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Adding and subtracting by hand: Metaphorical representations of arithmetic in spontaneous co-speech gestures☆

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ABSTRACT

This study investigated the spontaneous co-speech gestures produced by speakers who were talking about the concepts of addition and subtraction in a television news setting. We performed a linguistic and co-speech gesture analysis of expressions related to the concepts of addition (*N plus N, addition, add*) and subtraction (*N minus N, subtraction, subtract*). First, we compared the linguistic frequency of these structures across several corpora. Second, we performed a multimodal gesture analysis, drawing data from a television news repository. We analyzed 423 co-speech gestures (169 for subtraction and 254 for addition) in terms of their axis (e.g., lateral, sagittal) and their direction (e.g., leftwards, away from their body). Third, we examined the semantic properties of the direct object that was added or subtracted. There were two main findings. First, low-frequency linguistic expressions were more likely to be accompanied by co-speech gestures. Second, most gestures about addition and subtraction were produced along the lateral or sagittal axes. When people spoke about addition, they tended to produce lateral, rightwards movements or movements away from the body. When people spoke about subtraction, they tended to produce lateral, leftwards movements or movements towards the body. This co-speech gesture data provides evidence that people activate two different metaphors for arithmetic in spontaneous behavior: ARITHMETIC IS MOTION ALONG A PATH and ARITHMETIC IS COLLECTING OBJECTS.

1. Introduction

How do people understand numerical concepts, such as quantities and operations? One general account—termed *conceptual metaphor theory* (CMT)—suggests that people understand abstract concepts via metaphorical mappings to experiences of the human body (e.g., Lakoff, 1987; Lakoff & Johnson, 1980). In this paper, we consider evidence that numerical concepts—specifically, the concepts of addition and subtraction—are understood in terms of conceptual metaphors.

Conceptual metaphors involve understanding an abstract target domain in terms of a more familiar source domain. In this sense, conceptual metaphors allow people to map concrete bodily experiences, such as movement through space, onto abstract concepts (Lakoff & Johnson, 1980). This is achieved by means of image-schemas, which are highly schematic structures that emerge from our sensory and motor experience (Hampe & Grady, 2005). For example, people may understand the abstract concept of "life" in terms of a journey. People express this metaphorical mapping in everyday language when they speak about life using linguistic expressions related to journeys (e.g., "she's taking new path," "he's reaching the end of the road"). People also use this metaphor more creatively; for example, in Robert Frost's poem, *The Road Not Taken,* life choices are presented as forks in a road. Thus, life is understood as a journey along a path (Lakoff, 1993).

Although conceptual metaphors are routinely expressed in language, CMT holds that these metaphorical mappings are not simply a linguistic phenomenon. Instead, these metaphorical mappings are the psychological basis of the concepts themselves. As Semino (2008) puts it, conceptual metaphors allow speakers to "talk and, potentially, think of something in terms of something else" (p. 1). If this is the case, then purported metaphorical mappings should be evident not only in language, but also in other aspects of human behavior.

Lakoff and Núñez (2000) applied this perspective to numerical

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concepts, arguing that two central conceptual metaphors underpin concepts of arithmetic, and these metaphors reflect pervasive bodily experiences. One of these metaphors, ARITHMETIC IS COLLECTING OBJECTS, views numbers as collections of objects, and views arithmetic operations as modifying those collections in specific ways. Under this metaphor, numerosity is conceptualized in terms of the size of collections, with bigger collections representing larger numerosities. Addition is construed in terms of adding objects to a collection, and subtraction is construed in terms of removing objects from a collection. The other metaphor, ARITHMETIC IS MOTION ALONG A PATH, views numbers as points in space, and views arithmetic operations as moving from point to point along a path. Under this metaphor, addition is construed in terms of rightwards motion along a line, and subtraction is construed in terms of leftwards motion along a line. This mapping is achieved by means of *fictive motion* (described in detail in Talmy's seminal work, see Talmy, 2000a, 2000b), which is a process by which objects that cannot move obtain metaphorical motion. Lakoff and Núñez (2000) provide compelling evidence from everyday language for each of these mappings. For example, people talk about subtraction as *taking away*, reflecting the ARITHMETIC IS COLLECTING OBJECTS metaphor. Similarly, people talk about numbers as being *close together*, reflecting the ARITHMETIC IS MOTION ALONG A PATH metaphor (Núñez, 2004).

The idea that numbers are points in space, and that differences between numerical values are like distances, has also been addressed by theories of mathematical cognition, notably the *A Theory of Magnitude* (ATOM) proposal (Walsh, 2003). ATOM holds that people employ the same cognitive resources when representing spatial, numerical, and temporal magnitude, because they are all part of a general magnitude system. This general account is compatible with the alignment of number and space suggested by CMT (Winter et al., 2015).

The conception of numbers as locations in space is also captured in conventional mathematical inscriptions, such as the number line. In cultures that use a left-to-right writing system, larger numbers are positioned in locations further to the right on the horizontal number line, and smaller numbers are positioned in locations further to the left. However, number lines are not solely external representations; there is a large body of evidence suggesting that people conceive of numbers in terms of a *mental* number line (de Hevia, 2016; Fias et al., 2011; Knops, 2018). The mental number line is thought to reflect the physical number line used in mathematics, with larger numbers located to the right and smaller numbers located to the left.

One phenomenon that provides compelling evidence for the existence of the mental number line—and the metaphorical structuring of number in terms of space—is the *spatial-numerical association of response codes* (SNARC) effect (Dehaene et al., 1993). The original study of the SNARC effect demonstrated that people who read from right to left respond faster to larger numbers with the right hand and smaller numbers with the left hand, even when making judgments that are not related to magnitude (i.e., judging whether numbers are even or odd). Subsequent studies have documented this pattern in a variety of response modalities, including the eyes, the head, and even the feet (for a review, see Fischer & Shaki, 2014). Further, this pattern is robust, regardless of whether the numerical information is presented visually or auditorily (Nuerk & Willmes, 2005) and regardless of whether responses are provided in-person or online (Cipora et al., 2019). The SNARC effect is modulated by cultural and linguistic experience, with Hebrew speakers presenting a left-to-right SNARC effect (Shaki & Fischer, 2008; Zohar-Shai et al., 2017).

The SNARC effect highlights the *locations* of numbers on the mental number line, but it does not address the spatial structuring of arithmetic operations in terms of *motion* along the number line, as reflected in the ARITHMETIC IS MOTION ALONG A PATH metaphor. A different behavioral phenomenon has been taken as evidence for a conception of arithmetic as motion along the mental number line, namely, the *operational momentum* effect. Operational momentum is the idea that people sometimes "overshoot" when moving along the mental number line, overestimating the outcomes of addition operations and underestimating the outcomes of subtraction operations (McCrink et al., 2007; Pinheiro-Chagas et al., 2018). This effect occurs, both when people estimate the outcomes of operations that are presented non-symbolically (e.g., with dots) and when people indicate locations on a number line to show the outcomes of operations that are presented symbolically (Pinhas & Fischer, 2008). Related work on participants' movements of a computer mouse in a mental arithemtic task also revealed deflections to the right for addition and to the left for subtraction (Marghetis et al., 2014), aligning with the idea that arithmetic operations are conceptualized in terms of motion along a mental number line.

