Oral Kinesthetic Deficit in Adults Who Stutter: A Target-Accuracy Study

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ABSTRACT. The current study was based on the hypothesis that chronic developmental stuttering in adults involves a deficiency in oral kinesthesia. The authors used a target-accuracy task to compare oral kinesthesia in adults who stutter (*n* = 17) and in normal speakers (*n* = 17). During the task, participants were instructed to make accurate jaw-opening movements in visual and nonvisual feedback conditions. The authors further contrasted oral movement control in a normal response time condition with that in a reaction time condition. Overall, the adults who stutter consistently made significantly less accurate and more variable movements than the control participants in the nonvisual condition, but particularly in the reaction time condition. In general, the present findings suggest that chronic developmental stuttering involves an oral kinesthetic deficiency, although without direct measures of somatosensory function, one cannot exclude a motor deficit interpretation.

Key words: jaw, kinesthesia, sensorimotor, speech, stuttering

Accomplishing a movement goal involves a sensorimotor process in which the generation of appropriate muscle forces and movement amplitudes requires sensory information that is related to the movement goal. Understanding how sensory information is incorporated into the movement goal, as online feedback or, alternatively, as predictive feedforward information, remains a multifaceted research issue, but there is a general consensus that intact sensory information is required for voluntary movement control in the long term (McCloskey & Prochazka, 1994).

Kinesthesia is one sensory modality that is integrally involved in achieving many movement goals. Kinesthesia is generally defined as the perception of position and movement of the limbs and body, along with the perception of motor effort (Gandevia, 1996). A complete loss of kinesthesia because of large-fiber sensory neuropathy produces pervasive movement impairments that are characterized by discoordination and movement accuracy errors (Ghez, Gordon, Ghilardi, Christakos, & Cooper, 1990). Partial kinesthetic deficits are also implicated in movement impairments because patients with movement disorders, including Parkinson’s disease, dystonia, and cerebellar degeneration, show specific kinesthetic deficits (Grill, Hallett, Marcus, & McShane, 1994; Rickards & Cody, 1997; Rome & Grunewald, 1999).

The effect of a kinesthetic deficit on speech movement disorders has not been evaluated, even though the necessity for intact oral sensation for speech movement control has been recognized (Kent, Martin, & Sufit, 1990). We posit that an oral kinesthetic deficit would have explanatory potential for the movement abnormalities of stuttering that are observed during stuttering episodes, fluent speech, and certain nonspeech tasks (Grosjean, van Gulen, de Jong, van Lieshout, & Hulstijn, 1997; Kleinow & Smith, 2000; Peters & Boves, 1988; van Lieshout, Peters, Starkweather, & Hulstijn, 1993; Watson & Alfonso, 1987). Possible evidence for aberrant oral kinesthesia in stuttering comes from studies in which adults who stutter showed significantly larger oral movements than control participants on a minimal movement task when visual feedback was not available (Archibald & De Nil, 1999; De Nil & Abbs, 1991). Because the detection of a position change without visual feedback is more dependent on intact kinesthesia (Gandevia & McCloskey, 1987), De Nil and Abbs’s results suggest coarser oral kinesthetic resolution in adults who stutter.

In the current experiment, we tested whether adults who stutter can make accurate jaw-opening movements to a spa-
tial target within the speech movement range (a portion of this study has been reported previously as an Abstract; Loucks & De Nil, 2001b). We selected jaw movements because adults who stutter showed the coarsest kinesthetic resolution for movements of that articulator during the aforementioned minimal movement task (De Nil & Abbs, 1991) and because somatosensory information is available to control jaw-opening movements during speech (Loucks & De Nil, 2001a; Tremblay, Shiller, & Ostry, 2003). Our first hypothesis was that adults who stutter will produce significantly less accurate and more variable jaw movements to a spatial target than will nonstuttering control participants when visual feedback is not available and thus reliance on kinesthesia is increased. However, we predicted no differences in performance between the two groups for movements completed in the presence of visual feedback. Although deficient performance on that task by persons who stutter does not necessarily exclude a motor deficit explanation, in the absence of a direct measure of kinesthesia or a perturbation of kinesthesia (e.g., tendon vibration), a kinesthetic explanation can be supported if increased jaw position error occurs only in a nonvisual condition.

