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Bimanual gestures: Expressions of spatial representations that accompany speech processes

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The present study investigated a possible relationship between gestures and spatial processes underlying speech, with a focus on both unimanual and bimanual gestures. The amount, form, and type of gestures accompanying spontaneous verbal responses were quantified in five conditions that manipulated the degree to which the verbal description required spatial elaboration. Two conditions that required spatial elaboration included describing one's present house or lounge. To assess gestures accompanying temporally ordered events, a third condition required description of one's daily routine. The two remaining conditions assessed time periods associated with the past (describe the house you lived in as a child) and future (describe the house you would like to live in 15–20 years from now). Higher levels of gesture were found in spatial conditions compared to the temporally ordered routine condition for bimanual gestures, and the reverse was found for unimanual gestures. These results are described in terms of a hypothesised link between bimanual gestures and spatial cognition.

When we speak, our hands often move as a non-verbal accompaniment to our verbal expression. The primary focus of gesture research has been on what function, if any, these gestures perform. Some hand movements describe size or shape or the spatial relationship between objects, while others provide emphasis to a particular word or phrase. The prevailing view has been that these movements perform a communicative function, conveying information to the audience rather than a role for the speaker (Kendon, 1988, 1994). This view is supported by evidence that access to the non-verbal channel provides the audience with a greater level of comprehension than access to speech alone (e.g.,

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Graham & Argyle, 1975). Problematic for this view, however, is evidence that these hand movements do not disappear when any possible communication function is removed, such as when the speaker no longer has visual access to the listener (Lickiss & Wellens, 1978; Rimé, 1982). Further support for a non-communicative function derives from studies where restriction of a speaker's hand movement produces an adverse effect on the content and fluency of speech (Rauscher, Krauss, & Chen, 1996; Rimé, Schiaratura, Hupet, & Ghysselinckx, 1984). Rather than entering into this debate, the present study investigated the speech circumstances that are associated with a high fluency of gestural movement of the hands, and the form that these movements tend to take, to explore a possible relation between these movements and spatial cognitive processes.

In particular, we were interested in exploring the incidence of gestures as accompaniments of verbal descriptions that require spatial elaboration. A specific aim was to explore this relationship with respect to bimanual gestures, which have received far less attention in the literature than unimanual gestures. We begin with a brief review of definitions of gesture, including specifications of precisely which forms of gesture are within and outside the scope of our discussion. We then review literature that points to a strong bias to examine and focus on unimanual gestures in relation to speech, leading to the starting point of our own investigation.

Several types of identifiable hand movements occur with speech. The present paper will concentrate on one type: the spontaneous hand and arm movements that co-occur with speech and are related to the speech content in some way (i.e., excluding self-touching movements). Such movements will be referred to as ''gestures'', although these movements have also been referred to as ''object-focused'' (Freedman & Hoffman, 1967), ''free movements'' (Kimura, 1973a, 1973b), ''illustrators'' (Ekman & Friesen, 1969), and ''gesticulations'' (Kendon, 1988) by other authors. Following other studies, determination of whether a hand movement is speech-related is made on a fairly impressionistic basis, based on the perception of a relationship between the meaning or rhythm of the accompanying speech and hand movements that occur in close temporal proximity (Freedman & Hoffman, 1967).

A number of gesture classification schemes exist within the literature (e.g., Efron 1972; Ekman & Friesen, 1969; Freedman & Hoffman, 1967; McNeill, 1985). These schemes are generally in agreement concerning the way in which gestures are grouped into sub-classes of speech-related hand movement, and differ mainly in the terminology used. Generally, a distinction is made between gestures that serve to represent a concept and those that are produced as an emphasis of speech. Some common gesture forms include those in which the hands perform a symbolic function. For example, ''iconics'' express a concept, such as a horseshoe shape drawn in the air by both hands to represent the semi-circular spatial arrangement of chairs at a meeting (McNeill, 1985). Often gestures produced in association with less concrete speech content do not have such a clear link between movement form and the associated speech. McNeill (1992) refers to gestures that represent abstract concepts as ''metaphoric''. Other gestures indicate objects or locations by a point of the finger or an outstretched arm. These ''deictic'' gestures (McNeill, 1985) will be simply referred to as a ''point'' for the present purposes.

Those gestures that are not necessarily symbolic but follow the rhythm of speech and emphasise a word or phrase tend to be simple and repetitive, and do not carry any additional information within their form. Such movements have been referred to as ''batons'' (Ekman & Friesen, 1969), ''punctuating'' movements (Freedman & Hoffman, 1967), ''speech primacy'' movements (Barrosso, Freedman, Grand, & Van Meel (1978), and ''beats'' (McNeill, 1985).

Although gesture and speech are not necessarily temporally or semantically interrelated (Garber & Goldin-Meadow, 2002), often the two modalities convey similar semantic information. According to McNeill (1992), gesture presents meaning globally and as such cannot be broken down into smaller meaningful units. In contrast, speech proceeds in a linear fashion with a hierarchy of components from sentences, to phrases, to words, morphemes, and phonemes. McNeil further asserts that speech conforms to socially learned standards of grammar and syntax, while the hands in gesture are not subject to these standards of form and therefore may be more free to convey meanings that are difficult to express in the speech channel (McNeill, 1992). Although we are not in disagreement with these claims, we also suggest that some categories of gestures might be explicitly linked with other cognitive processes. For example, spatial cognitive processes might underlie certain gesture types, due to the relationship of both gestures and verbal descriptions to the same conceptual systems. Our specific proposal is that bimanual gestures might be predominant accompaniments of spatial descriptions, given that we know from our other research that bimanual actions rely heavily on spatial processes (Franz, 1997) and on spatial representations in particular (Franz & Ramachandran, 1998; Franz, Waldie, & Smith, 2000).

There are some clues in the gesture literature that support this proposed relationship. Stephens (1983, cited in Lausberg & Kita, 2003) reported that verbal narrations that were structured tightly around a global theme were often bimanual, while gestures accompanying lists of events of a story were often unimanual. Similarly, Lausberg and Kita (2003) demonstrated evidence that bimanual gestures occurred with descriptions of spatial relationships.

