Evidence of Embodied Cognition Via Speech and Gesture Complementarity

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Abstract. We are studying how students talk and gesture about physics problems involving directionality. Students discussing physics use more than words and equations; gestures are also a meaningful element of their thinking. Data come from one-on-one interviews in which students were asked to gesture about the sign and direction of velocity, acceleration, and other quantities. Specific contexts are a ball toss in the presence and absence of air resistance, including situations where the ball starts at greater than terminal velocity. Students show an aptitude for representing up to 6 characteristics of the ball with 2 hands. They switch quickly while talking about velocity, acceleration, and the different forces, frequently representing more than one quantity using a single hand. We believe that much of their thinking resides in their hands, and that their gestures complement their speech, as indicated by moments when speech and gesture represent different quantities.

Keywords: embodied cognition, gesture
PACS: 01.40.Fk

INTRODUCTION

What happens in a rich environment when the studied event can be represented in multiple ways? For example, when thinking about a ball being tossed in the air, you could imagine your hand representing the position of the ball, with a thumb or finger depicting the directional information. In this way, new information and insight can be developed for both the speaker and those with whom the speaker is conversing. In this paper we investigate three instances from individual interviews in which students were asked to discuss, both verbally and with hand movements, a ball being tossed into the air. The question of interest is very similar to the coin toss problem asked by Clement [1]. The intent of our interviews was to gain evidence for the idea that students can think about multiple variables simultaneously.

Students participating in interviews tell us what they know through more than just what they say. Both speech and gesture provide information about a person's thinking, and provide a means of information transfer for the speaker [2]. Following McNeill and others, we believe that gestures are an extension and act of thought itself [3,4]. In previous studies, diSessa found that when reasoning about a physical system, study participants would sometimes use their hands to describe how a hypothetical system might behave [5]. Roth and Welzel [6] further described how gesture often precedes language, and Scherr [7] extended these results, describing how gestures could stand in the place of speech.

Whether or not a person intends their gestures to be communicative, hand movements provide information to a listener that may not be accessible via the speech used [2]. Sometimes, words such as "here," "there," and "you all" can be accompanied by pointing gestures, so that the listener knows to what or whom the speaker is referring [8]. In such situations, the gesture and the speech match.

A mismatch occurs when the speech and the gesture of a speaker differ and each conveys different information [9]. Previously, mismatches have been described as evidence that a student was ready to learn [9]. We believe gesture-speech mismatches may have another advantage, in that they may suggest that a person is thinking about two concepts at the same time. In this paper we describe situations where students represent multiple quantities at once. We argue that gestures and speech together indicate that a speaker is thinking about two different concepts at once.

MULTIPLE SIMULTANEOUS REPRESENTATIONS

Data come from three instances during two individual interviews in which the students discussed a simple physics problem using their hands and speech. The students had recently completed a sophomore-level course in mechanics, and were recruited via e-mail. The students were all asked to discuss the motion

of a ball being tossed into the air, and then they were asked to let one hand represent the velocity of the ball and let the other hand stand for its acceleration. Students were eventually asked to show the forces acting on the object. All participants were told to consider cases involving both the presence and absence of air resistance.

Anthony - Complementary Gesture and Speech

Anthony described the motion of a ball thrown into the air and ended his description at the moment the ball started to come back down from its peak. In Table 1, we give the text of Anthony's speech and connect Anthony's speech to the gesture phrase made at that specific time, using the notation of spatial locations shown in Fig. 1. For example, Anthony said, "or, it starts here," as he moved his hand from point a to point 1, as shown in Fig. 1.

We account for the complexity of Anthony's speech and gesture by observing that he talks and gestures about both position and speed, but at different times. Anthony provided evidence that he was conceptualizing two different ideas in several ways.

TABLE 1. Speech versus Gesture

"Well, as you go along the velocity, you have some initial velocity, or, it starts here. It goes here, you reach the maximum, and then it goes, back up more."