Our second hypothesis was that between-groups differences in movement error would increase when the task was performed under time pressure. Our reasoning was that time pressure, as operationalized in a reaction time condition, will increase the sensorimotor demands of the task by limiting movement preparation time and increasing movement speed. Preliminary data obtained for the present study indicated that both movement error and peak velocity increased significantly in a reaction time condition compared with that in a normal response time condition (Loucks & De Nil, 1999). Increased motor demands should impair the movement accuracy of the adults who stutter to a greater extent if chronic stuttering is related to a sensorimotor deficit.

**Method**

**Participants**

Seventeen right-handed men who stutter (age range = 18–43 years) and 17 right-handed control participants (15 men and 2 women, age range = 20–40 years) were recruited. The sample size required to achieve a power of 0.8 was estimated to be 9 participants per group for a univariate analysis of variance (ANOVA) with an alpha = .025 (Systat Version 11.0). We estimated the effect size of 0.8 from the group difference in jaw movement amplitude between adults who stutter and control participants reported by De Nil and Abbs (1991). All participants reported a negative history for neurological, psychiatric, cognitive, and linguistic disorders other than stuttering in the experimental group. Each participant provided a conversational speech sample and read a text passage out loud. We videotaped speech samples, and, subsequently, a qualified speech-language pathologist scored the samples by using the Stuttering Severity Index (SSI; Riley, 1994). As a measure of stuttering severity, the frequency of stuttering events in conversational speech and reading samples, the duration of stuttering events, and the frequency of behaviors secondary to stuttering are combined in the SSI so that a single score is generated. The intrarater reliability of the SSI ranges from 82%–99%, and the intrarater reliability ranges from 84%–100% (Riley). On the basis of the SSI scores, none of the control participants showed evidence of stuttering. The SSI results for the stuttering group indicated that 1 participant had very severe stuttering, 5 had moderate stuttering severity, 2 had mild stuttering severity, and 9 had very mild stuttering severity. Each of the stuttering participants reported that they had stuttered since early childhood and had received some form of therapy for stuttering. To assess the intrarater reliability of the SSI scores for the stuttering group, a second rater rescored 8 participants. The correlation between the two sets of scores was .93 (p < .001), which closely approximates the published SSI reliability scores (Riley). In Table 1, the age, SSI rating, and therapy history of the adults who stutter are shown. The Human Ethics Review Committee at the University of Toronto approved the study. All participants provided informed consent before participating in the experiment.

**Task Description**

The task required accurate jaw-opening movements from a baseline position to the target position, followed by a return to baseline. In each condition, the participant faced a computer monitor, which displayed the baseline and target as static horizontal lines (target width = 1 mm) and a cursor.

**Table 1. Age, SSI, and Years Elapsed Since Last Treatment for Participants Who Stutter**

<table>
<thead>
<tr>
<th>Participant no.</th>
<th>Age</th>
<th>SSI</th>
<th>Diagnostic category</th>
<th>Years elapsed since previous therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>20</td>
<td>Mild</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>43</td>
<td>14</td>
<td>Very mild</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>30</td>
<td>Moderate</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td>19</td>
<td>Mild</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>42</td>
<td>16</td>
<td>Very mild</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
<td>19</td>
<td>Moderate</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>7</td>
<td>Very mild</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>26</td>
<td>Moderate</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>24</td>
<td>Moderate</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>15</td>
<td>Very mild</td>
<td>5</td>
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<tr>
<td>11</td>
<td>30</td>
<td>11</td>
<td>Very mild</td>
<td>21</td>
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<td>14</td>
<td>31</td>
<td>7</td>
<td>Very mild</td>
<td>&gt;25</td>
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<td>15</td>
<td>26</td>
<td>37</td>
<td>Very severe</td>
<td>7</td>
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<td>Very mild</td>
<td>3</td>
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<td>17</td>
<td>39</td>
<td>23</td>
<td>Moderate</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

Note. SSI = Stuttering Severity Index (Riley, 1994).
controlled by jaw movement. The distance between the target and baseline on the monitor was exactly 6 mm, which falls within the typical range of jaw movements during speech (Gracco & Lofqvist, 1994; Smith & Kleinow, 2000). The task involved two within-participant variables: feedback and time. The feedback variable involved a visual condition in which continuous visual feedback of the movement cursor was available and a nonvisual condition in which the visible cursor was removed at trial onset. The time variable involved a self-selected response time condition (SSRT) in which the participant initiated movements when ready, and a reaction time (RT) condition in which the movements were initiated as rapidly as possible.