Accumulating evidence reveals that gestures often accompany spatial descriptions (see Table 1). For example, Lavergne and Kimura (1987) found higher levels of gesture during spatial topics compared to verbal or neutral topics. Neutral topics included a description of the speaker's daily routine, and spatial topics included a description of the arrangement and décor of the speaker's bedroom. The authors suggested that the high level of gesture

TABLE 1
Characteristics of studies demonstrating a relation between gesture level and content of verbal information

Source	*High gesture condition/type of gesture*	*Low gesture condition/type of gesture*	*Condition differences*
Sainsbury and Wood (1977)	Description of living room	Personal relationships	Spatial versus neutral
Barrosso et al. (1978)	Concrete word definition/ Representational	Abstract word definition	Concrete versus abstract
Riseborough (1982)	Descriptions of physical activities, pictures/ Representational	Story-telling	Spatial, visual versus verbal
Lavergne and Kimura (1987)	Description of bedroom	Abstract word definition, daily routine	Spatial versus verbal or neutral

observed in the spatial task was a product of the speakers' ''deliberate'' use of the gesture channel to convey concrete objects and the spatial relationships between them. This suggestion is in line with the position taken by Kendon (1994) who considers that gesture plays a vital role in the communication of meaning. According to Kendon, an individual has the power to choose to convey some meaning verbally and some via gesture.

As mentioned above, the predominant focus of gesture research has been on unimanual gestures, although there are some exceptions. Kimura (1973a) classified the gestures of right-handed speakers according to hand of movement and found that reliably more gestures were performed by the right hand than the left hand. She related this asymmetry to the hemisphere of speech specialisation, based on results of a dichotic listening task. Kimura hypothesised that participants who demonstrated right-hand dominance in gesture were more likely to have speech represented in the left hemisphere. Similar conclusions have been proposed based on other studies of right-handed participants across a variety of speaking situations (e.g., Dalby, Gibson, Grossi, & Schneider, 1980; Glosser, Wiley, & Barnoski, 1998; Lavergne & Kimura, 1987). A demonstrable relationship between bimanual gestures and spatial cognition might pose a challenge to this basic idea, suggesting that gesture handedness is also significantly influenced by factors other than hand dominance or speech lateralisation.

Existing evidence poses some challenge to the basic hypothesis of Kimura. Lavergne and Kimura (1987) investigated unimanual gesture in right-handed participants engaged in speaking about neutral, verbal, and spatial topics. A hemispheric asymmetry was expected on the basis of the spatial versus verbal content, with verbal associated with stronger left hemisphere processing and spatial associated with stronger right hemisphere processing. Contrary to this intriguing possibility, the nature of the task did not appear to affect hemisphere asymmetry in processing. Notably, that study focused on unimanual rather than bimanual gestures.

The few studies that have reported an incidence of bimanual gestures give some gauge of the occurrence of this gesture form. Kimura (1973a, 1973b) reported that bimanual gestures were more prevalent than movements involving the left hand only, but occurred at a lower rate than right-handed movements. In addition, from the data reported in Dalby et al. (1980, Table 1), one can calculate that the overall incidence of bimanual gestures was nearly 25% of the gestures produced by lecturers and students conversing in pairs. In addition, Glosser et al. (1998) reported that almost 50% of all gestures produced by the neurologically normal control participants in their study were bimanual.

McNeill (1992) suggested that the hands coordinate to present a single meaning in symmetrical bimanual gestures, and these gestures do not seem to differ from unimanual gestures in their meaning or function. He further suggested that as with unimanual gestures, symmetrical bimanual movements might be under the control of a single hemisphere, which is likely to be the speech hemisphere (the left in most individuals). A further assertion from the McNeill laboratory is that bimanual gestures that are characterised by differentiated movements tend to be used to depict relationships between objects or ideas (McNeill & Pedelty, 1995). Glosser et al. (1998) classified bimanual gesture according to movement form, and reported that bimanual gestures produced by differentiated movements of the two hands constituted less than 5% of the bimanual category in patients (people with Alzheimer's disease) as well as neurologically normal control participants.

Based on clues from past studies, we hypothesised that bimanual gestures will be found to represent a significant proportion of gestures during speech, and that bimanual gestures will be more predominant than unimanual gestures as accompaniments of speech on topics involving spatial relations. Accordingly, the present experiment examined the amount, form, and type of gesture across five conditions that required descriptive speech. Participants were asked questions that they were to reply to verbally. A one-way mirror was used to record the hand movements that accompanied participants' verbal replies to the series of questions designed to tap different degrees of spatial elaboration, and different demands on memory and imagination. Notably, other research has suggested that due to task difficulty, referring to times other than the present may result in a higher level of gesture (Marcos, 1979; Sainsbury & Wood, 1977). Accordingly, our memory and imagination conditions provided controls for task difficulty.

METHOD

Participants

A total of 22 first-year psychology students from the University of Otago participated as a partial course requirement. Data from 15 were included in the study, with the remainder excluded because of insufficient levels of gesture. Thus, one immediate conclusion from our study is that not all people gesture. Of our sample, 67% of participants met our inclusion criterion of gesturing spontaneously for more than 1% of the total observation period. This criterion was equal to 3 seconds (or 90 frames at 30 frames per second) of speech-related hand movement during the 5-minute observation period. The 15 participants included 3 males and 12 females ranging between 17 and 21 years of age ($M = 19.07$, $SD = 1.18$). Of these, 3 claimed to be left-handed and 12 claimed to be right-handed.

Apparatus

The experiment was conducted in a small room that was adjacent to a control room where an assistant carried out videotaping through a one-way mirror. The participant and experimenter were seated opposite one another in comfortable chairs in the testing room. The participant's chair was at a 45-degree angle to a video camera, which was behind the one-way mirror. This recording angle was chosen because it allowed movement onset to be easily detected (in offline video analysis) without the participant looking squarely at the one-way mirror. The video camera (Sony Video Hi 8 V900E) was focused on the participant's hands in their resting position with sufficient allowance for large bimanual movements. A tape-recorder that was located next to the experimenter's chair recorded the participant's speech. The experimenter used a stopwatch to keep time for each condition during the session.