Speech	Gesture
Well, as you go along the velocity,	0 → a → 0
You have some initial velocity,	0 → a
Or, it starts here.	a → 1
It goes here, you reach the maximum,	1 → 2
And then it goes,	2 → 3
back up more.	No Hands

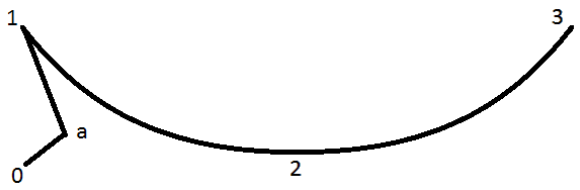

FIGURE 1. Diagram of Anthony's hand movements during this episode, as drawn from video recordings.

He began by defining his left hand to be the velocity of the ball. Anthony at first moved his hand up as though he were "graphing" the position-versus-time graph. However, when he said "or, it starts here," and moved his hand, it suggested that his hand was shifting into another space and representation. Based on what followed, we believe he was creating a makeshift speed-versus-time graph.

We note that Anthony set his left hand to the task of portraying the speed of the ball at the same moment that his speech shifted to describing the position of the ball. His speech from point 0 to point 1 referred to the speed of the ball or the listener attending to it (i.e. "as you go along the velocity"), while the speech at point 1 suggested the word "it" referred to the ball. The referent of "it" is suggested once it is observed that Anthony said the word "maximum," referring to position. However, his gesture travelled down from point 1 to point 2 while talking about the maximum. From this, we conclude that Anthony's left hand was describing the velocity going to zero at the maximum height of the ball's trajectory. And yet, after raising his hand back up (representing the velocity increasing as the ball drops), he finishes the gesture. Once he released his gesture, his speech reverted back to describing the speed of the ball by saying, "it goes back up more" (this, just after his hand had fallen). This separation of tasks suggests to us that, while his hand was between locations 1 and 3, Anthony was coordinating two characteristics of the ball at the same time: the position of the ball with speech, and the speed of the ball with the hand.

In the few seconds after this episode, the interviewer (author EAC) asked Anthony what he meant by "maximum," while mimicking the gesture Anthony had used. In response, Anthony described the series of events once more. When he again reached point 2 with his left hand, his right hand came up and was held above his left, while Anthony said "maximum height." Because of the use of a separate hand to represent position, we find support for our interpretation that Anthony used his left hand to represent velocity. In a later example, we return to the issue of using multiple gestures simultaneously to represent different information.

Jeff – Gestures adding information

Another student, Jeff, also provided gestures that extended his speech, in this case using his hands to describe the sum of forces acting on a ball as it fell from its maximum height. The quote above Fig. 2 gives Jeff's speech, while the gestures Jeff made at the marked points in the quote are shown below in the figure. (The pictures in Fig. 2 are recreations of the

original video data, created in an attempt to increase image clarity. The perspective of images 4 and 5 has been changed to provide clarity about hand position.)

"and so air resistance[1] opposes[2] gravity[3] when it's falling down.[4] So your[5] acceleration is actually decreasing, as objects fall."

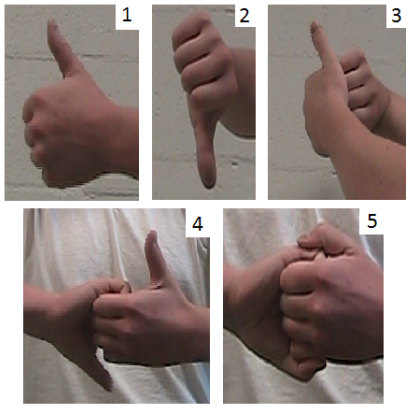

FIGURE 2. Gestures portrayed by Jeff.

Jeff's speech described each of the forces that were acting on the ball as the ball was falling toward the ground. Jeff's hands portrayed both of these forces, air resistance and gravity. At moments 3–5, though, additional information not given in the speech was conveyed by the hands. The hands come together, and the thumbs on the hands curl in. We interpret these gestures as showing the two forces coming together, such that the hands then portray the acceleration of the ball as a whole.

We can see that Jeff clearly defined one hand to be the air resistance force, while the other was defined as the force due to gravity. These two hands were distinctly and emphatically separated when Jeff spoke about them. In the moment that Jeff brought his hands together and moved his fingers in, it appears that he was no longer separating these two ideas, and had formed them into one idea – his clamped "double fist" – which he spoke of as being the acceleration.

