The Effect of Concrete Materials on Children's Subsequent Numerical Explanations: Metaphorical Priming

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Abstract: This paper contributes evidence for the claim that gestures used to support numerical thinking can simulate prior concrete experiences. 114 children aged 6-9 years explained a numerical relationship (additive composition) three times consecutively. All children explained without materials for the 1st and 3rd explanation. For the 2nd explanation, children were randomly assigned to one of three conditions to use: physical objects; a number line; or no materials (control condition) to explain their thinking. Findings showed how using physical objects significantly influenced the particular types of gestures (e.g. splitting), hand morphology (e.g. pinching), and words (e.g. "take", "big") that children used in subsequent explanations without materials. Similar (although less pronounced) priming effects were found for the number line condition. The study provides support for conceptual metaphor theory (used to categorize gestures and language), and the potential for gesture research to address long-standing questions concerning the role of concrete materials in learning.

Introduction

As well as the importance of informing everyday pedagogy, substantial research has examined if and how children's interaction with physical materials supports learning in order to evaluate new digital forms of interaction and also to better understand the relationship between action and cognition. Gesture research has offered a unique window into this research area by suggesting that some gestures, which are used to explain particular concepts, simulate prior interactions with physical materials. The contribution of this paper is to support this claim by demonstrating how asking children to explain a particular numerical relationship *with* physical materials significantly influences the types of gestures and language children subsequently use to explain their thinking *without* materials. By providing evidence of this internationalization of action experience, the work reported provides empirical support for claims surrounding the embodied nature of cognition.

The role of physical materials in learning

From plastic blocks to a counting abacus, physical learning materials are pervasive in early learning classrooms, and have been designed and advocated by many educational pioneers, from Frobel to Dienes. Such use has attracted a wealth of research attempting to understand how, and if, they support children's learning, particularly in domains such as mathematics. Unfortunately, although a relatively recent meta-analysis suggests a slight positive effect (Carbonneau, Marley, & Selig, 2012), there remains a lack of consensus over their benefits (McNeil & Jarvin, 2007), and research remains limited in its capacity to inform everyday practice.

It is not simply their pedagogical value however that has attracted research into physical learning materials. These objects encapsulate fundamental questions concerning the relationship between action and cognition. In this regard, the last two decades has witnessed increasing interest in this field, owing to two main reasons. The first is that new technologies are changing children's interaction with the world, raising pertinent questions about the subsequent impact on conceptual development. As well as addressing concerns that devices (e.g. mouse/touchscreen) limit accessibility, researchers have investigated the potential for more interactive devices (e.g. tangible technology/gesture recognition devices) to leverage body based learning mechanisms (Manches, O'Malley, & Benford, 2010).

The second reason for renewed interest in physical learning materials concerns theoretical developments in cognitive science over the last twenty years regarding the relationship between body-based experience and cognition. Embodied Cognition is an umbrella term capturing various claims that cognitive processes are best understood when perceived as grounded in our body's interaction with the world. One of the more controversial claims of Embodied Cognition is that our 'offline' thinking (thinking in the absence of relevant stimuli) is body-based (Wilson, 2002).

Whilst the importance of action experiences is a core feature of prominent cognitive developmental theories, Embodied Cognition differs in its proposition that that these experiences are not simply precursors to more abstract thinking, but are encoded as an integral part of developing concepts in the form of sensor-motoric representations. One interpretation of this proposal is to emphasize the importance of particular action experiences in learning, thereby providing a novel rationale for the benefits of physical materials (Pouw, van Gog, & Paas,

2014) , as well as new forms of digital designs that can elicit and dynamically represent particular physical actions (Abrahamson, 2009).