Conditions

There were five speech conditions labelled ''past-house'', ''present-house'', ''future-house'', ''lounge'', and ''routine''. The first three conditions were to assess speech and gesture measures associated with a verbal description of approximately equal spatial elaboration but with different demands on memory or imagination. The ''past-house'' condition was worded in the form ''please describe the house that you lived in as a child''. If participants lived in more than one house during this period, they were asked to describe the house they had lived in for the longest time. The ''present-house'' condition was phrased ''please describe the flat or house where you live now''. The ''future-house'' condition asked participants to ''please describe the house you would like to be living in, in 15–20 years time''. These three questions were designed to be similar in the level of spatial detail required and differed only in the time period assessed.

A fourth question was included to also elicit responses with spatial detail, but in this case the detail required was thought to be greater than in all the house conditions, given that the subject would be required to home in on a more specific spatial area. This condition, referred to as ‘‘lounge’’, was worded in the form ‘‘please describe the arrangement and décor of your lounge’’. The final question was included to assess gesture and speech associated with a description of an ordered sequence of events, and was more neutral with respect to spatial relations (Lavergne & Kimura, 1987). Thus, the ‘‘routine’’ condition was worded ‘‘please describe your typical university day routine’’.

Digitising equipment

The videotape recorder sampled at a rate of 30 frames per second. A time-clock window was added to videotape recordings to provide a visual read-out time to the nearest frame. A Panasonic television (TC- 21S10M) and a Panasonic Video Cassette Recorder (NV-HD670) were used to view video clips. Video clips were digitised using a Matrox Marvel G200 AGP video card and Matrox Video Tools for Windows 95/98 (version 1.21 04S), and video clips were saved to an AVI file type. Editing and analysis were carried out using Adobe Premiere 5.1 on a workshop-built PC with a K6-2 450 MHz processor, 128 MB RAM, and a 15 Gigabyte hard disk.

Procedure

Upon entering the testing room, the experimenter directed the participant to the chair located opposite the one-way mirror and the hidden video camera. The one-way mirror was not obvious to participants due to the angle of the chair. Participants were informed that the project examined word generation and memory in response to a set of five predetermined questions. Participants were aware that their responses would be tape-recorded, and they could plainly see the audio recorder present in the room. Experimental consent was obtained and participants were informed that they could withdraw from the project at any time.

The experimenter began tape-recording, which gave the assistant in the control room a cue to begin video recording. The experimenter then asked the participant the set of predetermined questions in a randomised order. For each question, the experimenter started the stopwatch and the participant verbally answered the question. After speech had continued for a sufficient period (more than 1 minute) the experimenter signalled the conclusion of the response period to the participant by saying ‘‘thank you’’. The experimenter then asked the next question until all five questions had been asked. The experimenter prompted the participant during the interval of free speech, asking further questions where necessary in order to encourage speech to continue for a full minute. The experimenter did not gesture during the course of the testing session.

Participants were fully debriefed as to the nature and purpose of the study. At this time, participants were informed that their hand gestures had been videotaped, and that they could either request that the videotapes be erased immediately, or give their consent for video data to be included in the study and then erased following the completion of the project. All participants gave their consent for video data to be analysed and included in the study. These and all procedures were in accordance with the ethical guidelines of the University of Otago, Department of Psychology.

Data reduction

Analyses were performed on the first 60 seconds of continuous speech in each condition, excluding major pauses where the participant required prompting. Speech that occurred during this gesture period was fully transcribed for each speech condition for each participant, and a measure of speech fluency was obtained. Speech fluency was defined as the number of words spoken within the gesture period. Abbreviated words such as ''there's'' (there is) were counted as a single word.

Amount of gesture. Arm or hand movements that temporally co-occurred with speech were identified and recorded on transcripts and data analysis sheets. These movements will be referred to as gestures (see Appendix). Self-touching movements were not included in the analysis although they were recorded. Clips were viewed frame-by-frame to determine the onset and offset of each gesture surrounding speech content. The coder viewed each clip as many times as necessary to ensure accuracy with sound being audible during this time. The point at which the hand left a resting position or a change in hand position could be detected was recorded as gesture onset. The point at which hand movement ceased, the hand reached a rest position, or the hand came into contact with the body, was recorded as gesture offset. Amount of gesture was assessed as the duration during which gesture accompanied speech, calculated as the number of frames between these two points. This value was generally expressed in seconds (by dividing the number of frames by 30). We will refer to this as ''amount of gesture during speech''.

Gesture handedness. Gestures were also coded with respect to hand of movement. The stroke or meaningful phase of the gesture follows a preparation phase where the hands get ready to perform the gesture, and precedes the retraction phase where the hands return to a rest position (McNeill, 1992). The classifications were as follows: Unimanual (left-handed or right-handed) or Bimanual (bimanual symmetrical or bimanual differentiated). Unimanual gestures were characterised by movement performed by a single hand (the left or right hand only). Bimanual gestures involved the movement of both hands.

Bimanual symmetrical gestures were defined as those gestures in which the left and right hands moved with (approximate) mirror symmetry with respect to the body midline. Bimanual differentiated gestures were defined as gestures with both hands moving at the same time, but with different movement patterns produced by each.

Gesture type. Gesture type was coded according to the following classifications, developed using a combination of McNeill (1992), Ekman and Friesen (1969; which were adapted from Efron, 1972), and Freedman and Hoffman's (1967) gesture coding systems, as outlined earlier. Referring to the Appendix, concrete representational gestures were those in which the hands described a concrete idea, for example, the size or shape of an object, or depicted a spatial relationship. Abstract gestures were those that accompanied more abstract forms of speech, for example those coinciding with the words ''it was'' or ''even though''. Point gestures were those that consisted of pointing movements indicating an object or place. These tended to be carried out by the index finger or an outstretched arm. Some classification schemes refer to concrete, abstract, and point gestures as representational because they tend to accompany descriptions of objects, spatial relationships, or concrete ideas.

Non-representational (beat) gestures refers to those that emphasised the word or phrase they accompanied, without providing additional information. For example, beats usually take the form of small upward and downward movements (see McNeill, 1992). Occasions where a word replacement or change in sentence structure occurred within the gesture duration (i.e., between the onset and offset marker) are referred to as correction movements. Gestures where a pause in speech occurred within the gesture duration were coded as speech hesitations. This pause in speech could be either filled (i.e., verbal) or unfilled. Prompting gestures refers to when the gesture seemed to correspond with the effort to recall a word, e.g., grasping at the air, or a clicking of the fingers.

