The authors investigate the effects of stuttering on gesture and find that during bouts of stuttering the coexpressed gesture always waits for fluent speech to resume. The net effect is that gesture maintains temporal synchronization with speech.

What Stuttering Reveals About the Development of the Gesture-Speech Relationship

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Humans have gestured from the first moment they began to speak, if not from long before (Armstrong, Stokoe, and Wilcox, 1995). Despite the ancientness of the link between gesture and speech, it remains mysterious. In particular, the degree to which gesture and speech form separate (as opposed to integrated) communication systems is not well understood. Do gesture and speech constitute two independent streams of communication, each with different functions and structures? Or do gesture and speech form a single stream of communication with one function and structure? Much of the available research on the nature of gesture comes from investigations of gesture as a sole means of communication, in the absence of speech. Such work has found that in the absence of speech gesture takes on all the functions and structures normally carried by speech. This is shown by the gesture invention of deaf children (Goldin-Meadow and Mylander, 1984; Chapter Seven) and by the related phenomena of sign language creation and its cross-generational acquisition by deaf children worldwide (Chamberlain, Morford, and Mayberry, forthcoming; Padden and Humphries, 1988). Thus there is indisputable evidence that gesture has the potential to function in place of speech (Goldin-Meadow, McNeill,

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and Singleton, 1996). By contrast, in this chapter we consider cases in which speech is always present as a primary means of communication but, at the same time, is highly disrupted. The question we have been investigating is what happens to gesture in the case of chronic stuttering. We have discovered that a great deal happens to gesture in such cases, which points to the existence of an underlying organizing principle of cotemporality in spontaneous gesture-speech expression (see Chapter One).

We began our work with the hypothesis that gesture might compensate for difficulty in speech expression, based on our knowledge of how gesture takes on the full range of functions and structures of speech in the absence of speech. Observation of our first subject who stuttered, however, quickly convinced us that this hypothesis was wrong. The subject, a man who had suffered from severe stuttering all his life, produced a spontaneous narration elicited by an animated cartoon. His stuttering had the effect of frequently interrupting and sometimes completely halting his speech expression. Some of his stuttering blocks lasted for many seconds, and throughout these blocks he never executed a single gesture. Instead, if he were initiating a gesture when stuttering began, his hand would stop in midair and remain frozen there until the moment when fluent speech resumed, at which point he would complete the gesture. The phenomenon we observed was not due to any inability on the subject's part to move his hands, during stuttering or otherwise. He would easily move his hand while stuttering to scratch his neck or head. Something else was going on: the timing of this man's gestural expression was cemented to the timing of his vocal expression, even though his speech was horribly interrupted by stuttering.

Indeed, this persistent coexpression of gesture with speech is the major feature we have discovered that characterizes the gesture-speech relationship in chronic stutterers. The discovery provides compelling evidence that gesture and speech are deeply and intricately integrated during the act of speaking spontaneously (Mayberry, Jaques, and Shenker, 1997; Mayberry and Shenker, 1997; Scoble, 1993). Before describing the studies that led to this discovery, it is important to contextualize them by briefly describing the speech disorder known as stuttering.

A Typology of Speech Disfluency

All speakers are occasionally disfluent when speaking. For this reason it is important to distinguish between two kinds of speech disfluencies. The most common type consists of word and phrase repetitions, phrase and word revisions, and pauses and fillers, such as "um," "yeah," or "uh." This kind of disfluency is termed normal because it is a common element in all speakers' spontaneous speech. Note that word production is left intact during normal disfluencies. By contrast, stuttering disfluencies break up word production with initial phoneme or syllable repetitions, voiced or voiceless sound prolongations, or both. Research has shown that untrained listeners identify stuttered speech in terms of the presence and frequency of such disfluencies, not the normal ones as we have defined them here (Lewis, 1991).

A noticeable amount of stuttered disfluencies in the speech of a child or adult is called stuttering. Stuttering is a speech disorder of unknown etiology that affects approximately 1 percent of the population. It usually begins in childhood, with gradual onset between the ages of two and five. Eighty percent of children who stutter eventually stop stuttering spontaneously (Bloodstein, 1993). Stuttering appears to have a significant genetic component (Smith, 1990), because it is sex-linked, affecting more males than females (at a ratio of three to one), and tends to run in families.