Both the SNARC and the operational momentum effects provide compelling evidence that people activate the ARITHMETIC IS MOTION ALONG A PATH metaphor when engaging in tasks that require numerical judgments or operations. However, it is worth noting that in these tasks, numerical concepts are the overt focus, so participants in these experiments may intentionally recruit this metaphor for the task at hand. If conceptual metaphors are the foundation of people's concepts of number and operations, they should also be evident in contexts that are not explicitly numerical. Indeed, several researchers have described everyday linguistic expressions that manifest the ARITHMETIC IS COLLECTING OBJECTS metaphor and the ARITHMETIC IS MOTION ALONG A PATH metaphor (Núñez & Marghetis, 2015). However, linguistic expressions cannot definitively show that such metaphors are the psychological basis of concepts, as they could be based on linguistic conventions, rather than on the underlying concepts.

Other forms of spontaneous behavior—ones that are less subject to conventional pressures—may be a better index of underlying concepts of number and operations. One such behavior is spontaneous gesture. Gesture and thought are tightly related, but spontaneous gestures are idiosyncratic and not subject to conventional standards of form (McNeill, 1992). Speakers gesture more when tasks are cognitively complex (Goldin-Meadow et al., 2001; Kita & Davies, 2009; Melinger & Kita, 2007), and they frequently gesture when talking about spatial and motoric concepts (Alibali, 2005), as well as when talking about abstract ideas, such as time (Casasanto & Jasmin, 2012). Some scholars have argued that gestures derive from mental simulations of perceptual experiences and motor actions (Hostetter & Alibali, 2008, 2019), and those gestures play a crucial role in how people manipulate, schematize, and explore spatiomotor information (Kita et al., 2017). As such, gestures may provide a window on the spatial and motoric metaphors that underlie thought.

Núñez and Marghetis (2015) have argued that both the ARITHMETIC IS COLLECTING OBJECTS metaphor and the ARITHMETIC IS MOTION ALONG A PATH metaphor are manifested in speakers' gestures. Marghetis (2015) conducted a study in which undergraduate students were primed with a mental imagery task that involved either sliding a bead on a wire (highlighting motion along a path) or combining collections of beads (highlighting collecting objects). Following the imagery task, participants were asked to explain why the sum of an odd number and an even number is always odd. In their explanations, participants routinely produced spontaneous gestures that depicted collecting objects or that traced motion along a horizontal path—and moreover, participants tended to produce gestures that depicted the metaphor that had been primed for them in the imagery task.

Marghetis's (2015) findings suggest that people's spontaneous gestures may reveal the metaphorical structuring of their concepts. However, in this study, participants were guided to activate specific metaphors in the imagery task. Do people express these metaphors spontaneously in their gestures, even when not prompted to do to? If they do, this would be compelling evidence for the metaphorical structuring of numerical concepts.

The advent of multimodal corpora has enabled a new type of quantitative approach to addressing such questions. With these corpora, it is now possible to examine large numbers of examples of linguistic expressions and to analyze the gestures produced by speakers when uttering them. For example, in the domain of number, Woodin et al. (2020) analyzed over 700 videos in which people used expressions like *tiny number* or *huge number*, and they found that people produced size-based numerical gestures in spontaneous communication, as had previously been attested in laboratory experiments (Lindermann et al., 2007).

Research to date on using such corpora has focused in part on questions regarding gestural frequency. For example, Pagán Cánovas et al. (2020) analyzed over 8000 clips of people using temporal linguistic expressions, and they reported an inverse relation between gesture frequency and linguistic frequency—people were more likely to produce gestures with less frequent linguistic expressions. Building on this past work, in the present study, we examine the frequency of gestures about addition and subtraction concepts, and whether these frequencies are associated with the frequency of the linguistic expressions for those concepts.

In this research, we examine the linguistic and gestural patterns people use in spontaneous communication about the two most common arithmetic operations: addition and subtraction. We addressed three primary research questions: (1) How frequently do people produce co-speech gestures in spontaneous communication about addition and subtraction? (2) Does the frequency with which people produce gestures for addition and subtraction concepts relate to the frequency of the linguistic expressions they use to express those concepts? (3) Along what axes and with what direction of motion do people gesture when speaking about addition and subtraction? Based on the findings, we draw inferences about the nature of the conceptual metaphors that people activate for addition and subtraction.

2. Methodology

2.1. Dataset and tools

Data were obtained from the *NewsScape Library* (http://newsscape.library.ucla.edu/), a television news repository managed by the UCLA library and the Case Western Reserve University library. This database is part of the Red Hen Lab, an international consortium for research on multimodal communication managed by Mark Turner and Francis Steen (https://www.redhenlab.org/). The base of the NewsScape library is the UCLA NewsScape Archive, developed by the Department of Communication at UCLA, which has been supplemented with data from a wide range of languages, including English.

This multimodal repository contains data from 2004 until the present day, and it includes approximately 500,000 h of TV news programs (e.g., talk shows, news reports, debates) as well as an over-5-billion-word database composed of television subtitles. The dataset enables researchers to look up specific linguistic expressions and to view the exact moments on television when those expressions were uttered. This feature is very useful for the study of multimodal communication (and for the purpose of this study, gesture), since it allows the analysis of how people communicate through different modalities when they use specific linguistic structures.

The co-speech gestures in the NewsScape library are produced by a wide variety of speakers in a wide variety of communicative situations, such as one-on-one conversations, open discussions, political speeches, and interviews. Spontaneous gestures from the NewsScape library might differ in some ways from the ones employed in non-television settings, but they are presumably close to the gestures produced by people in the general population in everyday settings.

Additionally, we employed three corpora to obtain overall frequencies for the items in the linguistic searches that we performed in NewsScape. The first was the English Web Corpus 2015 (EnTenTen), a 15-billion-word corpus that contains textual material from the internet, excluding unwanted word content like menus, incomplete sentences, and advertisements. This corpus is provided by Sketch Engine, a specialized tool for linguistic research (Kilgarriff et al., 2014). The second corpus was the Corpus of Contemporary American English (COCA), one of the most widely used English corpora, which contains around 1 billion words from different genres (Davies, 2017). We employed the spoken version of COCA, which includes over 120 million words. The third corpus was a subset of the 2016 NewsScape library (Uhrig, 2018), which is integrated in the corpus software CQP-Web (Hardie, 2012).

2.2. Linguistic searches

We designed two sets of linguistic searches, one for addition construals and one for subtraction construals.

The first set of linguistic searches focused on the concept of addition. We performed three different searches. The first search was for a simple structure that involved the addition of two numbers, following the structure [N] [*plus*] [N], in which N was any numeral, either an Arabic numeral (e.g., *1*) or a number word (e.g., *one*). This initial search presented an overwhelming number of hits unsuitable for manual analysis, so we narrowed the scope of [N] to the numerals one to five. The second search was for [*add*] [NP] (e.g., *add clouds*; *add hundreds of jobs*; *add instructors and add teachers*), to ensure that the object being added was always mentioned by the speaker. Due to the extremely high frequency of this structure, we performed this search for only one year of the NewsScape corpus (2016) and collected a sample of the hits. The third search was for the noun [*addition*], excluding the instances of the connector *in addition* (e.g., *she will be a great addition to the team; new additions at the very top of the campaign*). Due to its high frequency, we also restricted this search to the 2016 NewsScape corpus, and we collected a sample of the hits.

The second set of linguistic searches focused on the concept of subtraction. The searches were designed to be parallel to the ones for the addition construal. The first search was for [N] [*minus*] [N], mirroring the search performed for [N] [*plus*] [N]. The number of hits obtained in this search, however, was very limited, so we kept the search open for all numerals. The second search was for the verb [*subtract*] [NP] (e.g., *subtract that equation; subtract Trump's personality; subtract this incident*). Due to the reduced number of hits compared to *add* [NP], we kept this search open across the whole corpus. The third search was for the noun [*subtraction*] (e.g., *politics are about addition, not subtraction*; *there is no subtraction from the Golden State Warriors*; *that is a map about subtraction*). Due to its relatively low frequency, we also kept this search open across the whole corpus.