Design

A within-subjects design was employed. The independent variable was speech condition, of which there were five types (past-house, present-house, future-house, lounge, and routine). The order of condition was randomised across participants. Movement type (left-hand, right-hand, bimanual symmetrical, and bimanual differentiated) was coded from digitised video footage. Gestures were also coded according to gesture type (concrete, abstract, point, beat, speech hesitation, correction, and prompt).

A univariate repeated measures ANOVA was employed unless otherwise specified. Two primary analyses were of interest. To analyse effects of speech condition on movement type, a 5×4 repeated measures ANOVA was employed. To analyse effects of speech condition on gesture type, a 5×7

repeated measures ANOVA was employed. More specific analyses were also performed. A 5 × 2 (speech condition × unimanual gesture) repeated measures ANOVA was employed using data from the 12 right-handed participants (out of the total 15 participants) to assess whether asymmetry of unimanual gestures was present. In addition, a single factor ANOVA assessed the reliability of speech fluency (number of words per minute) for each condition. Analyses were also employed with the number of words accompanying each gesture bout as the dependent variable. An alpha level of .05 was used to assess statistical significance for all tests. Greenhouse-Geisser corrected probabilities and their associated reduced degrees of freedom, are reported to the nearest integer for all main effects and interactions. Where data transformations were necessary, these are described preceding each set of analyses. Planned contrasts were utilised to examine main effects. *SD* and *M* indicate untransformed standard deviation and mean values in parentheses, to the nearest decimal place. Error bars on figures indicate standard error of the means.

RESULTS

Reliability

A random selection of 20% of the video clips was coded independently by a second observer in order to generate a measure of interrater reliability. The reliability coder studied the category definitions but was otherwise naïve to the aims and hypotheses of the study. Agreement between coders was 98% (n = 15) for gesture duration (amount of gesturing accompanying speech), 94% (n = 20) for movement type, and 71% (n = 56) for gesture type. Generally differences between the two coders in assignment of gesture type were in coding abstract versus beat gestures. Of note, prior to debriefing no participant suspected that gesture was the variable of interest.

Speech conditions

Gesture duration data for each speech condition was transformed using a logarithmic [(log $(\times+1)$] transformation, because means and standard errors were found to be significantly correlated. Following this procedure, normality of residuals was found to be reasonable. Figure 1 presents the mean gesture duration in seconds for each speech condition collapsed across the movement types.

Amount of gesturing during speech revealed significant differences across the five speech conditions, $F(3, 39) = 13.46$, $p < .001$. Amount of gesture during speech output ranged from 8.6% of the gesture period in the lounge condition to 2.3% in the routine condition on average. As shown in Figure 1, a significantly lower level of gesture was produced when participants described their daily routine compared to other conditions, $F(1, 14) = 17.09$, $p = .001$. In addition, a

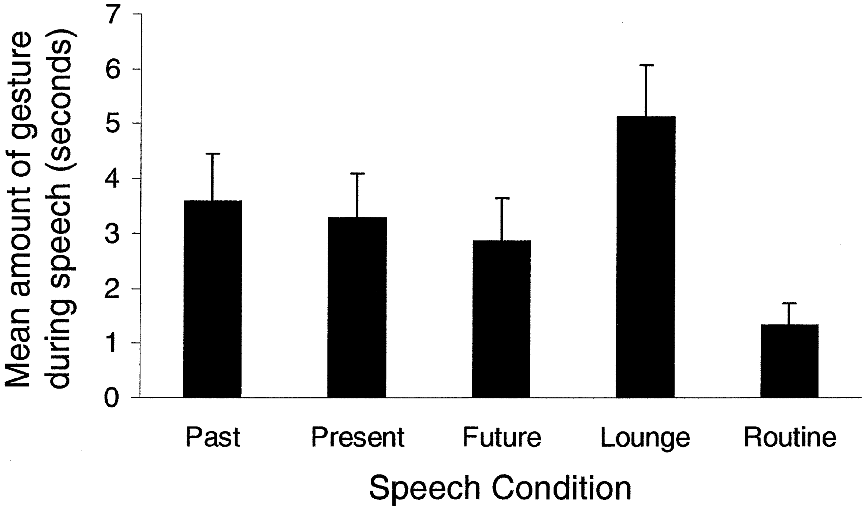

Figure 1. Mean amount (duration) of co-speech gesture and standard errors for each speech condition.

higher level of gesture occurred in response to the lounge condition compared to the other conditions, $F(1, 14) = 86.25$, $p < .001$.

To more thoroughly examine the proposed relationship between spatial elaboration and gesture level, we analysed the three conditions that examined the present time but differed in level of spatial elaboration (lounge, present-house, routine). A higher level of gesture was produced in the lounge condition (highly spatial) compared to the present-house condition (moderately spatial), $F(1, 14) = 10.14$, $p = .007$, and in the present-house condition compared to the routine (spatially neutral) condition, $F(1, 14) = 8.19$, $p = .013$. These findings are generally consistent with reports from earlier laboratories which have suggested that level of gesturing increases with elaboration of spatial detail (see earlier).

To examine the novel issue of whether demands on memory or imagination are related to the level of gesturing produced, we directly compared the past-house, present-house, and future-house conditions only. This comparison revealed no reliable difference in amount of gesture for the three time periods $F(2, 28) = 1.13$, $p = .336$. As these results suggest, task difficulty associated with the different temporal memory or imagination demands is not the critical issue in determining gesture amount during speech.