Action experiences and conceptual development

An important question raised by embodiment theories therefore concerns which types of actions might be more beneficial for developing particular concepts. Should we encourage children to move their hands together when learning the concept of addition for example? After all, most forms of interaction in learning tasks, from pens to computer mice, generate some form of action. This has led researchers to refer to the extent to which particular actions are 'congruent' with the concept at hand (Segal, 2011). According to Bakker, Antle and Van Den Hoven (2012), the relationship between particular actions and concepts depends upon the embodied metaphors underlying the concept. Metaphor in this context refers to the mapping of bodily originating schemata onto a conceptual domain (Lakoff & Johnson, 1980) (e.g. mapping body experience of balance with the 'abstract' concept of justice). Bakker et al. suggest that such metaphors might be identified from existing theoretical literature or investigated through empirical work examining the way individuals move their bodies when articulating their thinking about particular concepts.

Gesture research

The most prominent way we move our bodies when thinking is through our hands, and in support of embodied claims, research has demonstrated that the main function of gesture is to support the speaker's thinking rather than just the listener's comprehension (Tellier, 2009). The last two decades has seen increasing work investigating the way children and adults gesture when explaining their mathematical thinking (e.g. Alibali & Nathan, 2011; Goldin-Meadow, Kim, & Singer, 1999). Edwards (2009) for example, examined student teachers' explanations of fraction concepts. Of the 251 gestures generated by the 12 participants, 32% referred to fractions. Of these 81 were categorized as primarily metaphoric, where the pictorial content presents an abstract idea rather than a concrete object or event, and 35% as primarily iconic, that "bear a close formal relationship to the semantic content of speech" (McNeill, 1992, p.14), interpreted here as visually resembling their concrete referents.

Whilst many researchers view the categories of iconic and metaphoric gestures as both constituting a broader category of *representational* gestures (where the hands depict aspects of meaning in speech literally or metaphorically - Alibali & Nathan, 2011), Edwards' work provides great insight into the types of concrete experiences that may have influenced participants' thinking. From her data, Edwards categorized two types of iconic gestures: *iconic-concrete,* that refer to concrete objects or processes "often related to tangible materials utilized in early instruction about fractions" (Figure 1), and *iconic-symbolic*, that refer to gestures that "re-enacted the physical process of writing out a mathematical procedure, or referred to visual locations and elements of mathematical symbols". These categories highlight the potential to examine gestures in order to understand how prior perceptual and action experiences may have shaped thinking. What is not clear is whether gestures simulate *particular* experiences with materials, or whether there exists any underlying embodied metaphors for the range of gestures generated.

Figure 1. Iconic-concrete gestures (Edwards, 2009).

Embodied metaphors of number

In their seminal book, "*Where mathematics comes from*", Núñez and Lakoff (2000) propose that there are two fundamental body-based metaphors underpinning concepts of number. The first is *Arithmetic is object collection **(OC)*** which is a mapping from experiences with physical objects to the domain of numbers. The second is *Arithmetic is motion along a path **(MP)***, which is a mapping from experience moving along point locations in a linear direction to the domain of numbers (e.g. steps when walking). In the OC metaphor, numbers are "collections of objects of the same size" and in the MP metaphor numbers are "point locations on a path". According to the authors, these metaphors draw upon early body experiences such as manipulating groups of objects or walking in discrete steps.

It is possible to re-examine the gesture categories identified in Edwards' research in light of the conceptual metaphors proposed by Núñez and Lakoff. As suggested in Edwards' definition of iconic-concrete gestures, many gestures seemed to portray simulated action with physical objects such as fraction pieces. Such gestures therefore appear relevant to the Object Collection metaphor – individuals conceptualizing numbers as if they were physical collections of objects. It is possible, although more difficult, to relate other iconic-concrete gestures described by Edwards to Lakoff and Núñez' MP metaphor. For example, describing fractions as a line being split at different points. Perhaps more difficult is to relate either conceptual metaphor to those categorized by Edwards as iconic-symbolic, where participants' gestures simulated interaction with mathematical procedures or symbols. Whilst it remains possible that individuals' concepts of these procedures or symbols pertain to particular metaphors (e.g. "+" symbol being conceptualized as the bringing together of object collections, or movement along a pathway), this cannot be as readily deduced from these types of gestures.