The aforementioned searches were performed in the COCA and EnTenTen corpora to obtain the frequencies of the linguistic structures, and they were performed in the NewsScape repository to obtain the video data.

2.3. Multimodal data processing

The linguistic structures described in the previous section were the starting point for the collection of gesture data from the NewsScape library. After performing the searches, we reviewed each clip individually to curate the dataset, using a three-stage process. For the co-speech gestures that were semantically related to the linguistic expressions, we then performed a more detailed linguistic and multimodal analysis. The data curation and analysis process is depicted in Fig. 1.

2.3.1. Filtering the dataset

The first stage of data curation focused on filtering the dataset, detecting any cases that could be considered noise. This included instances in which the same video clip was repeated (e.g., the same interview broadcast in different channels), cases in which the audio and video were not aligned or there were technical issues (e.g., audio or video were not available), and cases in which the expression in the TV subtitles did not correspond to the expression that was uttered (e.g., the terms *addition* and *add* were often found when speakers uttered *addiction*

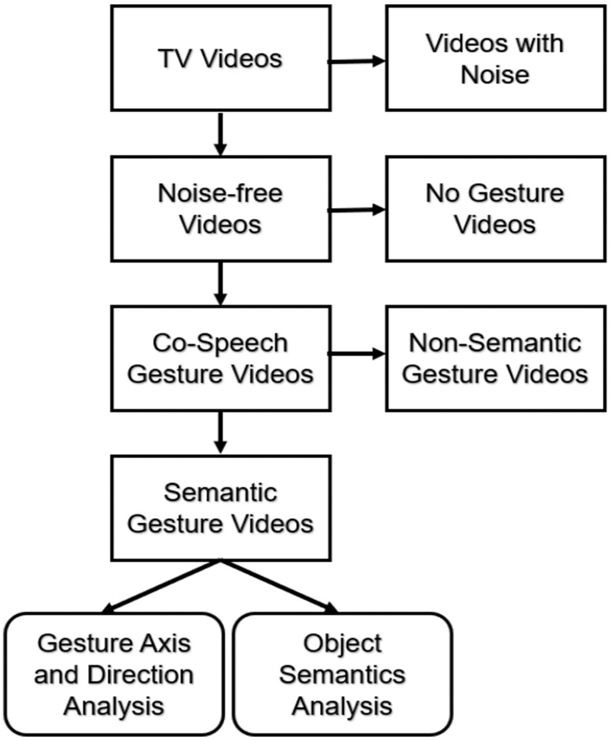

Fig. 1. Flowchart depicting the curation and analysis process.

or *act*, among others).

2.3.2. *Coding visibility of the hands*

The second stage of data curation involved distinguishing between clips in which the hands of the speaker were visible and those in which they were not visible. In some cases, clips contained a voiceover, such that the speaker could not be seen onscreen (e.g., a reporter describing an event while showing a photo). In other cases, the speaker's hands were not visible due to the camera angle, banners or text, or because the gesture was produced outside the camera frame.

2.3.3. *Identifying clips with semantic and non-semantic gestures*

The third stage of data curation focused on the cases in which the hands of the speaker were visible. Clips were classified into one of three categories: clips in which the speaker did not produce a gesture, clips in which the speaker produced a gesture that was not semantically related to the linguistic expression (e.g., beat gestures, self-adaptors) and finally, clips in which the speaker produced a co-speech gesture that was semantically related to the linguistic expression. The hits in this last category then underwent a more detailed linguistic and multimodal analysis.

To establish reliability, a second coder analyzed a subset of the clips that included gestures and classified whether each gesture (N = 188 gestures, 33% of the dataset) was semantically related to the co-occurring linguistic expression or not. There was a strong agreement between coders for classifying gestures as semantic or non-semantic gestures (κ = 0.819).

2.3.4. *Linguistic analysis: object semantics*

The hits that contained a semantically related co-speech gesture co-occurring with either *add* [NP] or *subtract* [NP] were further analyzed in terms of the semantics of the direct object (i.e., the element that was being *added* or *subtracted*). For each of these cases, we annotated whether the direct object was an abstract entity (e.g., *the president's personality*), a physical entity (e.g., *lemon*), or a numerical value (e.g., *roughly 600$ billion trade deficit*).

2.3.5. *Gesture analysis: axis, direction, and hand*

For the multimodal analysis, we coded the axis along which the gesture was produced, the direction of movement, and the gesturing hand. First, we annotated the axis as lateral, sagittal or vertical. In some cases, the gesture(s) presented no clear axial movement (e.g., merely indicated a point in space); such gestures were tagged as "punctual" gestures. Some clips also included unclear gestures; these cases were not included in the final analysis. Second, we annotated the direction of the movement: lateral gestures could be produced either rightwards or leftwards, and if the speakers used both hands, they could also be produced inwards (moving the hands together) or outwards (moving the hands apart). Gestures along the sagittal axis could be produced away from the body or towards the body. Vertical gestures could be produced upwards or downwards. Punctual gestures presented no axial movement. Third, we also annotated the gesturing hand as either the right hand, the left hand, or both hands together. We did not analyze any body movements that were not produced with the hands, such as head movements, gaze, or any other body movements.

A second coder analyzed a subset of the data (N = 150 semantic gestures, 33% of the dataset) in terms of gesture axis. There was almost perfect agreement between coders in identifying the axis along which the co-speech gesture was produced (κ = 0.908). The second coder also analyzed the same subset of the data (N = 150 semantic gestures, 33%) in terms of direction of motion. There was also strong agreement in coding direction of motion (κ = 0.833).

3. Results

3.1. *Linguistic frequency*

The overall frequency of the linguistic expressions related to addition was much higher than the frequency of expressions related to subtraction. *Addition* and *add* are employed with a wide range of verbs, idiomatic expressions, and discourse connectors, so their high frequency did not come as a surprise. The construction *N plus N* occurred at a much lower frequency, due to its much more restrictive use (Table 1).

On the other hand, *subtraction* and *subtract* have a narrower usage, which is often restricted to the domain of numerosity. The construction *N minus N* was even more infrequent than the construction *N plus N* (see Table 1).

3.2. *Multimodal analysis*

3.2.1. *Data curation and gesture frequency*

The linguistic searches in the NewsScape library resulted in a total of 4808 hits, distributed as follows: 96 hits for [N] *minus* [N], 656 hits for *subtraction*, 601 hits for *subtract*, 2225 hits for [N] *plus* [N], 600 hits for *addition* and 600 hits for *add*. This data was filtered according to the procedure described in Section 2.3, removing all data that was considered to be noise. This resulted in a total of 2247 clips being removed

Table 1
Linguistic frequency of the addition and subtraction construals across corpora.

		Linguistic expression frequency per million words (pmw)			
		EnTenTen2015	COCA	NewsScape 2016	Average
Subtraction	*subtraction*	1.24	0.94	0.24	0.81
	subtract [NP]	2.43	3.35	0.33	2.15
	[N] minus [N]	0.04	0.10	0.06	0.06
Addition	*addition*	178.88	96.94	28.63	101.48
	add [NP]	330.45	277.18	71.96	226.53
	[N] plus [N]	0.01	0.54	1.02	0.52

because the clips were repeated (1256 hits), because they were false positives (i.e., they did not include the target expression; 986 hits), or because the audio or video of the clip was not working (5 hits). For a full breakdown of this first data curation stage, please see Table S1 in the Supplementary materials.