From a psycholinguistic standpoint, it is important to know that stuttering does not appear randomly in the speech stream. To the contrary, research has shown that instances of stuttering show a highly systematic relationship to the structure of speech. First phonemes and syllables of words are most likely to be stuttered, as are the first words of sentences and clauses. Content words are far more likely to be stuttered than closed-class words (Wingate, 1988). The patterning of stuttering with the structure of speech is believed to reflect neurolinguistic and motor planning. The beginnings of sentences, clauses, and phrases are where demands on language planning are the greatest. In addition to the psycholinguistic planning, the central nervous system must also simultaneously coordinate the oral-motor, laryngeal, and respiratory patterns required to execute speech.

The manual gestures of individuals who stutter have not been studied previously. This may be due to the fact that gesture has traditionally been thought of as separate from speech and hence unrelated to the disorder of stuttering. Two studies investigated the effects of stuttering on what was called "nonspeech behavior," or, more specifically, head, eye, and lip movements during fluent versus stuttered speech (Schwartz, Zebrowski, and Conture, 1990). Conture and Kelly (1991) noted that the hand of one subject who stuttered froze in midair in association with a stuttering block, but they gave no details on this observation. Their observation presaged our primary discovery, which we discuss later in the chapter after describing the two most widely held theories about the nature of the gesture-speech relationship.

Hypotheses About the Nature of the Gesture-Speech Relationship

The links between gesture and speech during spontaneous expression are only beginning to be studied and described. There are currently two competing hypotheses concerning how gesture is tied to speech. One hypothesis is that gesture and speech are separate communication systems and that the links that exist between the two modes are governed by the requirements of speech expression (Butterworth and Beattie, 1978; Butterworth and Hadar, 1989; Feyereisen, 1997; Feyereisen and deLannoy, 1991; Levelt, Richardson, and La Heij, 1985). The "independent systems" hypothesis holds that gesture is an

auxiliary system with respect to speech and that it functions as an aid to speech during temporary or sporadic failures, such as when coughing, having a mouth full of food, or being unable to put words to thoughts. Note that this hypothesis requires that there be feedback links to gesture from speech. The implication of this hypothesis is that speech must stumble or fail for gesture to appear. This hypothesis predicts that gestures will appear more frequently in stuttered versus fluent speech, since stuttered speech is characterized by frequent failures in speech execution.

An alternative hypothesis is that gesture and speech form an integrated system that functions as a single communication stream (Kendon, 1975, 1980; McNeill, 1985, 1992, Chapter One; Morrel-Samuels and Krauss, 1992; Rauscher, Krauss, and Chen, 1996). According to this framework, gesture has multiple links to speech. These links are in the psycholinguistic domains of discourse structure, grammatical structure, lexical structure, and prosody. Gesture and speech are posited to co-occur during spontaneous expression because both convey different aspects of the same message or thought (McNeill, 1985). In contrast to the predictions of the independent systems hypothesis, the "integration" hypothesis predicts that stuttered speech will be accompanied by fewer gestures than fluent speech because gesture and speech form a single system. The prediction is that when speech is attenuated or disrupted by stuttering, gesture will be attenuated or disrupted as well.

We turned to the speech disorder of stuttering to help shed light on this question (Mayberry, Jaques, and Shenker, 1997; Mayberry and Shenker, 1997; Scoble, 1993). From an experimental standpoint, stuttering gives us the opportunity to observe gesture production when the production of speech is subject to frequent disruptions of varying durations. If gesture and speech form an integrated system, then gesture should be disrupted along with stuttered speech. Alternatively, if the links between gesture and speech are illusory, stemming from the fact that the two express similar meanings at the same time, then gesture should break away from speech when the latter is slowed or stopped by stuttering. We conducted two experiments to test these predictions, one with adults and one with children.

Gesture Production During Fluent and Disfluent Speech

The procedure throughout our studies was to test each subject individually. After explaining that we wished the subject to narrate the events depicted in an animated cartoon in detail to someone who has not seen the cartoon, we showed the subject one cartoon segment. We then asked the subject to narrate its content to an unfamiliar and neutral listener. By neutral we mean that the listener would make no comments other than, "anything else?" and would produce no gesture himself. We repeated the protocol two additional times, until the subject had seen and narrated the entire cartoon. We videotaped the subject's narration for later transcription.