Other authors have proposed different categorizations for gestures explaining different number concepts (e.g. Arzarello, Robutti, & Bazzini, 2005). In this work, it is often possible to relate different gestures to the OC and MP metaphors, although perhaps more difficult for complex concepts which involve increasing levels of symbolization. This would suggest therefore that it might be easier to examine the role of the OC and MP conceptual metaphors in the development of more basic number concepts.

Examining metaphorical gestures in early number concepts

Whilst the notion that all number concepts can be reduced to underlying conceptual metaphors has been called to question (see Kövecses, 2008), the proposal can be scrutinized empirically. More recently, Marghetis (in Núñez, Marghetis, Cohen-Kadosh, & Dowker, 2014) examined the language and gestures of adults asked to explain the numerical concept of 'odd and even' – a relatively early number concept. In this study, adults were first primed according to the two metaphors. In the 'path' condition, participants were asked to imagine a bead moving along a string; in the 'object' condition, participants were asked to imagine combining different collections. In subsequent explanations of odd and even, participants deployed two main types of gestures: those simulating manipulation of objects (hand moving inward shaped as if grasping, pinching or holding), and those simulating movement along a line (pointing handshape, tracing motion along a horizontal axis). Moreover, as predicted, the priming mental imagery was reported to have had a significant effect on conceptualization.

Marghetis' metaphorical priming study design demonstrates the potential for investigating the role of the OC and MP metaphors in early numerical concepts, which therefore provides a window into the types of interaction experiences that might influence the development of these concepts. However, the reported study focused on a single concept and with adults, where the influence of priming may be quite different to children who are still developing their numerical thinking. More importantly, detail is missing about the range and prevalence of gestures generated that is required to evaluate the extent to which individuals' numerical thinking can be captured by the two embodied metaphors proposed by Núñez and Lakoff. The study reported in this paper was designed to address this important gap in the literature.

Study aims

The overarching aim of the authors' work is to understand the role of physical interaction in early numerical development; this paper addresses this aim by examining the role of the OC and MP metaphors in young children's numerical concepts. The paper reports a study that examined the effect of metaphorical priming on children's explanations of a specific numerical relationship: additive composition. Analysis initially focused on the effect on children's gestures during their explanations; however, this was then extended to examine the effect on metaphorical language. Although Núñez et al. (2014) refer to words that pertain to the OC and MP metaphors (see section 2.5.3), the summary of Marghetis' study does not indicate whether changes in the use of particular words were analyzed. We are not aware of existing work that has quantitatively analyzed changes in metaphorical language in this domain (although notable work has detailed more microgenetic changes, e.g. Roth, 2002).

The study design therefore echoes that reported in Núñez et al. (2014), with several key differences. Firstly, the study was carried out with children (aged 6-9 years old) not adults. Secondly a larger sample was involved (n=114). Thirdly, the study captured participants' pre-priming explanations, therefore providing more robust analysis of the effect of priming. Fourthly, this paper reports greater detail on how particular gestures and language were categorized according to the two metaphors. Fifthly, this study reports the effect on metaphorical language. Finally, the materials used for metaphorical priming were familiar classroom materials, thereby providing greater ecological validity in terms of educational implications.

The main research question for the study reported was: *What is the effect of metaphorical priming on young children's numerical explanations?*

Method

The study adopted an embodied cognitive theoretical paradigm, whereby cognitive processes are considered as grounded in the body's interaction with the world. The study methodology employed metaphorical analysis of concept explanations, interpreting gestures (and accompanying speech) in terms of metaphors within the concept domain.

Numerical concept explanation task: Additive composition of number

Additive composition is the concept that a number is composed of other smaller numbers, for example, that 8 can be decomposed into 2 and 6, or 1 and 7. Additive composition is core to numerical development (Martins-Mourao & Cowan, 1998), an overarching concept that connects numerous topics and applications, and is thought to form a conceptual base for the development of children's elementary arithmetic as well as their understanding of the decade numeration system (i.e. understanding that 12 is comprised of 10 and 2) (Nunes et al., 2007). This concept is also evident in the use of flexible addition strategies, for example, decomposing 6+7 into 6+6+1 in order to exploit knowledge of double facts (i.e. 6+6+12).