After this first filtering process, the total number of hits was reduced to 2561. During the second filtering stage, we removed 1657 hits in which the hands of the speaker were not visible. This occurred either because the video presented a voice-over (708 hits) or because the hands of the speaker were outside the camera frame or were covered by other elements in the frame (949 hits). This resulted in a final list of 904 hits in which the hands of the speaker were clearly visible (henceforth, "visible hits"): 292 for subtraction and 612 for addition (see Supplementary materials, Table S1).

The clearly visible hits were further classified in terms of whether the speaker produced a non-semantic gesture, produced a semantically related gesture, or did not produce any gesture (Table 2). Some differences can be observed between the expressions. Notably, for addition, speakers did not produce gestures in 39% of cases, whereas for subtraction, speakers did not produce gestures in only 23% of cases (Table 2). The distribution of hits across categories (no gesture, non-semantic gesture, semantic gesture) differed significantly for addition and subtraction, $\chi^2(2, N = 904) = 93.94$, $p < .001$.

We also explored whether speakers gestured with one vs. both hands at different rates when speaking about addition and subtraction, The distribution of one-hand vs. both-hands gestures was comparable for addition and subtraction, $\chi^2(1, N = 411) = 2, 1905$, $p = .139$.

3.2.2. Relations between linguistic and gesture frequency

Once we obtained the frequency of the linguistic expressions (Table 1) and their proportion of co-speech gestures (Table 2), we could then examine the relation between linguistic frequency (Table 1) and gesture frequency (Table 2). As noted above, some past research has found that high-frequency expressions are less likely to be accompanied by co-speech gestures and vice versa (e.g., Pagán Cánovas et al., 2020).

We used linear regression to evaluate the association between log average corpora frequency (Table 1) and likelihood of gesture (Table 2) for the noun and verb expressions examined in the present study. The relation was in the predicted direction, but it did not reach statistical significance, $b = -8.411$, $F(1, 4) = 5.672$, $p = .075$, $\eta_p^2 = 0.59$. Because this analysis was based on very few data points, as in this study we considered only six expressions, we also analyzed the data together with the data from Woodin et al. (2020), presented in Table 3, which also examined linguistic expressions about numerical concepts. In this combined analysis, the relation was statistically significant, $b = -9.234$, $F(1, 8) = 7.277$, $p = .027$, $\eta_p^2 = 0.48$.

High-frequency expressions (such as *add* and *addition*) were less likely to be accompanied by co-speech gestures, while lower frequency expressions (such as *subtraction* or *tiny number*) were more likely to be accompanied by co-speech gestures (see Fig. 2).

3.2.3. Gesture analysis

We next examined the axes along which speakers produced gestures for each construal (Fig. 3). For the subtraction construals, most co-speech gestures were produced along the lateral axis (N = 119). Speakers produced fewer gestures along the sagittal axis (N = 22) and the vertical axis (N = 11), and they produced very few punctual (N = 8) and unclear (N = 7) gestures.

Some differences were observed when looking at individual subtraction expressions: for *N minus N*, speakers produced the highest percentage of lateral gestures (10 out of 12, 83.33%). For *subtraction*, speakers produced a lower percentage of lateral gestures (35 out of 62, 56.45%) and a higher percentage of sagittal gestures (11 out of 62, 17.74%) and punctual gestures (7 of 62, 11.29%) than they did for the other subtraction expressions (see Supplementary materials, Table S2).

For the addition construals, most of the co-speech gestures were produced along the lateral axis (N = 110). Speakers produced fewer sagittal (N = 41) and punctual (N = 61) gestures, and even fewer vertical (N = 25) and unclear (N = 4) gestures (see Fig. 2). In terms of differences across addition expressions, for the *N plus N* expression, speakers produced the highest percentage of lateral gestures (81 of 161, 50.31%) and punctual gestures (52 of 161, 32.3%). For the expression *add,* speakers produced a greater percentage of sagittal gestures (27 of 49, 55%) than they did for the other addition expressions (see Supplementary materials, Table S2).

We also examined whether the distribution of axes of motion differed for gestures produced with one vs. both hands. It did for the addition construals, $\chi^2(3, N = 250) = 8.196$, $p = .042$, but it did not for the subtraction construals, $\chi^2(3, N = 161) = 2.857$, $p = .414$. For the addition construals, the proportion of gestures produced with both hands was greater for the sagittal axis (58.5%) than for the other axes (37.4% lateral, 32% vertical, and punctual 32.8%)).

3.2.4. Gesture direction

For the subtraction construals, most co-speech gestures were produced in a leftwards direction (N = 68), as would be expected if subtraction were conceptualized as movement to the left on a mental number line. There were fewer cases with a rightwards (N = 38), inward (N = 6), or outward (N = 7) direction of motion (see Fig. 4). The distribution of motion directions was similar for *N minus N* and *subtract*, and there was greater variability for *subtraction* (see Supplementary materials, Table S2).

Example 1, presented in Fig. 5, illustrates this pattern.

1) …so, if you run a trade deficit, that **subtracts** from GDP… (2016-08-13_1200_US_MSNBC_MSNBC_Live, 1375–1380, NewsScape Library).

Click here or scan QR code.

Table 2
Number and percentage of visible hits that had no gesture, non-semantic gestures, and semantic gestures.

	Linguistic expression	No gesture	Non-semantic gesture	Semantic gesture	Total visible hits
Subtraction	[N] minus [N]	7 (26%)	8 (29%)	12 (45%)	27
	subtraction	20 (19%)	23(22%)	62 (59%)	105
	subtract	39 (24%)	26 (16%)	95 (59%)	160
	TOTAL	66 (23%)	57(20%)	169 (58%)	292
Addition	[N] plus [N]	100 (32%)	58 (18%)	161 (50%)	319
	addition	79 (53%)	26 (17%)	44 (30%)	149
	add	59 (41%)	36 (25%)	49 (34%)	144
	TOTAL	238 (39%)	120 (20%)	254 (42%)	612

Table 3
Linguistic frequency (pmw) and gesture proportion for expressions in the current study and expressions studied by Woodin et al. (2020).

	Linguistic expression	Corpus frequency per million words				Semantic gesture proportion	
		EnTenTen	COCA	NewsScape 2016	Average	Gesture	No Gesture
Current study	add	330.45	277.18	71.96	226.53	45.37%	54.62%
	addition	178.88	96.94	28.63	101.48	35.77%	64.22%
	N plus N	0.01	0.54	1.02	0.52	61.68%	38.31%
	subtract	2.43	3.35	0.33	2.15	70.89%	29.1%
	subtraction	1.24	0.94	0.24	0.81	75.60%	24.39%
	N minus N	0.04	0.10	0.06	0.06	63.15%	36.84%
Woodin et al. (2020)	large number	21.05	7.89	3.89	10.94	74.1%	29.1%
	small number	5.14	4.78	2.96	4.29	70.9%,	25.9%
	huge number	2.38	1.06	1.81	1.75	77.7%,	22.3%
	tiny number	0.11	0.14	0.09	0.11	90.4%,	9.6%

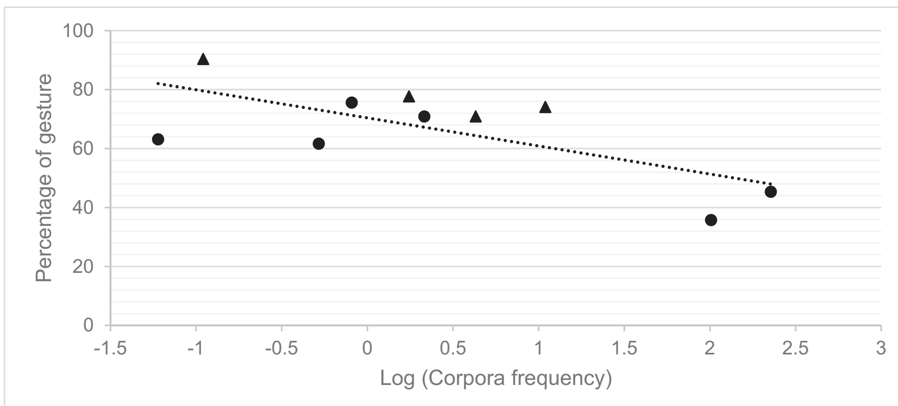

Fig. 2. Relation between corpora frequency (log) and percentage of hits with co-speech gestures for linguistic expressions in the current study (circles) and in Woodin et al. (2020) (triangles).