Each trial was initiated by an acoustic signal (750 Hz, 300 ms) that cued the participant to position his or her jaw at the baseline (mouth-closed position). After 5 s, a second acoustic go signal (500 Hz, 300 ms) cued the participant to initiate the movement. The movement period lasted 10 s, after which a third tone (900 Hz, 300 s) signaled trial offset. Each participant performed 10 trials in each 2 (feedback) × 2 (time) condition, for a total of 40 trials. We randomized the presentation order of the feedback condition, but the SSRT condition always preceded the RT condition so that possible accuracy decrements in the RT condition were prevented from affecting the SSRT condition.

A training phase, which preceded the experiment, involved 5 practice trials under visual feedback and 10 practice trials without visual feedback for each target. All participants made highly accurate movements in the visual training condition. In the nonvisual training condition, a static horizontal line appeared on the monitor after each practice trial; the line indicated the peak amplitude relative to the target, thus providing accuracy feedback. All participants used the feedback effectively to meet the training criterion of three highly accurate movements on sequential trials.

**Experimental Setup**

The participant sat in a chair facing a computer monitor positioned at a distance of 60 cm and at eye level. We recorded jaw movements by using a strain-gauge transducer that followed movements in the inferior–superior dimension (Barlow, Cole, & Abb, 1983). The strain gauge was calibrated to within ± 0.1 mm accuracy. The distal extension of the transducer was inserted into a custom denture molded to the mandibular dentition of the participant. The transducer signal was preamplified, low-pass filtered (20 Hz), and then digitized (500 samples/s). The participants were instructed to maintain an erect head posture and to move only their jaw during a trial.

**Dependent Variables**

The dependent variables used were measures of movement accuracy and variability. Constant error is a measure of movement bias that indicates the difference between the peak movement amplitude and the target position (Schmidt & Lee, 1999). Constant error can be positive or negative, reflecting overshoot or undershoot of the target, respectively; however, group means are subject to cancellation because of positive and negative constant error values. For that reason, we used the mean absolute constant error (constant error) for each participant in the statistical analysis, as recommended by Schmidt and Lee. Variable error is essentially the standard deviation of the peak amplitude (Schmidt & Lee). Because constant error and variable error are orthogonal, they provide complementary but independent information. We included three other variables to compare the movement patterns of the groups: (a) RT (s), (b) movement time (s), and (c) peak velocity (mm/s).

We first filtered the jaw movements from each trial forward and backward with a 20-Hz, low-pass, fourth-order Butterworth filter, followed by a custom MatLab (The MathWorks, Natick, MA) routine that automatically identified peak jaw displacement on each trial and differentiated the displacement data, which resulted in a measure of velocity. Peak velocity was identified automatically as the largest negative peak in the velocity trace. Movement onset was determined from the velocity trace as a deviation from baseline that was equal to 10% of peak velocity. We defined RT as the interval between the onset of the go signal and movement onset. We defined movement time as the interval between movement onset and the peak amplitude of the movement. At the time of data analysis, we rejected a movement trial if the movement was initiated before the go signal or if the peak amplitude was reached after the movement offset signal. Approximately 2% of the movement trials were rejected.

**Statistical Analysis**

We analyzed constant error (CE) and variable error (VE) separately by using repeated measures ANOVA. The design consisted of the two within-participant variables, feedback and time, and the between-groups variable. We adjusted a nominal p value of .05 for the separate accuracy and variability hypotheses (p = .05/2 hypotheses = .025). We analyzed the movement pattern variables (peak velocity, movement time, and RT) by using separate repeated measures ANOVAs with the same variables as are listed for the accuracy variables. We adjusted the nominal p value of .05 by the three factorial tests (.05/3 tests = .017).