Unimanual versus bimanual gestures

Figure 2 presents the amount of gesturing during speech (mean gesture duration) collapsed across all speech conditions for each movement type. When considering the bimanual symmetrical and bimanual differentiated categories

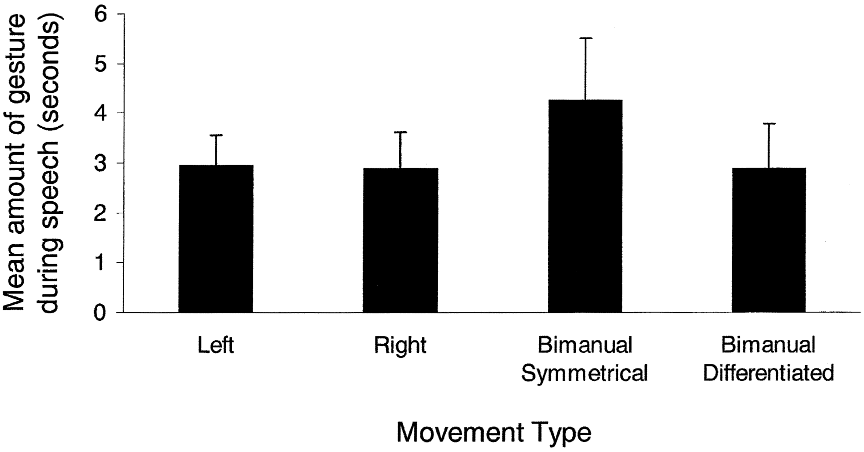

Figure 2. Mean amount (duration) of gesture and standard errors for unimanual left, unimanual right, bimanual symmetrical, and bimanual differentiated movement types across all speech conditions.

separately (in comparison to the other two unimanual conditions), no significant effects of movement type or interactions between movement type and speech condition were found, $F(2, 31) = 0.95$, $p = .427$ and $F(6, 83) = 1.53$, $p = .118$. However, when considering the two types of bimanual gestures combined, it was clear that the amount of bimanual gesturing during speech was larger than the amount of unimanual gesturing during speech (Bimanual: $M = 3.6$, $SD = 5.3$ s, Unimanual: $M = 2.9$, $SD = 3.9$ s: $p < .05$ on post hoc comparison). The mean duration of bimanual gesture (55%) was 10% higher than the mean of both unimanual gesture categories combined (45%). As can be seen in Figure 2, bimanual symmetrical gestures represented the most common movement type, comprising approximately 60% of the total bimanual gestures ($M = 4.3$, $SD = 6.0$ s). The total amount (again, measured in duration) of left-handed, right-handed, and bimanual differentiated gestures was very similar across these three types (Left: $M = 3.0$, $SD = 3.8$ s, Right: $M = 2.9$, $SD = 4.0$ s, Bimanual differentiated: $M = 2.9$, $SD = 4.4$ s). Bimanual symmetrical gesture accounted for almost 33% of the total measured duration of time gesturing during speech, while the other movement categories accounted for approximately 22% each.

Movement type versus speech condition

Figure 3 presents the mean proportion of gestures classified into each movement type, for each of the speech conditions. Bimanual symmetrical gestures represented the most common movement type in all but the routine condition. In the routine condition, bimanual symmetrical gestures occurred at a much lower level, with a corresponding increase in the incidence of both left- and right-

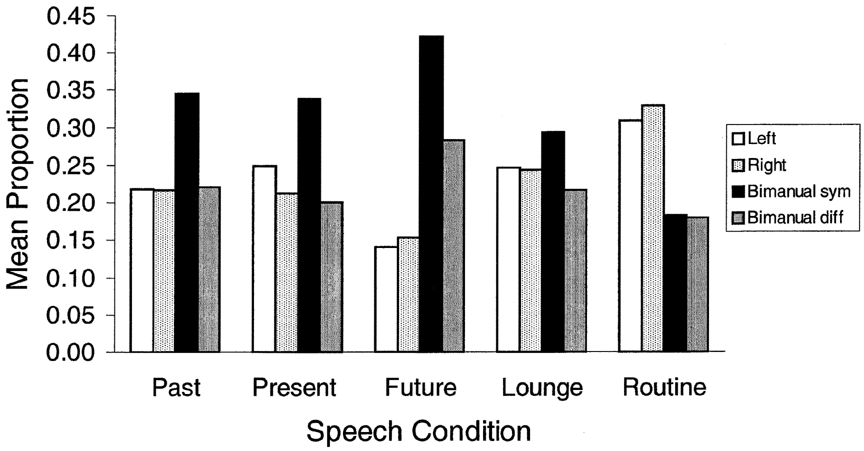

Figure 3. Mean gesture proportion according to speech condition for unimanual left, unimanual right, bimanual symmetrical, and bimanual differentiated movement types.

handed unimanual gestures. In the future-house condition, unimanual gestures occurred at a reduced rate, and large proportions of both bimanual symmetrical and bimanual differentiated gestures were observed. In the lounge condition, the four gesture types were similar in their incidence. These qualitative observations were all verified statistically in post hoc tests (all $p < .05$). It is of interest, specifically, that the amount of bimanual symmetrical gestures was largest in the future-house condition, in which one might argue that the highest demands on spatial imagination are required.

Right–left asymmetry

Data from right-handed participants were considered separately to more closely evaluate claims in the literature that are based solely on right-handers (see earlier). Table 2 presents the mean duration for unimanual left- and right-handed gestures for right-handed participants and the asymmetry values for each condition ($n = 12$). Asymmetry values were calculated by subtracting the duration of time spent gesturing with the left hand from the duration of time spent gesturing with the right hand on all unimanual gesture bouts. Accordingly, a positive value indicates that the duration during which right-hand gestures were produced exceeded the duration during which left-hand gestures were produced (right-hand asymmetry), and a negative value indicates that left-hand gestures exceeded right (left-hand asymmetry). As shown in Table 2, right-hand gestures exceeded left-hand gestures in all but the routine condition where a left-hand asymmetry was found. The largest asymmetry in unimanual gestures was found in the future-house condition, with right-handed gestures exceeding left by 1.3

TABLE 2
Mean right–left asymmetry, and mean gesture duration in seconds for the past-house, present-house, future-house, lounge, and routine conditions for the 12 right-handed participants

Hand of gesture	*Gesture amount expressed as mean duration (seconds)*					
	Past	*Present*	*Future*	*Lounge*	*Routine*	*Overall mean*
Left-handed	2.78	2.24	0.94	4.19	1.47	2.32
Right-handed	3.91	2.85	2.19	5.49	1.31	3.15
Asymmetry (R–L)	1.13	0.61	1.26	1.31	−0.16	0.83

seconds on average. Despite these observations, due to large variability, there were no statistically significant differences in gesture duration between the left and right hands, $F(1, 11) = 1.95$, $p = .190$, and speech condition did not significantly interact with the unimanual mode (left or right hand), $F(3, 37) = 0.287$, $p = .885$. Thus, although the trend in our data is in the same direction as results by other laboratories (Dalby et al., 1980; Glosser et al., 1998; Kimura, 1973a, 1973b; Lavergne & Kimura, 1987), these effects were not significant in our study. Note that due to the small number of left-handers, meaningful comparisons could not be performed between handedness groups.