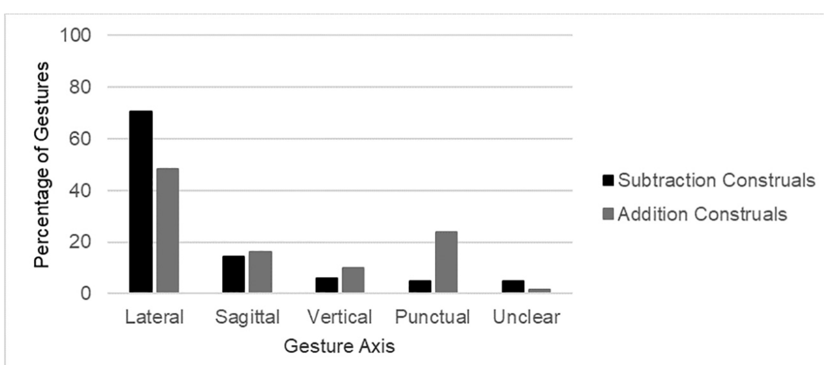

Fig. 3. Percentage of co-speech gestures produced along each axis for the addition and subtraction construals.

Example 1 is an instance of a leftwards gesture co-occurring with the verb *subtract*. At the beginning of the clip, the speaker positions his hands with both palms facing each other in front of his body. When he utters the verb *subtracts*, he moves his right hand to the left over his left hand, until it reaches the area close to his left shoulder (Fig. 5).

Considering gestures that involved motion along the sagittal axis, most of the subtraction gestures were produced with motion towards the body (N = 22). That is, speakers had their hands in front of them and they moved them closer to the central area of the body. There were only 2 cases that were produced with motion in the opposite direction, that is, with motion away from the body (Fig. 6).

Example 2, presented in Fig. 7, illustrates a sagittal gesture for subtraction:

2) …the deeds, when you think about… You **subtract** the polarizing business model of the media, you have… (2019-02-04_2200_US_FOX-News_The_Five, 1805–1811, NewsScape Library).

Click here or scan QR code.

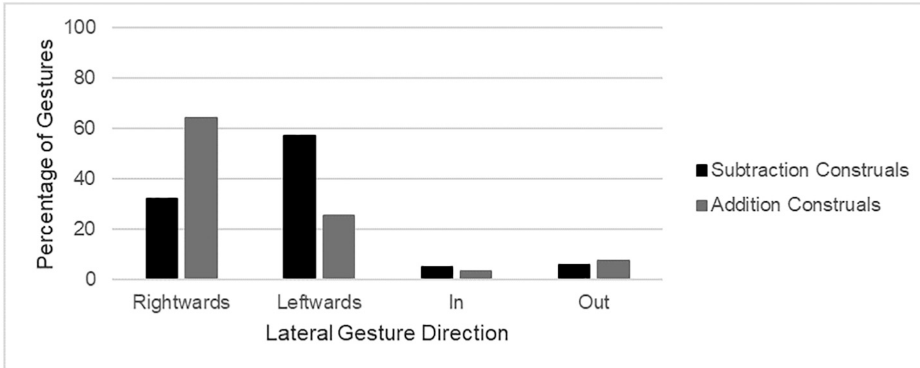

Fig. 4. Percentage of lateral gestures that used each direction of motion for the addition and subtraction construals.

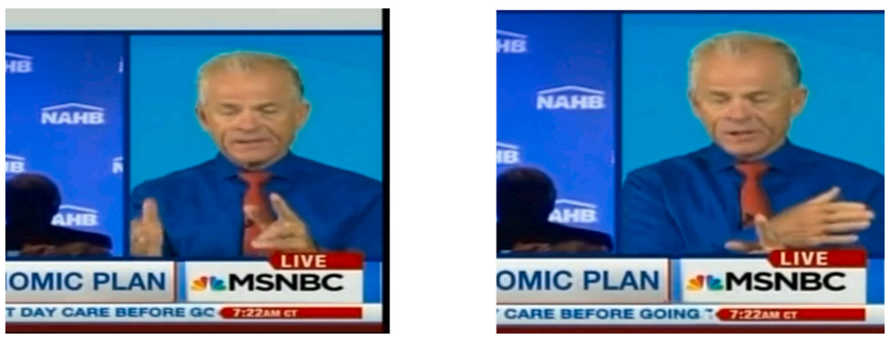

Fig. 5. Example 1: leftwards lateral gesture for subtraction.

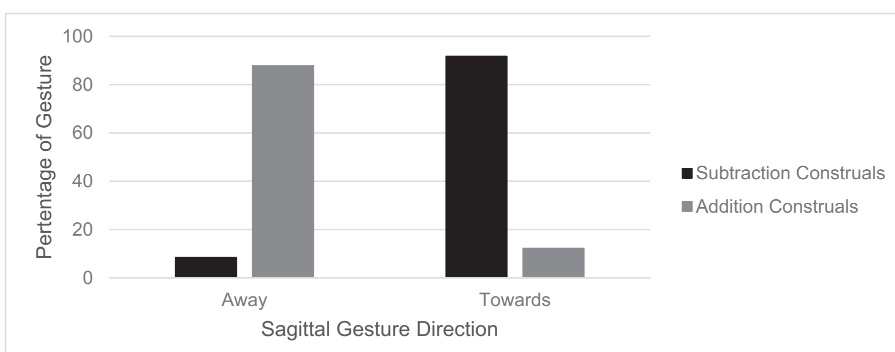

Fig. 6. Percentage of sagittal gestures produced in each direction for the addition and subtraction construals.

Fig. 7. Example 2: towards-the-body sagittal gesture for subtraction.

Example 2 is an instance of a towards-the-body gesture produced with the left hand while the speaker says *subtract*. The speaker extends his left arm in front of him, then he grabs (an imaginary) something with his hand, and immediately after, he pulls his hand back above his shoulder, keeping it in a closed-fist position (Fig. 7).

For the addition construals, most of the lateral gestures were produced with a rightwards direction of motion (N = 79), as would be expected if addition were conceptualized as movement to the right on a mental number line. All other directions of motion were much less frequently employed (see Fig. 4).

Example 3, presented in Fig. 8, shows an instance of a speaker performing two co-speech gestures along the lateral axis. The first one is produced while the speaker says *add amendments*: his right hand moves rightwards from a resting position, with an open palm facing upwards. Immediately after that, when the speaker says *subtract*, he moves both hands to the left: the right hand moves from the right to the center of the body, while the left hand moves to the left.