**Results**

| CE |

Movement accuracy, measured as | CE | , varied considerably across the different movement conditions, as shown in Figure 1A. The movements of both groups were clearly more accurate in the visual condition than in the nonvisual condition. A significant main effect for feedback, F(1, 32) = 84.8, p < .001, supported that observation. A significant effect for the time variable was also detected, indicating that | CE | increased significantly in the RT condition, F(1, 32) = 14.8, p = .001.
Overall, the movements of the stuttering group were significantly less accurate than those of the control group, as indicated by a main group effect, $F(1, 32) = 6.2, p = .018$. However, as suggested in Figure 1A, the adults who stutter performed disproportionately worse in the nonvisual feedback condition. That differentially worse performance was demonstrated by the significant Group × Feedback interaction, $F(1, 32) = 14.5, p = .001$. The Group × Time interaction also was significant, indicating that the RT condition differentially affected the $|CEI|$ of the groups, $F(1, 32) = 5.8, p = .022$. In addition, a significant three-way interaction was obtained; Group × Feedback × Time, $F(1, 32) = 5.6, p = .024$. As evidenced in Figure 1, that complex interaction indicated that the $|CEI|$ of the stuttering group increased in the nonvisual condition in comparison with that in the visual condition, whereas the $|CEI|$ of the control group showed minimal change. Similarly, in comparison with the SSRT condition, the $|CEI|$ of the stuttering group increased to a greater extent than did that of the control group in the RT condition.

Several extreme values were also detected, as shown in the box and the whisker plot of $|CEI|$ (see Figure 1A). The circles represent values that are more than three times greater than the interquartile range. Those extreme values were evident for 2 control participants in the nonvisual condition and 1 stuttering participant in the visual–RT condition. A trimmed analysis of $|CEI|$ without those 3 participants did not change the results.

VE

A related pattern was detected for jaw movement variability, as shown in Figure 1B. Both groups showed significantly lower movement variability with than without visual feedback, $F(1, 32) = 79.9, p < .0001$. A significant effect for the time variable indicated that VE increased significantly in the RT condition compared with that in the response–time condition, $F(1, 32) = 22.4, p = .0001$.

As for the $|CEI|$ findings, the overall VE of the stuttering group was significantly higher than that of the control group, $F(1, 32) = 8.6, p = .006$. The Group × Feedback interaction, $F(1, 32) = 12.9, p = .001$, was also significant, indicating that the movement variability of both groups increased in the nonvisual condition; but, descriptively, the stuttering group’s variability increased to a greater extent. The interaction terms of Group × Time or Group × Feedback × Time were not significant for VE.

As an additional analysis, we measured total variability post hoc. Total variability indicates overall accuracy or error relative to target position, rather than an overshoot or peak amplitude variability (Schmidt & Lee, 1999). The total variability results were similar to those reported for VE, as indicated by significant effects for feedback, $F(1, 32) = 123.2, p < .001$, and time, $F(1, 32) = 123.2, p < .001$. The movements of the stuttering group were significantly less accurate than those of the control participants—for group, $F(1,
32) = 17.5, \( p < .001 \)—but particularly in the nonvisual condition—Group \( \times \) Feedback, \( F(1, 32) = 27.9, p < .001 \). None of the other interactions were significant.

**RT**

The movement onset times of both groups were highly similar and followed the same pattern. In the SSRT condition, the participants in both groups initiated their movements 500–600 ms after the go signal; whereas in the RT condition, the participants initiated their movements approximately 300–400 ms after the go signal (Figure 2A). Movement onset occurred significantly earlier in the RT condition than in the SSRT condition—for time, \( F(1, 32) = 16.4, p < .0001 \)—but none of the other main effects or interactions were significant.

**Movement Time**

Both groups had similar movement times across the experimental conditions (Figure 2B); movement times were significantly shorter in the RT condition—that is, for time, \( F(1, 32) = 36.8, p < .0001 \)—but the other main and interaction effects were not significant.

**Peak Velocity**

In comparison with the SSRT condition across both groups, the peak velocity of the jaw-opening movements increased markedly in the RT condition; for time, \( F(1, 32) = 28.2, p < .0001 \) (see Figure 2C). The peak velocity of both groups also increased significantly in the nonvisual condition compared with that in the visual condition—for feedback, \( F(1, 32) = 8.1, p = .008 \)—which contributed to the significant interaction between time and feedback, \( F(1, 32) = 7.1, p = .012 \), and indicated that peak velocity was highest in the nonvisual RT condition. None of the group effects or interactions was significant.