As with Anthony, we find a moment of mismatch. Where Anthony talked about one kinematic quantity and gestured about another, Jeff's speech was a demonstration of his thinking about the total acceleration of the ball, and his gesture combination was demonstration of his thinking about the forces adding together. Pictures 4 and 5 (and the transition between them) in Fig. 2 support our point. We suggest that they portray the concept of summing the forces together. Jeff was thinking about two ideas at the same time.

Stated differently, in pictures 3 through 5 in Fig. 2, we see evidence of the gesture providing information that is not contained in the speech – forces combining and leading to an acceleration that goes to zero during the fall. Without the gesture, the connection between Jeff's first and second sentences is not made. With the gesture, we see that the second statement follows from the first. The gesture complements the speech.

Anthony – Gestures showing multiple descriptors

In our third example, we return to the point that multiple gestures are possible at once. We provide evidence that Anthony simultaneously produced a match and a mismatch of speech and gestures.

In this episode, Anthony was discussing the full trajectory motion of the ball, speaking of its position, velocity, and energy. Table 2 shows how Anthony's fingers moved in the beginning of the episode, where the points as labeled refer to the superscripts in the quoted material. At the depicted moments, his hand was held high up in the air. Fig. 3 depicts how his hand and fingers moved from point 3 to the end of the episode. Note that in Fig. 3, Anthony's hand is resting at point 3 with his fingers as shown in the second row of Table 2. Anthony's hand travels down and to his right from point 3 to point 4, while his thumb and index finger separate.

TABLE 2. Speech and Gestures of Anthony: 2nd episode.

"Your velocity will still increase to some point, and then it will become like[1], a zero point at the very top,[2] because it's all potential so there's no velocity. And then, once you[3] start moving again you have kinetic so then[4] your velocity's gonna increase."

Speech	Gesture
Start → 1	
1 → 2	

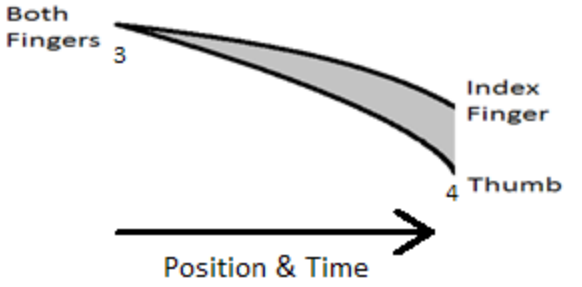

FIGURE 3. Anthony's hand and fingers after point 2.

In contrast to the previous example from Anthony, we observe in this episode that he spoke about velocity the entire time. Throughout the episode, the location of his hand represented the height of the ball (consistent with being "at the very top" – the one time he refers to position in his speech). The fingers on his hand provided additional information. His index finger and thumb, as shown in Fig. 3, appear to indicate the magnitude of the speed. Gestures 1 and 2 occurred while the hand was held at maximum height. As the hand dropped (and moved to the right), his fingers separated while Anthony said "velocity's gonna increase." His hand moved down (consistent with position), not up (as would have been required for the hand to represent speed). So, during gestures 3 and 4, there was a mismatch between speech and hand location and there was a match between his speech and his fingers.

We argue that the combination of hand position and finger separation distance indicates that Anthony was thinking about two ideas at once. We suggest that speech (in this case Anthony's) can readily describe one idea, while the body (in this case hands and fingers) can show multiple ideas at the exact same time.

DISCUSSION

In the instances described above, students were asked to use speech and gesture to convey information relevant to the task they were given, describing the velocity and acceleration of a ball thrown in the air. We find that students conveyed some information with speech alone, some with gesture alone, and some with both speech and gesture. There were both gesture matches and mismatches. From this, we argue that Anthony and Jeff were coordinating multiple ideas as they described the ball toss situation, as shown especially in those moments when they produced gesture-speech mismatches. These ideas might convey different information (talking about position while gesturing about velocity) or they might connect ideas from one sentence and the next (such as describing how forces come together and lead to an acceleration).

Students using both speech and gesture show us that they are thinking about more than one thing at the same time. While speech typically expresses one thought at a time, the hands (and fingers) seemingly allow for complementary thoughts beyond what can be portrayed in speech.

ACKNOWLEDGMENTS

We thank Virginia Flood and Jonathan Shemwell from the University of Maine for their contributions to this paper. The work in this grant was supported in part by the National Science Foundation under Grant DUE 0941191.

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