3) …but obviously, as you **add amendments**, it **subtracts** from somebody else who doesn't think that should be in there. … (2018-12-11_1900_US_FOX-News_The_Daily_Briefing_with_Dana_Perino, 460–466, NewsScape Library). Click here or scan QR code.

Concerning sagittal gestures, the data for addition show the opposite pattern as found for subtraction: most of the co-speech gestures were produced with motion away from the body (N = 36), and only a few cases (N = 5) presented motion towards the body (see Fig. 6).

Example 4, presented in Fig. 9, is an instance of a speaker producing two co-speech gestures (one for addition and one for subtraction), both along the sagittal axis. The speaker produces the first one while saying *add*: she moves her left hand in front of her, while keeping her hand in a pinching posture (thumb and index slightly opened, while the rest of the fingers touch the palm), as if *adding* something to an imaginary container. Immediately after, when she says *subtract*, she performs a pulling gesture with the same hand, as if grabbing something with her left hand and bringing it closer to her body.

4) …when you **add** another commitment, you need to **subtract** one. Get your husband to walk the dog because… (2017-01-23_1500_US_KNBC_Today, 5834–5840, NewsScape Library). Click here or scan QR code.

Overall, the gesture direction data suggest that, among gestures produced along the lateral axis, subtraction gestures tended to be produced in a leftwards direction, while addition gestures tended to be produced in a rightwards direction. This association was statistically significant, $\chi^2(1, N = 216) = 28.13$, $p < .001$. Among gestures produced along the sagittal axis, subtraction gestures tended to be produced with a towards-the-body motion, while addition gestures tended to be produced with an away-from-the-body motion. This association was also statistically significant, $\chi^2(1, N = 65) = 39.37$, $p < .001$.

We also examined whether the distribution of motion directions differed for gestures produced with one vs. both hands. For addition construals, the distribution of motion directions for one-hand vs. both-hands gestures did not differ in direction for lateral gestures, $\chi^2(1, N = 110) = 2457$, $p = .116$, or for sagittal gestures, $\chi^2(1, N = 41) = 1081$, $p = .298$. Similarly, for subtraction construals, the distribution of motion directions for one-hand vs. both-hands gestures did not differ for lateral gestures, $\chi^2(1, N = 106) = 2334$, $p = .126$ or for sagittal gestures, $\chi^2(1, N = 24) = 0{,}145$, $p = .703$.

3.2.5. Semantic analysis

For cases in which the verbs *add* and *subtract* were accompanied by co-speech gestures, we also analyzed the nature of the direct object of the expression (Fig. 10). As mentioned in Section 2.3, we classified each direct object into one of three categories: a physical entity (*the contract*; *the president*), a numerical value (*subtract from 700,000*; *add 57 to that*) or an abstract entity (*the risks*; *things*).

For *subtract*, speakers employed the lateral axis most frequently, regardless of the type of entity that they were subtracting. This tendency was particularly prominent when speakers referred to numerical entities, and it was slightly less prominent for abstract entities (for which sagittal gestures were slightly more frequent) and physical entities (for which vertical gestures were slightly more frequent).

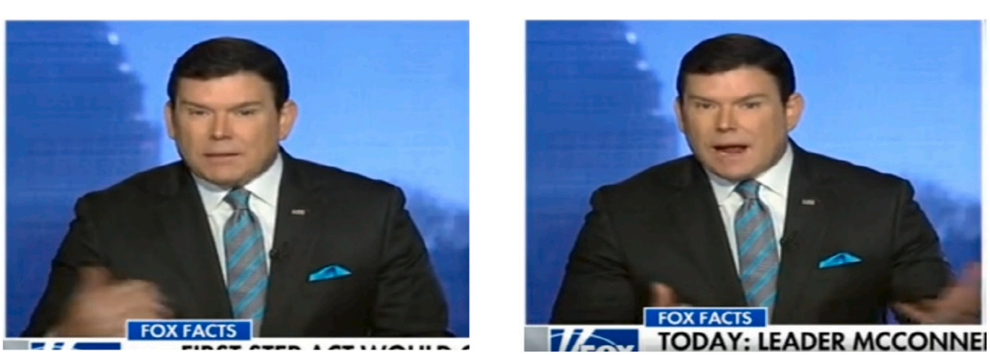

Fig. 8. Example 3: rightwards addition gesture with the right hand, followed by a leftwards subtraction gesture with both hands.

Fig. 9. Example 4: an away-from-the-body sagittal gesture for addition, followed by a towards-the-body sagittal gesture for subtraction.

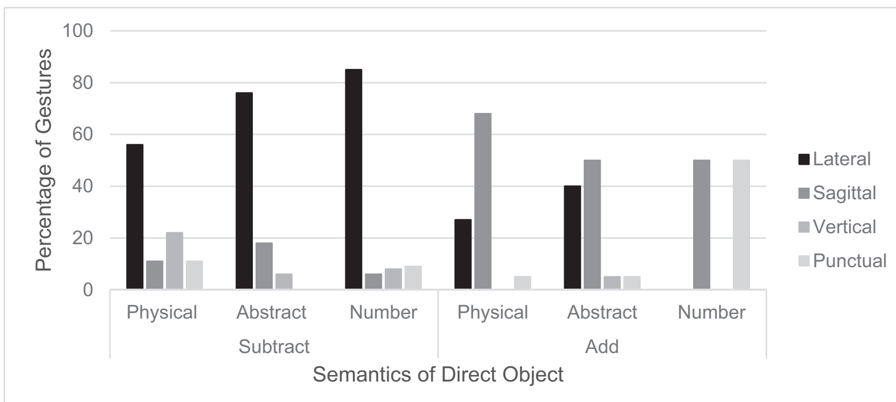

Fig. 10. Percentage of gestures in each direction for each type of direct object.

For *add*, the sagittal axis was the most frequent for both physical and abstract direct objects, and the lateral axis was the second most frequent. Because only 2 cases referred to numerical entities, there was not enough data to establish any type of gesture pattern for numerical direct objects.

The association between gesture axis and type of direct object was not significant, either for subtraction, $\chi^2(2, N = 80) = 2.63$, $p = .27$, or for addition, χ^2 $(1, N = 40) = 1.50$, $p = .22$.

4. Discussion

In this work, we analyzed multimodal data from a television corpus, with a focus on the co-speech gestures speakers produced when they spoke about addition and subtraction. There were two main findings. First, linguistic expressions that are less frequent were more likely to be accompanied by co-speech gestures. Second, most gestures about addition and subtraction were produced along the lateral or sagittal axes. When people spoke about addition, they tended to produce lateral, rightwards movements or movements away from the body. When people spoke about subtraction, they tended to produce lateral, leftwards movements or movements towards the body. We consider each of these findings, in turn.

4.1. Linguistic and gestural frequency

Our data revealed differences between the addition and subtraction construals in terms of linguistic and gesture frequency. Expressions that referred to subtraction (*subtract, subtraction* and *N minus N*) were very infrequent across corpora (a range from 0.06 pmw to 2.15 pmw). Addition expressions were much more frequent (ranging from 0.52 pmw to 226.53 pmw, see Table 1). These differences in frequency can be explained by the highly polysemous usage of *addition* and *add*¸ which are employed in a wide array of linguistic expressions, including phrasal verbs (*add up*, *add on*), connectors (*in addition*), and compound nouns (*add-on*).