As young children cannot be asked to simply explain their understanding of the concept term, a question was designed to elicit children's understanding of additive composition. The question draws upon the authors' prior work (Manches & O'Malley, 2016) that required children to explain the logical relationship between two addition parts. The problems were presented verbally (to minimize the effect of external stimuli) but could be represented symbolically as: $a + b = (a+1) + (b-1)$, e.g. $6 + 1 = 2 + 5$.

Design

Each child was asked to explain three additive composition questions consecutively, hence referred to as the 1st, 2nd, 3rd explanation, in a single session. For the 1st and 3rd explanation, children were given no relevant stimuli (e.g. materials or displays). For the 2nd explanation, children were randomly assigned (alphabetically) to one of three independent conditions: *No Materials* (control), *Object Collection* (OC), and *Motion along Pathway* (MP). The No Materials condition acted as a control, asking children to explain without materials (similarly to 1st and 3rd explanation for all children). In the OC condition children were given a collection of small yellow plastic Unifix® blocks. In the MP condition, children were given an 'empty number line'. The empty number line is a common numerical representation (Murphy, 2011) consisting of a horizontal line on paper marked with small vertical lines along its length. Children in this study were familiar with materials in both the OC and MP conditions, reflecting the attempts to ensure ecological validity in the study.

Participants

The study included 114 children aged from 6-9 years old (77-112 months), with parent and child consent. Three children were not included in the data as they were unable to answer the pre-explanation number questions, leaving 111 participants (M=94.75mths; SD: 10.05). Children were from 9 classes across three year-groups within a non-denominational primary school in Edinburgh serving children from age 3-12 years.

Procedure

Children were interviewed in 1:1 sessions with the first author who is also a qualified Primary teacher in a quiet but visible location in the school. Each child was given three explanation questions, unless they were unable to answer the initial addition questions. Three children were not able (they were given other questions they could succeed at), leaving a total sample of 111 children.

The format for the 1st, 2nd and 3rd explanation question was the same; they only differed by the sum total: 7, 8 and 9 always in that order. Whilst learning effects were expected, the study focused on between condition differences. An interaction effect between materials and addition total amount was not expected. The format for each explanation was as follows. First, children were asked to count out to the total (e.g. "*Can you count to n?*"), where n was 7, 8 then 9 for consecutive explanations. They were then asked the total of the addition sum of 1+ (n-1) e.g. "*What is 1 add 6*?"). Children were subsequently asked the total of the addition sum 2 + (n-2) (e.g. "*What is 2 add 5*?). Finally, for the explanation question, the interviewer reminded children of these two addition problems (e.g. "*So, 1 add 6 makes 7, and 2 add 5 makes 7, they both make 7. Can you explain to me* ***why*** *1 add 6 makes the same as 2 add 5?"*). The presentation of this explanation task was developed from pilot work and was designed explicitly to draw out children's thinking about the additive relationship (rather than re-state that the sums shared the same result). The choice of language was developed from advice from the class teacher; however, the methodological issue of possible conceptual priming in the question presentation is discussed later.

The 2nd explanation total was always 8. For children in the No Materials condition, the question presentation was the same as the 1st and 3rd. For children in the materials (OC and MP) conditions, the interviewer echoed the No Materials format, but adapted for the materials. In the OC condition, children were presented with 8 blocks and told to count how many there were. All children were able. The interviewer would then partition the materials into two spatial groups (1 and 7, then 2 and 6) whilst asking the corresponding addition problems. Blocks were recollected after each question to avoid modelling the actions for the explanation task. Finally, the interviewer would ask children to use the blocks to explain the numerical relationship. In the MP condition, the interviewer provided an A4 piece of paper (portrait) with 4 empty number lines in rows. Each would have 9 point-locations (i.e. number line to 8 as first point represents zero). Children were first given a pencil and asked to mark 8 on the number line (the last point on the right of line). If children made the error of counting the first point location (a common and interesting error in light of metaphors), they were corrected (several children did). The interviewer would then use the materials to represent amounts (drawing two arcs on the number line, e.g. from 0 to 1st point then 1st to 8th point) whilst asking the addition problems. Finally, for the explanation question, children were asked to use the number line and pencil to explain the numerical relationship.