Amount of gestures for the different classified types

The amount of gesturing during speech (as measured by duration) was first transformed using a square-root transformation [sqrt (X+1)]. This transformation stabilised data to approximate normality of residuals. As reported earlier, there was a highly significant main effect of speech condition on gesture type, and all contrasts remain unchanged by the transformation. Mean gesture duration in seconds for all gesture types collapsed across speech condition is shown in Figure 4.

The amount of gesturing during speech differed for the different gesture types, with the majority of gestures falling into some category of representational, (57% of the total), $F(3, 41) = 15.58$, $p < .001$. Of the total duration of representational gestures, an astounding 75% of time spent gesturing involved concrete gestures, and significantly less time involved production of abstract gestures, $F(1, 14) = 37.82$, $p < .001$. Beats constituted the second highest category (28%) of the total gesture amount, with significantly less gesturing time spent on beat gestures than concrete gestures, $F(1, 14) = 5.65$, $p = .032$. Point gestures accounted for 7% of the total classified gesture period. Gestures that were associated with a hesitation during speech accounted for 8% of the total gesture duration accompanying speech, which was significantly less total time during speech than for beat gestures, $F(1, 14) = 18.19$, $p = .001$. The

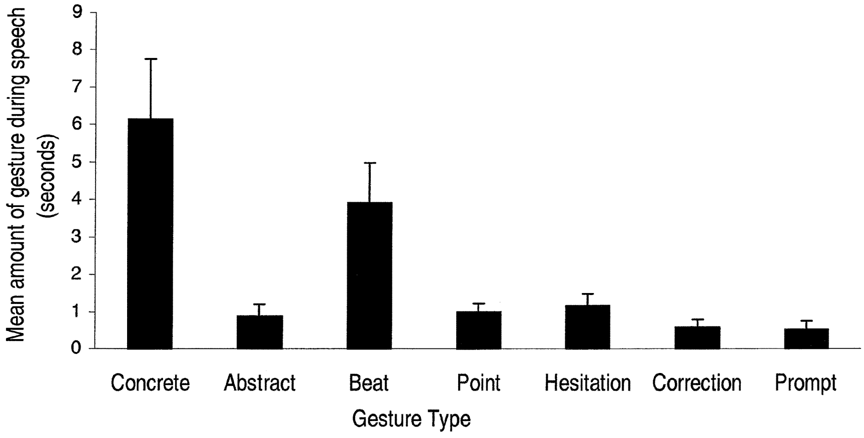

Figure 4. Mean amount (duration) of gesture and standard error for each gesture type.

occurrence of correction and prompting movements was relatively low, each accounting for approximately 4% of classified gesture duration.

Relationship between speech condition and gesture type

The incidence of gesture type differed significantly across speech conditions, $F(7, 95) = 4.85$, $p < .001$. Figure 5 presents the mean proportion of total gesture across each speech condition, for the four types of gesture that were primarily meaningful with respect to spontaneous speech content (concrete, abstract, beat, and point). Deviation contrasts revealed the following meaningful and significant interactions between gesture type and speech condition: A greater occurrence of concrete representational gestures was observed on average in the past-house condition relative to the other conditions, $F(1, 14) = 5.13$, $p = .040$. Significantly fewer point gestures were observed on average in the future-house condition compared to other conditions, $F(1, 14) = 15.33$, $p = .002$. Gestures in the highly spatial lounge condition comprised a larger proportion of concrete representational gestures compared to other types, $F(1, 14) = 19.73$, $p = .001$. Comparatively few abstract representative gestures were observed in the lounge condition compared to the other types, $F(1, 14) = 18.92$, $p < .001$. The routine condition produced a significantly lower incidence of correction and prompting gestures compared to the other types combined, $F(1, 14) = 9.88$, $p = .007$ and $F(1, 14) = 5.72$, $p = .031$, (not shown in the figure due to the low level of occurrence overall).

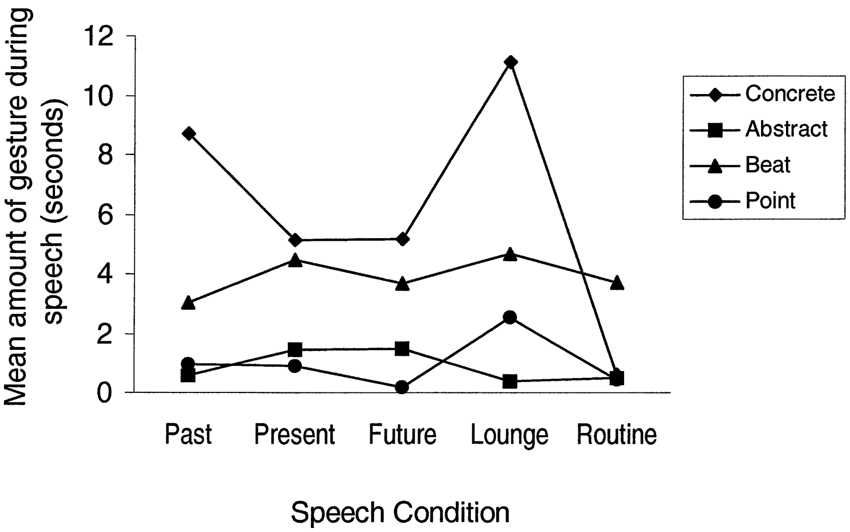

Figure 5. Mean amount (duration) of gesture for each of four common gesture types (concrete, abstract, beat, and point) in each speech condition.

Speech fluency

Mean overall speech fluency values for each speech condition are shown in Figure 6. Speech fluency rates were not found to differ significantly across the five conditions, $F(3, 37) = 1.73$, $p = .156$. These findings are important because they suggest that the baseline amount of speech was not reliably different across the speech conditions. Therefore, findings related to gesture amount or speech amount during the time in which gesture accompanied speech, were not related to or determined by the overall amount of speech that comprised the verbal answers. Although the average speech fluency appeared to be smaller in the future-house condition compared to the others, even this effect did not reach statistical levels of significance ($p > .17$).