Using this procedure we collected spontaneous gesture-speech samples from twelve English-speaking adults. Six subjects were chronic stutterers who had childhood onset of the disorder. The severity of their stuttering ranged from mild (5 percent or less of words stuttered) to severe (10 percent or more of words stuttered). Six control subjects with no history of stuttering were matched by age, sex, and highest level of education to the subjects who stuttered. We transcribed and coded each subject's videotaped sample for gestures, speech, and the temporal correspondence between the two, always in the same order and fashion for all subjects.

Speech Results. Analyzing the subjects' speech disfluencies, we found, as expected, that the main difference between the two groups was the frequency with which they produced stuttered disfluencies. There were no differences between the two groups with respect to the amount of normal disfluencies they produced while narrating the events of the cartoon.

The narration task was open-ended, which means that the subjects could speak for as long as they wished. Nevertheless, there was a strong effect of stuttering on the length, complexity, and content of the subjects' spoken narrations. The control subjects expressed on average 35 percent more words in 50 percent less time than did the subjects who stuttered. These findings underscore the difficulty chronic stuttering poses for speaking spontaneously. The subjects who stuttered truncated their narratives in the following fashion. First, there was a negative correlation between the frequency of stuttering and the richness of narrative detail and complexity of sentence structure. Thus, compared to the controls, the subjects who stuttered tended to give fewer narrative details, with fewer clauses and simpler sentence structures (specifically, less subordination and complementation). However, the subjects who stuttered required much more time than the fluent controls to complete their narrations, due to the frequent speech interruptions caused by their stuttering.

Gesture Results. The subjects who stuttered produced half the number of gestures produced by the fluent controls, with an average of 152 total gestures for the control subjects and only 82 gestures for the subjects who stuttered. Importantly, however, the attenuated gesture production we observed in association with stuttering was not a simple function of less speech being uttered by the subjects who stuttered. This was apparent when we measured the proportion of words the subjects spoke that were simultaneously coexpressed with gesture.

The fluent controls accompanied 78 percent of their spoken words with gestures, whereas the subjects who stuttered accompanied only 30 percent of their words with gestures. This difference in gesture production between the groups was also reflected in the amount of time that they gestured, or, put another way, the amount of time that the subjects' hands were in the air while speaking. The control group gestured for 70 percent of the total time they spoke, whereas the group who stuttered gestured for only 20 percent of the time they spoke.

Thus we can see that the speech disruptions caused by stuttering have several effects on gesture-speech expression. First, there is an attenuating effect on speech expression in terms of the linguistic content and structure of the spoken portion of the message: less is said in simpler sentences and over a longer period of time than is typical of fluent speech. Simultaneously, the gestures that accompany stuttered speech, rather than compensating for the reduced content and structure, show a similar overall reduction. Stuttered speech is accompanied by fewer, not more, gestures than fluent speech, with simpler forms and meanings (Mayberry, Jaques, and Shenker, 1997). The most straightforward explanation for this phenomenon is that gesture and speech form an integrated communication system, and hence stuttering affects them both.

Gesture During Speech Disfluency. We examined in detail the timing relationships between gesture and fluent versus stuttered speech. First we located all instances of normal and stuttered disfluencies in the spoken portion of the subjects' narrations and determined whether or not a gesture co-occurred with each instance of disfluency. We found that the normal disfluencies of all the subjects—controls and stutterers—were produced both with and without an accompanying gesture with equal frequency. This suggests that normal disfluencies (as we have defined them here) have little or no effect on gesture production. Our finding corroborates Kendon's observation (1975) that normal disfluencies, or what he termed *speech hesitations*, do not disrupt gesture production.

In direct contrast, we found that gesture was only rarely coproduced with stuttered disfluencies. In those rare instances when a gesture was coproduced with a stuttered speech disfluency, the gesturing hand would fall to rest during the moment of stuttering and then rise again, resuming production of the abandoned gesture within milliseconds of the resumption of speech fluency. In fewer instances the gesturing hand would cease moving entirely during the moment of stuttering. On these rare occasions the hand would freeze in midair and then resume movement within milliseconds of the resumption of speech fluency. In other words, gesture and speech were always, and without exception, temporally coexpressed during spontaneous expression.