As a second post hoc analysis, we analyzed the movements of 11 participants from each group to explore whether any other movement characteristic may account for the group differences in accuracy and variability. We compared the peak acceleration (mm/s²), number of velocity peaks, and the displacement at peak velocity (mm) of both groups by using the same analysis and variables as for the other movement variables. For peak velocity and number of velocity peaks, the only difference found was a main effect for the time variable. No group differences were present. However, a different pattern was found for displacement at peak velocity (Figure 3). The overall jaw amplitude at peak velocity of the stuttering group was significantly greater than that of the control group, \( F(1, 20) = 13.8, p < .001 \), but particularly in the nonvisual RT condition, \( F(1, 20) = 8.7, p = .004 \), for the Group \( \times \) Feedback \( \times \) Time interaction.

**Discussion**

Adults with chronic stuttering made less accurate and more variable jaw movements than normal-speaking control participants when visual feedback was not available. The marked group difference contrasts strongly with the visual condition, in which both groups displayed highly accurate movements. Our interpretation of those results is that both groups can perform the task accurately and reliably when visual and kinesthetic feedback are available, but the performance of adults who stutter degrades when the task depends primarily on kinesthesia. Evidence supporting

![FIGURE 2](image-url) Bar plot representation of the movement pattern variables for each group in the visual and nonvisual conditions at each time level. (A) Reaction time, (B) movement time, (C) peak velocity (error bars = ±1 standard deviation).
a kinesthetic interpretation of those findings comes from studies of individuals who have lost kinesthetic and proprioceptive sensation (Ghez et al., 1990; Ghez & Sainburg, 1995; Jackson et al., 2000). Those individuals show gross movement inaccuracy and discoordination when visual feedback is not available; instead, they require online visual feedback to make movements that approximate the task requirements, which demonstrates that the visual versus nonvisual feedback contrast is one strategy for manipulating kinesthesia.

The low ICET and VE of the control participants in the nonvisual conditions corroborate the findings from other studies of jaw kinesthesia. In those studies, normal speakers showed accurate jaw-position matching or sensitive resolution of jaw-position changes without visual feedback (Archibald & De Nil, 1999; De Nil & Abb, 1991; Jacobs, Van Steenbergh, & Schotte, 1992; Van Willigen & Broekhuysen, 1983). The inaccuracy and variability of the stuttering participants in the nonvisual condition are also in agreement with previous findings in which adults who stutter showed similar deficits on oral and bimanual movement tasks (Archibald & De Nil; De Nil & Abb; Forster & Webster, 2001). The current study extends those findings to an oral spatial task that encompasses a broad range of jaw movement speeds and response times. It needs to be pointed out, however, that these findings do not demonstrate that stuttering is primarily a kinesthetic deficit; rather, we interpret our findings as indicating an association between aberrant kinesthesia and the presence of stuttering.

It is recognized that nonspeech oral movements do not represent the multiarticulatory coordination required for normal speech production. It also remains unclear how aberrant performance on a nonspeech task is related to the speech dysfluences that characterize stuttering. However, oral movement tasks offer a number of advantages for stuttering research because they mitigate the particular criticism that sensorimotor anomalies in stuttering are secondary effects (i.e., related to the experience of struggling with stuttering) and that nonspeech oral tasks are not affected by linguistic processes. Therefore, it is our opinion that studies of nonspeech tasks with a clear movement goal are an appropriate first step in evaluating sensorimotor function in chronic stuttering.

**Movement Patterns**

In contrast to the group differences in accuracy and variability, both groups executed the movements in a similar manner. Each of the movement variables, RT, movement time, and peak velocity, showed a similar pattern across both participant groups, in that the responses and movements were faster and of shorter duration in the RT condition than in the SSRT condition. The null finding of group differences in those primary movement variables is an indication that movement velocity, duration, or response time measures do not account for the group differences in accuracy and variability.

The RT condition produced interesting effects. Not only did it change response time, but it also contributed to higher movement velocity and higher movement error in both groups (as predicted by our pilot study; Louchs & De Nil, 1999). We do not know whether the higher error was related to the decrease in preparation time or the increase in movement velocity, but those effects of RT on movement patterns merit further study. The disproportionately higher ICET of the stuttering group in the nonvisual RT condition indicated that the adults who stutter were more prone to target overshoot. That finding may indicate that the RT condition selectively increased the difficulty of the task for the adults who stutter. Higher error was not evident in the VE data, however, which suggests the RT effect was subtler than was the removal of visual feedback.