Among the expressions analyzed for this study, substantial differences in gesture frequency were observed for the addition and subtraction construals. For the nouns, gestures were more than twice as likely with *subtraction* than with *addition* (75.6% vs. 35.77%). For the verbs, the pattern was similar, with the likelihood of gesture much higher for *subtract* than for *add* (70.89% vs. 45.37%). For the structures N *minus* N and N *plus* N, gesture rates were quite similar (63.15% vs 61.6%), presumably due to the fact these expressions were limited to the domain of numerosity. However, the data for these two expressions presented a great disparity in sample size (*N minus N,* N = 12 semantic gestures; *N plus N,* N = 161 semantic gestures), due to the high frequency of *N plus N* in NewsScape (2255 total hits) and the rarity of *N minus N* (96 total hits).

There are two, non-mutually-exclusive approaches that may explain people's tendency to produce more co-speech gestures when speaking about adding than when speaking about subtracting. First, subtraction is a more complex mathematical operation than addition, as manifested in both children's and adults' poorer fluency with simple subtraction problems than simple addition problems (e.g., Campbell & Xue, 2001; Kamii et al., 2001; LeFevre et al., 2003), as well unique challenges in children's learning about subtraction (due, in part, to the working memory demands of counting backwards; e.g., Baroody, 1984). For both children and adults, one frequently-used strategy for subtracting is transforming a given subtraction problem to a related addition problem (e.g., Huebner & LeFevre, 2018; Siegler, 1989), and this strategy is sometimes explicitly taught to children as a means to ground the concept of subtraction (e.g., Paliwal & Baroody, 2020). Recent research further suggests that people tend to "default" to adding rather than subtracting when reasoning about objects, ideas, or situations (Adams et al., 2021). Taken together, these lines of work suggest that subtraction is indeed a more complex and demanding mathematical operation than addition. Given evidence that speakers produce gestures as a means to lighten the working memory load of speaking (e.g., Cook & Fenn, 2017; Goldin-Meadow et al., 2001; Pouw et al., 2014) it stands to reason that people might be more likely to use gestures when speaking about subtraction than when speaking about addition.

A second way to explain people's tendency to gesture more when speaking about adding than about subtracting is to relate it to linguistic frequency and informativity. The data pattern suggests that people gesture more with low-frequency expressions than with high frequency expressions. If we consider frequency to be a proxy for informativity (see Pagán Cánovas et al., 2020), the less frequent expressions *subtract* and *subtraction* may be considered to be less informative than the more frequent expressions *add* and *addition*. When an expression is less informative, speakers should be more likely to include a co-speech gesture that complements or reinforces the information conveyed in the linguistic expression. Co-speech gestures should be less necessary when linguistic expressions are more informative, since they are easier to predict and understand.

Of course, informativity cannot be completely reduced to frequency; in fact, some approaches to informativity have included other measures, such as the notion of statistical co-dependencies, in order to arrive at a more streamlined account. Piantadosi et al. (2010) followed this approach with word dependencies, and they were able to predict word length more accurately than when using frequency alone. Other studies have applied this approach to phone deletion (Cohen, 2008) or to the acoustic duration of words (Seyfarth, 2014).

The variety of expressions used in each of the "poles" in the present study (addition and subtraction) complicates the direct application of such methods in our case. It should also be noted that the notion of "informativity" is ultimately based on context, which is a multifaceted concept which includes not only lexical dependencies, but also syntactic and discursive context, and even general world knowledge. This complexity makes arriving at a precise measure of informativity difficult, so our use of frequency as a proxy for informativity is only a first step. At a minimum, when an expression is less informative, as indexed by its being less frequent, speakers should be more likely to include a co-speech gesture that complements or reinforces the information conveyed in the linguistic expression. Co-speech gestures should be less necessary when linguistic expressions are more informative, since they are easier to predict and understand.

The relationship between linguistic and gesture frequency and the informativity of linguistic expressions has previously been attested in the domain of time. Pagán Cánovas et al. (2020) analyzed several expressions that conveyed different temporal senses (e.g., deictic time as in *back then*, sequential time as in *before that*, and temporal demarcation as in *from start to finish*). They found that high-frequency temporal expressions were less likely to be accompanied by co-speech gestures, and low-frequency expressions were more likely to be accompanied by co-speech gestures. Other studies, such as Alcaraz Carrión and Valenzuela (2022), report a similar tendency with temporal expressions in both English and Spanish.

The current findings suggest additional questions about linguistic and gesture frequency that could be addressed in future research. We found that linguistic expressions for addition were more frequent than for subtraction, and correspondingly, gesture rates for subtraction were higher than for addition. This raises the question of whether there might be systematic relations between gesture rate and complexity of arithmetic operations, extending, for example, to multiplication, division, and exponentiation. Along similar lines, past research has shown that words for small numerosities (e.g., *one, five*) are significantly more frequent than words for high numerosities across several languages (Dehaene & Mehler, 1992). This finding raises the possibility that people might be more likely to produce gestures when they use words for high numerosities. These questions could be addressed with data from a broader range of linguistic expressions than those considered here.

4.2. Gesture axis and direction

Overall, speakers tended to produce both addition and subtraction gestures along the lateral axis (Fig. 3), as they do in other conceptual domains such as time (Casasanto & Jasmin, 2012; Valenzuela et al., 2020). This pattern is most likely due to the anatomical disposition of the hands and the greater amount of gestural space available in the lateral axis (Cienki, 1998). However, even though the lateral axis is the preferred one, the direction of the co-speech gestures varied depending on the construal. Subtraction expressions co-occur more frequently with leftwards gestures than with rightwards gestures or with gestures in other directions. Conversely, addition expressions co-occur more frequently with rightwards gestures than with leftwards gestures or with gestures in other directions (Fig. 4).

Thus, speakers tend to move their hands rightwards when adding and leftwards when subtracting. One likely explanation for this pattern is that speakers are indeed moving along an imaginary number line with their hands. The numerical quantity or item at hand is often placed around the center of the body; subtracting from the quantity is signalled by leftwards motion, and adding to the quantity is signalled by rightwards motion. Thus, speakers do not only represent the mental number line with their hands, but they also represent the type of arithmetic operation with the motion of their hands. These gesture data therefore suggest that speakers are activating the ARITHMETIC IS MOTION ALONG A PATH metaphor, with leftwards or rightwards motion, depending on the operation.

The number line gestures observed in this study share some features with the co-speech gestures that have previously been described for the domain of time. English speakers often create an imaginary timeline with their co-speech gestures, in which past times are signalled by gesturing to the left, and future times are signalled by gesturing to the right (Alcaraz Carrión et al., 2020; Valenzuela et al., 2020). In a similar fashion, the current data show that English speakers spontaneously rely on a mental number line when conveying numerical operations, moving their hands over the number line to represent addition with a rightwards motion or subtraction with a leftwards motion.

Even though most of the gestures in our dataset were produced along the lateral axis, there was also a relatively high number of sagittal gestures (see Fig. 3). We also observed systematic differences between addition and subtraction in the direction of co-speech gestures produced along the sagittal axis. *Addition* expressions were nearly always produced with an away-from-the-body motion (Fig. 6); speakers moved their hands from the area around their chest as if to an imaginary container that was placed in front of them (Fig. 9). The opposite pattern emerged for *subtraction* expressions (Fig. 6), which were usually produced with a towards-the-body motion; speakers moved their hands as if to pick up something from an imaginary container located in from of them and bring it closer to their bodies (Fig. 9). These types of co-speech gestures present a different metaphorical mapping, which is also motivated by our interaction with the physical world: the ARITHMETIC IS COLLECTING OBJECTS metaphor. In this case, speakers *add* objects to a collection located in front of them, or *subtract* items from that collection, and these actions are represented in their co-speech gestures. This idea is further supported by cases in which speakers seem to "pull" (Fig. 7) or "pick up" (Fig. 9) items from an imaginary container, simulating these actions with their hands. Speakers' sagittal gestures suggest that they sometimes conceptualize arithmetic operations in terms of objects being added to or subtracted from an external, imaginary container that is located in front of them.

