F(1, 102) = 11.41$, $p < .001$, $\eta^2\rho = 0{\cdot}10$. As for addition, the congruent action, sliding a bar to the desired number, was necessarily longer than the less congruent action, tapping the number directly. The interaction did not reach significance $F(1, 102) = 0.08$, $p > .05$ $\eta^2\rho = 0{\cdot}00$.

5. Discussion

The language used to talk about thought is the language used to talk about action. We sort through our ideas, organize them, toss some out, put others in memory. Our thoughts pile up, and we weigh them (e.g., Lakoff & Johnson, 1980). Such expressions are regarded as metaphoric, but can physical actions actually promote abstract thought? If thinking is internalized action, then re-externalizing thinking in the form of congruent physical action could help us think. Earlier we reviewed research showing that people use action to think, notably miniature actions in the form of gestures, and that action changes thought (e.g., Casasanto & Dijkstra, 2010; Chu & Kita, 2008; Glenberg & Kaschak, 2002; Goldin-Meadow & Beilock, 2010; Hostetter & Alibali, 2008; Jamalian et al., 2013; Tversky & Kessell, in press; Schwartz & Black, 1996; Schwartz & Black, 1999; Wexler et al., 1998). Here, we extended those findings by varying the congruence of the mapping of qualities of thought to qualities of action and the directness of the actions on the objects of thought. Congruence enhanced accuracy of performance and direct manipulation enhanced speed of performance as well as choice of strategy. Young children were more accurate in addition using one-to-one discrete actions equivalent to the sum and in number line estimation using continuous actions. Direct manipulation of objects on a touch pad facilitated performance in both math tasks by increasing speed of performance at no cost of accuracy.

Together, the findings support the idea that thinking can be internalized action and that re-externalizing the thinking as congruent action can facilitate the thinking. In both tasks, the actions were effective over and above the contributions of the spatial and diagrammatic representation, already known to support and affect thinking (e.g., Goldstone et al., 2011; Hegarty, 2011; Kirsh, 1995; Tversky, 2011).

5.1. Practical applications

The findings have applied as well as theoretical implications. Direct manipulation is preferable to mediated manipulation, and touch pads and tangibles encourage direct manipulation. In some sense, touch pads are even more direct than tangibles as the touch pads can link the manipulations on the objects directly to the cognitive consequences, in this case, on addition and number line estimation. Congruent mappings of aspects of action to aspects of thought and of aspects of displays to aspects of thought enhance performance. Congruent actions of the hands, even when they are demanded by an interface, and not spontaneous, enhance thought. Congruent actions can be effective and can be naturally induced by an interface, rather than relying on explicit instruction or spontaneity. Congruent actions and direct manipulation can be widely applied to math tasks, to comprehension of texts in science, literature, to creative construction tasks and more. The gestures spontaneously used in describing the problems or text can serve as clues to congruent actions.

5.2. Theoretical implications

There are congruences of *thought* and *action*, documented here and in prior research. There are also congruences of *thought* and *space* evident in language (e.g., Clark, 1973; Lakoff & Johnson, 1980; Talmy, 1983, 2000), diagrams (e.g., Goldstone et al., 2011; Kirsh & Maglio, 1994; Kirsh, 1995; Tversky et al., 1991; Tversky, 2001, 2011), and gesture (e.g., Cartmill, Beilock, & Goldin-Meadow, 2012; Goldin-Meadow, 2003; Hostetter & Alibali, 2008; Tversky, Heiser, Lee, & Daniel, 2009; Tversky, 2011). “Thumbs up,” “feeling up,” and plotting *liking* upwards are but a few. These correspondences are more than analogies; they entail abstractions, here, “up = positive,” irrespective of content. Actions in space create abstract meanings, whether in gesture or diagram.

Actions that organize things in space can create regular patterns in the world, patterns that are good gestalts: books lined up on shelves by size or topic, plates and bowls sorted by kind and piled in cabinets, dishes, silverware, and glasses distributed in table settings. These patterns represent the abstractions behind their creation: orders, dimensions, categories, hierarchies, one-to-one correspondences. The patterns are incorporated into diagrams and graphs that represent the same concepts. The actions that create the patterns, putting, stacking, sliding, distributing, are abbreviated as gestures that express the parallel abstract thought. These congruences are linked, space-thought, thought-action, action-space. The cycle linking action, thought, and space has been termed *spraction*, a contraction of space, action, abstraction (Tversky, 2011, 2013). Here we have presented evidence for the thought-action-space link, that congruent actions in space can augment thought.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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