In order to examine more closely the timing relationship between gesture production and speech disfluency, we located every instance in which either a normal or a stuttered disfluency occurred simultaneously with a representational gesture. We excluded deictic and beat gestures because their temporal duration was typically too brief for us to reliably observe the relationship between the motor execution phase of the gesture and the speech disfluency without instrumentation.

This microlevel investigation of the motor execution of gesture as a function of stuttered disfluencies revealed that syllable and phoneme repetitions and sound prolongations never coincided with the onset of the gesture stroke. Instead, the onset of the gesture movement always coincided with fluent (non-stuttered) speech. This is in direct contrast to the normal disfluencies of all the subjects, which often co-occurred with the onset of gesture movement.

These findings show that the onset of gesture movement, or the gesture stroke, is directly linked to word production. Stuttered disfluencies disrupt the temporal and prosodic patterning of speech. Words and syllables explode, and stress, timing, and prosody patterns all collapse as a consequence. Gesture production ceases entirely until all the dynamic subpatterns of the speech stream reunite and resume their flow. In the case of stuttering, then, the timing of gesture execution accommodates speech execution by starting and stopping and waiting if necessary for stuttering to stop and fluent speech to resume. The robust correspondence between fluent speech production and maintenance of gesture production demonstrates clearly that gesture and speech are not independent systems in spontaneous expression.

Although it is now evident that gesture and speech coexpression is tightly linked temporally in the spontaneous expression of adults, we wondered whether the same was true for children. The purpose of our second study was to determine whether stuttering shows comparable effects on the gesture-speech expression of children and, equally important, whether children show the same gesture-speech temporal coordination as do adults.

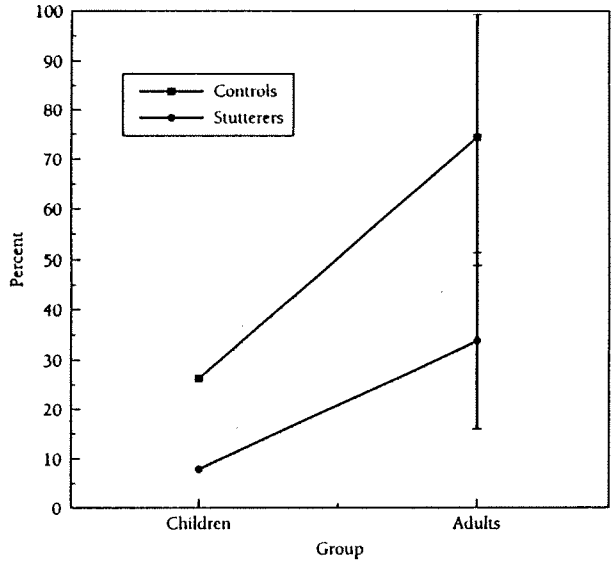
The Speech-Gesture Relationship in Children

The goal of our second study was to replicate and extend our previous findings to children. We elicited spontaneous language samples, using a cartoon-retelling task, from four boys who were eleven years old (DeDe, 1996). Two boys were clinically diagnosed by a speech-language pathologist as having a severe level of chronic stuttering (greater than 10 percent of words stuttered). Two other boys had no symptoms of stuttering and were matched by age and handedness to the two subject stutterers.

One of our immediate observations was that all the children gestured significantly less frequently in relation to their speech expression than did the adults, as shown in Figure 5.1. We believe this is an important finding, to which we will return after we describe the children's gesture-speech characteristics.

As was the case for the adult subjects, the control children produced many more total gestures than did the children who stuttered, at a ratio of nearly three to one, as shown in Figure 5.1. The control children simultaneously coexpressed 26 percent of their spoken words with gestures, whereas the children who stuttered simultaneously coexpressed only 8 percent of their spoken words with gestures. Moreover, the children who stuttered truncated their spoken narrations in many ways compared to the controls, as was the case for the adults. The children who stuttered said fewer words, in fewer clauses, and using simpler sentence structures and described fewer cartoon details than the controls. Finally, the children who stuttered, like the adult subjects, never used gestures to compensate for the speech difficulties caused by their stuttering. In the few instances in which a stuttered disfluency

Figure 5.1. Proportion of Spoken Words Accompanied by Gestures (WAG Ratio) for Stuttering and Control Subjects



interrupted speech during a gesture, the hand could be observed to stop moving during the stuttered disfluency and then resume moving when the stuttering block terminated.