There are clear challenges of balancing the presentation and usability of two different representations; however, the following points should be highlighted. First, all children were familiar with materials. Secondly, all children had been shown how to use the materials by the time of the explanation question. Thirdly, the study was not looking at performance with materials, but rather how materials primed particular forms of visual and motor imagery that would evident in their gestures and language in a subsequent explanation without materials.

Analysis

Out of 111 children, 97 children provided a verbal explanation of some form. Of these children, 59 (61.5%) used at least one *representational* gesture (iconic/metaphoric). The language and gestures employed by the young participants varied substantially, where this paper focuses on three forms of coded data that is proposed to capture children's metaphorical thinking. These are illustrated in Figure 2 and discussed subsequently.

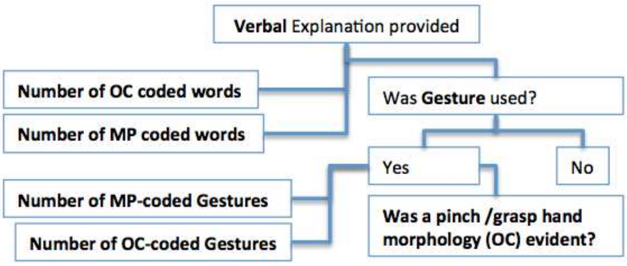

Figure 2: Metaphoric coding.

Metaphorical gesture: OC and MP

The 59 children who gestured generated a wide range of iconic gestures. Many gestures echoed Edwards' iconic-concrete categorization. Within these, it was possible to distinguish between those that seemed to simulate manipulation of objects. These were coded as OC gestures and included simulated splitting a collection of objects with two hands (Figure 3a) or collecting objects (Figure 3b) or others such as sweeping with a curved arm toward the body. The most prominent gesture, simulating collecting objects with two hands (Figure 3b), reflects that described by Núñez at al. (2014) for the OC metaphor. Our previous work (Manches & Dragomir, 2015) also reports a number of gestures appearing to simulate interaction with an imaginary linear pathway. Gestures including pointing up or down (Figure 3c), tracing multiple arcs (Figure 3d), or gesturing movement toward a space to the far right of the child. We coded these as MP gestures. The pointing up or down gesture seems to relate most closely to Núñez at al.'s (2014) description for the MP metaphor. Each explanation received a score for the number of OC and MP gestures used.

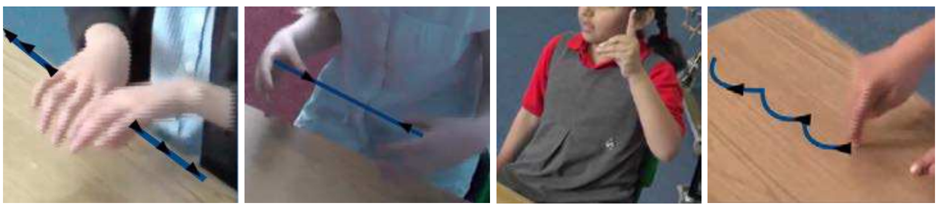

Figure 3a-d: OC and MP coded gestures: Splitting, Collecting, Pointing upwards, Arc Tracing.

Metaphorical hand morphology: OC

As illustrated by the work of both Edwards (2005) and Núñez et al. (2014), many children pinched or grasped when enacting an OC gesture; although some did not (e.g. flat hands). Moreover, many children created this hand morphology when not generating an identifiable OC gesture, for example, as part of a simpler deictic (pointing) gesture. It is possible that many children used a pinch or grasp to simulate manipulation of symbols, or materials such as a pencil. However, closer inspection of their language, coupled with the younger age group, suggested that this form of hand morphology simulated grasping physical objects. Therefore, children's explanations were coded according to the presence of at least one pinch or grasp during explanation.