Thus, co-speech gestures suggest that speakers have two ways of conceptualizing addition and subtraction: in terms of lateral movements along a mental number line or in terms of the manipulation of objects with respect to an external, imaginary container. To further elucidate the basis of these two types of conceptualizations, we performed a semantic analysis of the verbs *add* and *subtract*, looking at the types of entities that were added or subtracted, for cases in which direct objects were stated. We distinguished between cases in which speakers added a physical entity, an abstract entity, and a numerical quantity. Our initial hypothesis was that the type of conceptualization that speakers represented with their hands (i.e., the ARITHMETIC IS MOTION ALONG A PATH or the ARITHMETIC IS COLLECTING OBJECTS metaphor) could be related to the type of entity that was being added or subtracted in speech.

For the subtraction construal, most of the instances referred to either abstract entities or numerical values, with speakers favoring the lateral axis for all types of direct objects (see Fig. 9). Speakers were least likely to represent numerical quantities using sagittal gestures; however, the likelihood of using sagittal gestures was not significantly lower for numerical quantities than for physical or abstract entities. For the addition construal, speakers seemed to favor sagittal gestures when talking about physical and abstract entities. However, our dataset contained very few cases in which *add* made reference to numerical quantities; hence we could not make any fireproof conclusions.

Overall, the semantic analysis did not yield a statistically significant association between the nature of the direct object and the axis along which speakers produced co-speech gestures. However, because this phenomenon could be studied only for cases that included explicit direct objects, the analysis was constrained to two verbs (*add* and *subtract*), which limited the amount of relevant data. Future studies should aim to collect additional data to shed light on possible differences between the semantics of the item that is being added or subtracted and the type of co-speech gesture (and possibly the type of underlying metaphor) that speakers employ to conceptualize the arithmetic operation.

4.3. Limitations and future directions

Working with naturalistic data has many inherent limitations. The speakers in the clips that we analyzed were all adults, and we do not have any information about their backgrounds or about other characteristics that may influence their gesture production or their mathematics knowledge, such as their handedness, their level of education, their attitudes towards mathematics, or whether they also speak languages other than English. For some of clips that we analyzed, we also do not know for certain whether speakers were speaking entirely extemporaneously, or whether they had previously answered similar questions or planned what they were going to say in advance. The range of discourse contexts is also fairly limited; most of the clips that we analyzed were drawn from newscasts, interviews, or one-on-one conversations.

One unique discourse context in which people frequently communicate about mathematical information, but which was not represented in the current dataset, is the classroom. Given that speakers express conceptual metaphors for addition and subtraction in their gestures in everyday communication, it seems highly probable that teachers regularly do so in classroom settings, as well. Such gestures may be especially likely when arithmetic operations are the focus of instruction, as is often the case in mathematics and science instruction.

This possibility raises many new questions for future research. First, is instructional communication about mathematical concepts most effective when teachers' gestures *align* with the embodied activities or metaphors that are used in instruction? For example, if an arithmetic lesson focuses on manipulating collections of objects (as is common when learning whole number arithmetic in elementary school), would it be most beneficial for students' learning if the teacher speaks about operations while producing gestures along the sagittal axis, which manifest the ARITHMETIC IS COLLECTING OBJECTS metaphor? Alternatively, if an arithmetic lesson uses the number line (as is common when learning fraction and integer arithmetic in later elementary and middle school), would it be most beneficial for students' learning if the teacher speaks about operations while producing gestures along the lateral axis, which manifest the ARITHMETIC IS MOVEMENT ALONG A PATH metaphor and which may evoke the mental number line? Indeed, some research on integer arithmetic suggests that lessons that involve actions that manifest the ARITHMETIC IS MOVEMENT ALONG A PATH metaphor (with a number line) are more effective than lessons that involve actions that manifest the ARITHMETIC IS COLLECTING OBJECTS metaphor (with sets of colored chips that "cancel" each other out; see Nurnberger-Haag, 2015, 2018).

Second, is instructional communication about mathematical operations most effective when teachers' gestures align with the expected direction of motion? If a teacher is speaking about subtraction, for example, would their communication be more effective if they used a gesture along the lateral axis in a leftwards direction, than if they used a gesture along the lateral axis in a rightwards direction? Future research could address these questions in laboratory settings, where the content of the instructor's speech and gesture could be carefully controlled.

The present findings also raise many questions about people's use of the ARITHMETIC IS COLLECTING OBJECTS and the ARITHMETIC IS MOVEMENT ALONG A PATH metaphors in mathematical reasoning—questions that could potentially be answered by looking at people's gestures when they speak about mathematical tasks. Does people's use of the two metaphors depend on their level of mathematics knowledge? For example, do younger speakers rely primarily on the ARITHMETIC IS COLLECTING OBJECTS metaphor? Does use of the ARITHMETIC IS MOVEMENT ALONG A PATH metaphor increase with age and experience? Are people more likely to activate the ARITHMETIC IS MOVEMENT ALONG A PATH metaphor when they operate with fractions and negative numbers, for which a COLLECTING OBJECTS metaphor may be less apt? What types of gestures do speakers produce when communicating about other arithmetic operations, such as division or multiplication? Data from the gestures that speakers produce when they speak about a range of arithmetic tasks could be used to address these and many other questions about mathematical thinking and its development.

In this work, we focused on the co-speech gesture realizations that speakers produced most frequently: speakers tend to gesture to the right when adding, and to the left when subtracting. However, it is worth highlighting that roughly 30% of the lateral gestures presented the opposite pattern: speakers gestured to the left when speaking about addition, and to the right when speaking about subtraction. Why might speakers produce gestures that are incongruent with the mental number line (and for that matter, with the left-to-right writing direction)? The television data do not allow us to establish the reasons for these incongruent patterns, but there are several possibilities that could be addressed in future laboratory studies. For example, in some situations, speakers may adopt the interlocutor's viewpoint when producing a gesture. The handedness of the speaker or the physical position of the interlocutor may also play a role. Many of these factors cannot be teased apart in naturalistic data, but future studies in more controlled settings should focus on the why speakers sometimes produce gestures that do not conform to the most frequent pattern.

5. Conclusion

In this work, we drew on a large dataset of naturalistic communication, and we examined the co-speech gestures that speakers produced when talking about addition and subtraction. When people used linguistic expressions that were less frequent, they were more likely to produce co-speech gestures, suggesting that speakers are more likely to rely on gesture as part of their communication when linguistic expressions are less informative or less predictable. Further, when speaking about addition, people tended to produce lateral, rightwards movements or sagittal movements away from the body. When speaking about subtraction, they tended to produce lateral, leftwards movements or sagittal movements towards the body. These data suggest that speakers activate conceptual metaphors of arithmetic as motion along a path or as collecting objects, and they express these metaphors in their gestures. Spontaneous gestures can yield insights into the conceptual structure of mathematical thinking and how it is manifested in the body.

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Declaration of competing interest

This manuscript has not been published and is not under consideration for publication elsewhere. Likewise, we have no conflicts of interest to disclose. All the authors have approved this submission, and we confirm that the data collection and procedures follow the journal ethical guidelines.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2022.103624.

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