The Development of Gesture-Speech Coexpression

One of our experimental measures, "words accompanied by gesture" (WAG), allows us to compare the gesture-speech relationship in children with that of adults. It also allows us to compare the gesture-speech relationship in subjects who stuttered with that of controls. The WAG ratio measures the proportion of words spoken that are coexpressed with gestures. Comparing the WAG ratios of the adult subjects to those of the child subjects reveals a clear pattern of development, as shown in Figure 5.1. Observe that the WAG ratio increases 400 percent between preadolescence (eleven years) and adulthood (twenty-two to fifty-eight years). This is true for subjects who stutter and those who do not.

What develops between age eleven and adulthood that would account for this large change in the WAG ratio? One candidate explanation is that the frequency with which gesture appears in the speech stream reflects attentional demands during spontaneous speech expression. Although eleven-year-olds

have acquired nearly all of the rules of grammar and have large lexicons, their ability to produce linguistically packaged sentences within organized discourse while simultaneously thinking and planning what they want to say and remembering the characters and plot of an animated cartoon is no doubt more limited than that of adults. Perhaps this is what underlies the large increase in WAG ratios from preadolescence to adulthood. This explanation fits well with another of our gesture-speech findings (Nicholadis, Mayberry, and Genesee, 1997)—namely, that the emergence of gesture accompanying speech is paced by linguistic development in young bilingual children at the earliest stages of language development.

If our interpretation is correct, then this would mean that increases in attentional capacity are marked by concomitant increases in the WAG ratio during spontaneous expression. More specifically, we propose (1) that the act of speaking spontaneously requires more cognitive effort and attention on the part of children than it does on the part of adults and (2) that gesture appears concurrently with spontaneous speech only when sufficient cognitive attentional resources are available. This explanation is suggested to us by one of the major effects of stuttering on the WAG ratio—namely, that subjects who stutter show attenuated frequency of gesture production compared to fluent controls, even after amount of speech is taken into account. Perhaps the speech disorder of stuttering reduces gesture production because stuttering drains the cognitive, neurolinguistic, and neuromotor planning resources that are required for spontaneous gesture-speech expression.

Based on our findings we hypothesize that the frequency with which gesture appears in the speech stream may be indicative of how many attentional resources are required to plan and produce the spoken portion of the message. When the spoken portion of the message takes most of the available attentional capacity, little capacity remains for the gestural portion of the linguistic message to be expressed. Note that this hypothesis implies that speech is the first-priority mode of expression in terms of the use of processing resources during spontaneous expression, with gesture getting any resources that are left over.

Our rationale for proposing this particular explanation (that the attentional demands of speech expression determine the degree to which gesture will be produced with speech) is that it helps explain the large difference between children's WAG ratios and the ratios of adults and between the WAG ratios of individuals who stutter and the ratios of those who do not.

Hypothetical explanations aside, however, the most important insight that stuttered speech gives us into the nature of the gesture-speech relationship is that gesture is *always* temporally coexpressed with speech. Temporal coexpression characterizes the spontaneous expression of children and adults as well as that of individuals who stutter. Gesture execution is so tightly linked to speech production during spontaneous expression that gesture almost never uncouples from speech, even in the face of frequent and often massive disruptions to speech expression caused by stuttering.

Conclusion

Thus, through the window provided by chronic stuttering we can observe that gestural expression is a handmaiden to vocal expression. Gesture is paced and led by speech. Gesture starts and stops and waits if necessary for fluent speech to resume so that both gesture and speech can express their single message at the same time (Mayberry, Jaques, and Shenker, 1997).

In summary, the speech disorder of chronic stuttering offers multiple insights into the nature of the gesture-speech relationship in spontaneous expression. First, observations of stutterers provide compelling evidence that gesture and speech form an integrated communication system. When speech is present and assumes the primary responsibility for linguistic expression, gesture is tied to it in such an intricate and deep fashion that gesture shows frequency and timing patterns that are completely parallel to those of speech. Second, when stuttered disfluency disrupts the temporal patterning of speech, the temporal patterning of gesture is affected in tandem. Finally, the attenuating effects of stuttering on the frequency of gesture in the speech stream (the WAG ratio) and the contrastive WAG ratios of adults and children suggest that gesture production may be constrained by the attentional demands of the spoken portion of the message.

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