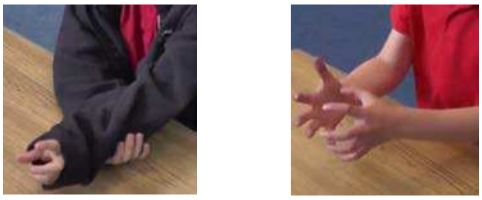

Figure 4a-b: Pinch and Grab hand morphology.

Metaphorical words: OC and MP

Whilst metaphorical language typically refers to collections of words, Núñez et al. (2014) refer to how particular words tend to suggest the OC metaphor (e.g. "big", "take") or MP metaphor (e.g. "up", "far"). In this paper, we report an initial examination of the frequency of words used in explanations that suggested the OC or MP metaphor.

The following procedure was used to code words used in explanations. Firstly, all videoed explanations were transcribed. The authors then coded a list of unique words independently on a five-point scale: *Confident OC*, *Possible OC*, *Neither/Either*, *Possible MP*, and *Confident MP*. A word was then coded as OC or MP if *both* authors independently rated the word as 'Confident' or 'Possible' OC or MP. In summary, from an initial list of 247 words (having removed non-words, e.g. fillers such as *uhm*), a list of 37 OC metaphor and 46 MP metaphor words were identified. This list corroborated and significantly extended words suggested in Núñez et al. (2014). Whilst there are clear limitations to the de-contextualized process of coding individual words, the focus of analysis for this paper was on the *change* in coded words between explanations according to condition.

Findings

The distribution of group data for three dependent measures (metaphorical gestures, hand morphology, language) was tested (Kolmogorov-Smirnov) and revealed significant departures from normality, therefore non-parametric analyses are reported. Analyses were also carried out on differences in measures between conditions for the 1st explanation. As expected from the random allocation of children to conditions, there were no significant differences found between groups for the 1st explanation.

Metaphorical gestures

In total, there were 13 OC gestures used by 13 children in the 1st explanation, and 49 used by 18 children in the 3rd explanation. A non-parametric between subjects analysis (Kruskal-Wallis) was carried and revealed a significant difference in the change of OC gestures between conditions ($\chi^2(2)=12.263$, $p=.002$). Mann-Whitney tests showed that a positive increase in OC gestures was significantly greater in the OC condition and the No Materials condition than the MP condition ($U=455$, $p=.002$, $r=.36$; $U=544$, $p=.011$, $r=.30$). There were no differences found between the OC and Control condition ($U=605$, $p=.159$, $r=.16$).

For MP gestures, 21 children used 24 gestures in the 1st explanation, and 17 children used 35 in the 3rd explanation. A non-parametric between subjects analysis (Kruskal-Wallis) was carried and revealed no significant differences in the change of MP gestures between conditions ($\chi^2(2)=3.166$, $p=.205$).

Pinch grasp morphology

Of the 59 children who gestured, just under half (25) used a pinch or grasp hand morphology in the 1st explanation, while 24 children did in the 3rd explanation. Each child was given a score of -1 if they used at least one pinch/grab in the 1st explanation but not in the 3rd, a score of 1 if they used at least one pinch/grab in the 3rd but not in the 1st explanation and a score of 0 if there was no change. A non-parametric between subjects analysis (Kruskal-Wallis) was carried and revealed a significant difference in the change of children using pinch/grab between conditions ($\chi^2(2)=7.17$, $p=.028$). Mann-Whitney showed that a positive increase in pinch/grab was significantly greater in the OC condition than the MP condition ($U=507$, $p=.012$, $r=.29$). Although the change in in pinch/grab was greater in the OC condition than the No Materials condition, this difference was not significant (U=569, p=0.057, r=.22). There was no difference between No Materials and MP conditions (U=650, p=0.446, r=.09). Therefore, there was a tentative priming effect: children who used physical blocks in the 2nd explanation increased the number of pinch/hand morphology in their explanations afterwards significantly more than children who used the number line, and more than the control although not significantly.