Amount of speech and gesture level

Gesture level in each speech condition was analysed according to the amount of speech that occurred during the duration of gesturing. The total duration of speech-related gesture in each speech condition was divided by the number of words produced within that same time interval, to produce a normalised score for each condition. In short, the pattern of results from these analyses was no different from that found when gesture amount was considered alone. Therefore, considering the amount of speech did not alter the results based on the overall amount of gesture accompanying speech.

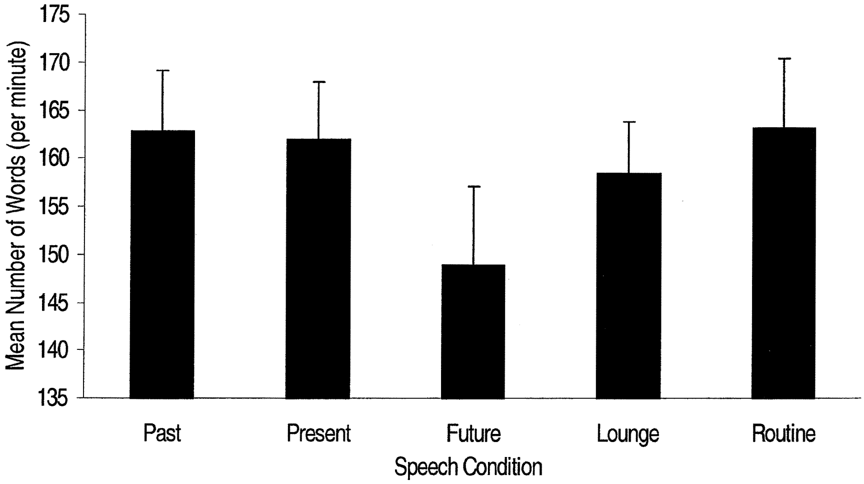

Figure 6. Mean speech fluency value (and standard error) for each speech condition.

Number of words and movement type

The number of words accompanying gestures was transformed using a logarithmic transformation to produce a reasonable normality of residuals in the data set. The number of words accompanied by gesture differed significantly across speech condition, $F(3, 35) = 13.23$, $p < .001$. Significantly fewer words accompanied gesture in the routine condition compared to the other conditions combined, $F(1, 14) = 13.09$, $p = .003$, and significantly more words were accompanied by gesture in the lounge condition compared to the other conditions combined, $F(1, 14) = 81.60, p < .001$. The (highly spatial) lounge condition produced a significantly larger number of words accompanied by gesture than the present-house spatial condition, $F(1, 14) = 15.07$, $p = .002$. The number of words accompanying gesture for the past-, present-, and future-house conditions did not differ significantly, all $F(1, 14) < 2.0, p > .05$, also paralleling the effects on gesture amount. The fact that the effects are similar whether measuring gesture duration or number of words during the gesture–speech bout suggests that gesture duration during speech (which is the easier of the two measures to quantify) is sufficient as a measure of amount of gesturing.

Individual differences

Figure 7 depicts mean percentage of the gesture period in which gesture accompanied speech, for each participant ranked in order from lowest to highest gesture level. There were large individual differences in the amount of gesture produced, with the percentage ranging between 1.12% and 60.82% of the observation period. Thus, in addition to the finding that approximately 30% of

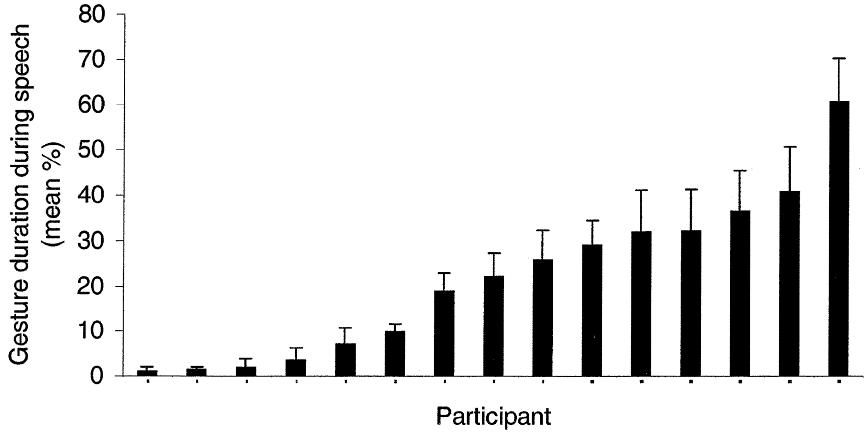

Figure 7. Mean percentage of gesture period (and standard error) spent in speech-related gesture for each participant.

tested individuals gestured infrequently or not at all (see Method), there was a wide range of gesture amount accompanying speech across participants who did gesture.

DISCUSSION

The present experiment examined gesture occurrence across a number of speech conditions that differed according to the level of spatial elaboration typically required in a response, and also in the memory or imagination demands. A primary finding was that gesture level differed significantly across the three speech conditions that assessed the present time. From these findings, we infer that there exists a relationship between observed gesture level and the degree to which a verbal description depended on spatial cognitive processes. We further verified from the videotapes that the spatial content of the speech output was clearly larger in the spatial conditions (lounge, present-, past-, and future-house) than in the non-spatial routine condition. A second finding of primary interest was that bimanual gestures accounted for more than half of classified gestures accompanying speech, with bimanual symmetrical gestures being the most highly represented movement type across four of the five conditions (all except the routine condition).

Also of primary interest, the highest overall level of gesture was observed in the highly-spatial lounge condition. An intermediate level of gesture was produced in the spatial condition in which participants described their present house or flat. The lowest gesture level was observed when participants described their daily routine. These results provide strong support for the hypothesised relationship between gestures and the spatial representations underlying speech output, consistent with earlier reports (e.g., Barrosso et al., 1978; Lavergne & Kimura, 1987; Riseborough, 1982; Sainsbury & Wood, 1977).