The absence of statistical group differences in RT is not consistent with the findings of previous studies, because adults who stutter typically show longer RTs (Rastatter & Dell, 1987; van Lieshout, Hulstijn, & Peters, 1996; Watson & Alfonso, 1987). However, longer RTs in adults who stutter are more typically found for speech and language tasks than for nonspeech tasks. One interpretation of the null finding for RT is that participants in both groups strategically used long RTs to maintain accuracy.

In general, the participants had lower velocities and longer movement times than those of typical jaw-opening movements for speech production (Gracco & Lofqvist,
1994; Smith & Kleinow, 2000), although the jaw-opening velocities in the RT condition approached the velocities observed in speech studies (Gracco & Lofqvist; Smith & Kleinow). That finding is potentially consistent with individuals’ adoption of a movement strategy in which movement rate is minimized to achieve accuracy—a sort of speed-accuracy tradeoff elicited by the accuracy requirements in combination with the fine target amplitude (Schmidt & Lee, 1999).

One other relevant finding was the displacement at peak velocity (PVd) values in a subgroup of adults who stutter (nonvison condition). Their PVd values actually approximated the target position, so their movements necessarily overshoot the target. A possible nonkinesthetic explanation for the movement overshoot may be that adults who stutter have impaired control over motor unit recruitment for fine oral movements. That possibility is worth noting because in the current paradigm, one cannot completely differentiate motor and sensory processes. Adults who stutter have shown significantly higher error than control participants on a labial force-production task (Grosjean et al., 1997), although group differences were not found for manual force production (Zelaznik, Smith, & Franz, 1994). Continued studies of oral force control are needed to enable us to differentiate whether anomalous movement control in adults who stutter is related to sensory or motor function.

A Sensorimotor Deficit in Stuttering

The role of kinesthesia in speech production differs from its role in the reproduction of a specific joint position. Speech is overlearned and highly automatic; therefore, kinesthesia (or proprioceptive information) more likely contributes in a feedforward or predictive manner (Gracco & Abbs, 1984; Tremblay et al., 2003) than in a feedback manner, as tested in the current study. However, our purpose in this study was to test oral kinesthesia in a group of stuttering individuals, rather than the role of kinesthesia in speech. Nonetheless, a kinesthetic deficit on an oral motor task is one indication that aberrant kinesthetic processing may also contribute to impaired feedforward or predictive use of sensory information during speech production. Testing that consideration requires theoretical models of speech production in which sensory input can perturb speech (e.g., Guenther, 2001; Perkell et al., 1997). The potential role of deficient kinesthesia in stuttering is supported by the observation that oral anesthesia appears to elicit a slight increase in stuttering severity in adult stutterers, suggesting that kinesthesia may be important in maintaining fluency (Hutchinson & Ringel, 1975). However, interfering with oral sensation by using local anesthesia does not elicit stuttering in nonstuttering individuals, suggesting that a somatosensory impairment, albeit temporary, does not directly cause stuttering.

A potential kinesthetic deficit in stuttering should be interpreted within a theoretical framework in which a sensorimotor integration deficit can be observed apart from actual stuttering during speech production. Although any deficit is likely subtle, anomalous sensorimotor function in adults who stutter has been observed in studies of oral perception, movement tracking, and vocal RT (Harris, Fucci, & Petrosino, 1991; Neilson & Neilson, 1991; Petrosino, Fucci, Gorman, & Harris, 1987; van Lieshout et al., 1996). A sensorimotor deficit interpretation is somewhat constrained because adults who stutter have normal oral reflexes (McClean, 1987; Smith & Luschei, 1983), whereas most sensorimotor disorders typically involve aberrant reflexes (Ludlow, Schulz, Yamashita, & Deleyiannis, 1995; Naumann & Reiners, 1997; Rothwell, Obeso, Traub, & Marsden, 1983). However, it also suggests that any sensorimotor deficit in stuttering would have a central neurological origin rather than reflex abnormalities.

The final consideration involves the observation that only 20%-40% of children who stutter continue to show chronic stuttering in adulthood (Bloodstein, 1995). Although chronic stuttering is likely the result of a complex interaction between different factors, including individual differences, a sensorimotor integration deficit may be a trait that could dispose certain children who stutter to chronic stuttering by impeding natural recovery or treatment effects. In that context, one should not just add anomalous sensorimotor function to a list of factors associated with stuttering. Rather, we believe that a view of stuttering that incorporates and recognizes a complex interaction between sensory and motor function along with linguistic factors is required to predict chronic stuttering and develop treatments to prevent chronicity.

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