Metaphorical words

Each child was given a score for OC and MP word change by subtracting the number of metaphorical words used in Explanation 1 from number of words used in Explanation 3. A non-parametric between subjects analysis (Kruskal-Wallis) was carried and revealed a significant difference in the change of OC words between conditions ($\chi^2(2)=7.43$, p=.024). Mann-Whitney showed that positive increase in OC words was significantly greater in the OC condition than both the No Materials (U=482, p=.015, r=.28) and MP (U=485, p=.024, r=.26) conditions. There was no difference between No Materials and MP conditions (U=679, p=.79, r=.03) In other words, there was a priming effect: children who used physical blocks in the 2nd explanation then increased the number of OC words they used without materials in the 3rd explanation.

A non-parametric between subjects analysis (Kruskal-Wallis) was carried and revealed a significant difference in the change of MP words between conditions ($\chi^2(2)=6.73$, p=.035). Mann-Whitney showed that a positive increase in MP words was significantly greater in the MP condition than the OC condition (U=473, p=.012, r=.29). Although the change in MP words was greater in the MP condition than the No Materials condition, this difference was not significant (U=559, p=.081, r=.20). There was no difference between No Materials and OC conditions (U=630, p=.391, r=.10), Therefore, there was a tentative priming effect: children who used the number line in the 2nd explanation increased the number of MP words they used relative to children who had used blocks, but not significantly more than children who used no materials.

Discussion

Much research has attempted to understand and evaluate the role of concrete materials in children's thinking and learning. In this regard, Embodied Cognition has offered a valuable framework to consider how children's sensory and motor experiences may shape cognition, and gesture research has provided a methodological tool with which to examine how prior concrete experiences may be simulated when articulating thinking. Although previous work has demonstrated the transition from action experiences to gesture (Roth, 2002), there is limited empirical work illustrating how particular action experiences significantly affect the types of words and gestures children produce when subsequently explaining their numerical thinking. The study reported in this paper addressed this gap by building upon the priming study design used by Marghetis (as cited in Núñez et al., 2014).

The current study examined the effect of action experiences on the language and gestures of young children explaining the numerical concept of additive composition. By drawing upon Núñez and Lakoff's (2000) conceptual metaphor theory, it was possible to codify and quantify three measures of metaphorical thinking: children's gestures, hand morphology, and spoken words. By randomly allocating children to one of three conditions, the study examined how particular experiences shaped children's subsequent thinking. As predicted, the use of physical objects in the second explanation significantly influenced (although effect sizes were generally small) the words and gestures children subsequently used in comparison to using a number line, and often more than the control condition. The finding that the effect was stronger in comparison to the number line condition than control is in itself interesting as it suggests that the actions in the number line group may have interfered with particular metaphorical thinking.

Limitations

There are a number of limitations in the study reported, many of which are discussed. These include the specificity of the task, context, materials, as well as the potential for interpretation in the methods used to quantify children's gestures and words. It is also important to emphasize the immediacy of the post-materials (3rd) explanation, after which the priming effect may soon have been lost. One interesting methodological issue was the format of the problem question. Although the study had been refined in various ways from pilot work (e.g. decision not to provide a the numerical problem visually, ensuring the interviewer did not gesture), the words used in the problem question ("add", "make") are arguably metaphoric (OC). This might explain the salience of the OC priming effect. However, this seems unlikely to fully explain the findings, particularly the effects found for the number line condition on MP metaphorical thinking. It is interesting to reflect on how these methodological issues have been addressed in other work, in particular the possibility of using metaphorical language or stimuli (e.g. number symbols are presented using particular spatial conventions).

Conclusion

The study reported in this paper indicates the potential to analyze the language and gestures children use to investigate how concrete experiences have influenced their thinking. The study contributes to previous work in providing support for the embodied nature of cognition, and the value of gesture research in examining the internalization of action experiences. The study is limited in evaluating whether such experiences have supported learning, yet provides a window into how this approach may address such a goal, thereby informing classroom practice or the design of new materials.

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