The present findings are consistent with recent models according to which gesture originates in activated non-propositional representations in working memory (e.g., Morrel-Samuels & Krauss, 1992; Rauscher et al., 1996). One proposal in the literature is that gesture occurrence is linked to the ''translation'' process that allows information in a non-propositional format to be expressed in speech. Riseborough (1982, p. 502) hypothesised that gesture occurs when there is a ''discrepancy between the units of thought and units of speech''. Accordingly, information stored in a spatial format will require translation into a verbal format and this translation may be associated with gesture production. This ''discrepancy'' hypothesis is similar to recent models relating the occurrence of gesture to the activation of different types of representations in working memory during the speech production process (e.g., Morrel-Samuels & Krauss, 1992; Rauscher et al., 1996). According to Krauss and Hadar (1999), gesture originates in the memory representations that are activated in short-term memory *prior* to the formulation of the meaning that is to be conveyed in speech.

A non-propositional representation may be a more appropriate format for the storage of complex information that would otherwise create a drain on processing resources when stored in the uneconomical propositional format. According to this model, and Riseborough's ''discrepancy'' hypothesis (1982), gesture is more likely to occur when the format of a representation to be verbalised differs from the format of speech, as in the present and lounge conditions.

Bimanual gesture

Our purpose was primarily to quantify the incidence of bimanual gestures to examine the novel hypothesis that bimanual gestures generally accompany forms of verbal information that rely on spatial cognitive processes. Movements employing the use of both hands (bimanual gesture) accounted for 55% of all gestures, exceeding the total occurrence of unimanual gesture by 10%. Of these bimanual gestures, approximately 60% were classified as bimanual symmetrical, in which the movements of the two hands were approximately symmetrical across the body midline. Bimanual movements therefore represented an appreciable category of gesture, with the majority being symmetrical in form, as predicted based on findings from Glosser et al. (1998).

The bimanual symmetrical category accounted for the largest proportion of gesture in all but the routine condition, where a relative increase in the incidence of unimanual gesture occurred. The largest difference in the occurrence of bimanual and unimanual gesture was found in the future-house condition, with bimanual gesture occurring at significantly higher levels than unimanual. When participants described their daily routines, bimanual gestures were observed at a much-reduced rate and an increase in the proportion of unimanual gestures was observed. This dissociation between bimanual and unimanual gesture occurrence in relation to the speech condition was rather striking. Clearly, gesture handedness and gesture type are most likely not completely independent factors, given that certain gesture types (i.e., point) tend to be performed unimanually, and others such as concrete iconics are often bimanual (Lausberg & Kita, 2003). However, our findings strongly suggest that other cognitive factors (such as spatial cognitive processes) mediate gesture performance. Of course, we cannot rule out the possibility that increasing levels of effort bring about increased levels of bimanual gestures, however, our results on the memory and imagination conditions do not support a significant role of task difficulty.

According to McNeill (1992), symmetrical bimanual movements do not differ from unimanual gesture in terms of their function. However, our results suggest that events ordered in time, such as one's daily routine, may tend to elicit unimanual gestures, whereas imagination may elicit bimanual gestures. We speculate that forms of imagination draw specifically on spatial cognitive processes that may differ from those cognitive processes that are used when remembering and/or articulating temporally ordered events such as those in the routine condition. These findings extend suggestions of earlier reports that bimanual gestures might accompany verbal descriptions of global themes or spatial relationships, whereas unimanual gestures tend to occur when articulating sequential lists of events (Stephens, 1983, cited in Lausberg & Kita, 2003).

Individual differences

Of our initial sample, approximately one third of participants did not perform enough gesture during speech to satisfy our relatively relaxed inclusion criterion. Thus, some people simply do not seem to produce many spontaneous gestures during speech. Consistent with previous findings (Sainsbury & Wood, 1977) participants varied widely in the amount of gesture produced, and each participant was relatively stable in the level of gesture produced across conditions.

Iverson (1999) found that the content of route descriptions of gesturing participants differed from that of non-gesturing participants. Those who gestured were more likely to convey direction and location information than non-gesturers whose descriptions included more information about landmarks. Descriptions of participants who did not gesture were ''segmented'' into a series of landmarks, in comparison with gesturing children who produced a ''global'' path description. As these findings suggest, individual differences in gesturing might also point to individual differences in cognitive processes associated with spatial representation.

Summary and conclusions

In the present study, bimanual movements accounted for more than half of the gestures that accompanied speech. Observing this strikingly large amount of bimanual gestures illuminates the importance of studying the cognitive processes that might mediate gesture production of not only one hand, but also both hands together. Of the bimanual gestures, symmetrical ones were the most prevalent, and these tended to accompany verbal descriptions of spatial layouts but not descriptions of daily routines. In contrast, unimanual gestures were the most prevalent accompaniments of verbal descriptions of daily routines (Figure 3). These findings pose some challenges to any general claim that right-handers (who primarily have left hemisphere speech production) prefer the right hand for gestures that accompany speech. Rather, the present findings suggest that gesture handedness is also influenced by cognitive factors other than handedness or speech lateralisation. An additional finding is that most gestures were of the concrete representational type (Figure 4) and virtually no concrete representational gestures were found in the routine condition (Figure 5). Collectively, these findings support the hypothesis that gestures (particularly bimanual symmetrical gestures) might be expressions of specific cognitive systems. We propose that the presence of bimanual gestures might reveal important insight into the processes of spatial cognition.

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APPENDIX

Gesture function: What purpose does the gesture seem to be serving? In order to classify the gesture, take both the meaning of the accompanying speech and gesture form into account.

Functional categories

Concrete: the hands describe or depict a concrete idea, e.g., size or shape of an object, or may depict a spatial relationship. There is a close similarity between the form of the gesture and the meaning of the accompanying speech.
Abstract: the gesture presents an abstract idea. The content of the gesture is invisible, e.g., a gesture coinciding with the words ''it was'' or ''even though''.
Point: the gesture is a pointing movement that indicates an object or place. Usually carried out by the index finger or hand. At a more abstract level may indicate direction or location.
Beat: the word or phrase the gesture accompanies is given significance. Form does not provide *any* additional information. Usually takes the form of a small upward and downward movement or wrist rotation (also called ''Beats'').
Hesitation: a pause in speech occurs within the gesture duration (between the onset and offset marker). Pause may be filled, i.e., ''um'', ''ah'', or unfilled (silent).
Correction: a word is replaced or sentence structure changed within the gesture duration (between the onset and offset marker).
Prompt: gesture seems to correspond with the effort to recall a word, (i.e., grasping at the air, clicking the fingers). Gesture coincides with speech failure or difficulty.