CORTICAL REPRESENTATION OF SWALLOWING: A MODIFIED DUAL TASK PARADIGM

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Summary.—It is unclear whether the cortical representation of swallowing is lateralized to the left cerebral hemisphere, right hemisphere, or bilaterally represented. As dysphagia is common in acute stroke, it is important to elucidate swallowing lateralization to facilitate earlier detection of stroke patients who may be at greater risk for dysphagia and aspiration. In this study, a modified dual task paradigm was designed to study laterality of swallowing in a group of 14 healthy, young, right-handed, male adults. The subjects were studied at baseline and with interference. Baseline conditions, performed separately, were continuous swallowing, finger tapping using the right and left index fingers, and word repetition. Interference tasks, including tapping with the right index finger, tapping with the left index finger, and word repetition, were completed with and without swallowing. Finger-tapping rate was measured, and x-ray samples of the swallowing task were taped to measure swallowing rate and volume swallowed. At baseline, the rate of tapping the right index finger was significantly faster than that of the left index finger. There was a significant decline in the tapping rates of both left and right index fingers with swallowing interference. The volume per swallow was significantly reduced during the interfering language task of silent repetition. These results offer partial support for a bilateral representation of swallowing as well as suggest an important left hemispheric contribution to swallowing. However, it cannot be concluded that the left hemisphere is more important than the right, as a comparable right hemisphere task was not studied.

It has been well established that the brainstem plays a major role in deglutition based on human lesion studies and animal models (Miller, 1999). There is also evidence that cortical brain regions are involved in swallowing.

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although it remains unclear whether the right or the left cerebral hemisphere is more critical or "dominant" for swallowing. Two competing hypotheses have been proposed: lateralization of function versus a bilateral representation of swallowing. Specifically, the control of swallowing may be lateralized exclusively to the right or left cerebral hemisphere, although there may not be a consistent pattern of lateralization across individuals. Conversely, swallowing may not be strongly lateralized, and there may be bilateral control of swallowing with or without some aspects being lateralized.

Empirical studies have provided partial support for each of these hypotheses. Certain studies have suggested that swallowing may be lateralized, as specific dysmotility patterns seem to be more common in the right versus the left hemisphere (Robbins & Levine, 1988; Robbins, Levine, Maser, Rosenbek, & Kempster, 1993; Daniels, Foundas, Iglesia, & Sullivan, 1996), and persistent dysphagia has been more common following right hemispheric stroke (Smithard, O’Neill, Martin, & England, 1997). Other investigators have not identified lateralization of swallowing (Chen, Ott, Peele, & Gelfand, 1990; Alberts, Horner, Gray, & Brazer, 1992; Johnson, McKenzie, Rosenquist, Lieberman, & Sievers, 1992; Daniels, Brailey, & Foundas, 1999; Daniels & Foundas, 1999). Positron emission tomography (PET; Hamdy, Rothwell, Brooks, Bailey, Aziz, & Thompson, 1999; Zald & Pardo, 1999), functional magnetic resonance imaging (fMRI, Hamdy, Mikulis, Crawley, Xue, Lau, Henry, & Diamont, 1999), and transcranial magnetic stimulation (Hamdy, Aziz, Rothwell, Brooks, Bailey, Aziz, & Thompson, 1996) methodologies have been used to investigate the lateralization of swallowing in vivo and have provided partial support for a lateralized but widely distributed cortical representation of swallowing with bilateral, asymmetric activation of the sensorimotor cortex (Hamdy, et al., 1996; Hamdy, Rothwell, Brooks, Bailey, Aziz, & Thompson, 1999). That is, swallowing was not localized to one specific hemisphere across subjects, but within each subject one hemisphere tended to be more important than the other in mediating swallowing.

Knowledge of lateralization of the cortical representation of swallowing is critical to understand fully the role of supratentorial regions in deglutition and how neurological disease, in particular stroke, may affect swallowing. However, based on the studies cited above, it remains unclear whether swallowing is lateralized and if so, whether it is hemisphere-specific. Given this problem, a dual task paradigm, used extensively in neuropsychology to investigate lateralized functions, may be applied to investigate the possible lateralization of swallowing in a group of healthy adults. This paradigm indirectly evaluates lateralized cortical systems by comparing performance on tasks at baseline and with a concurrent or competitive condition. The most common paradigm is the verbal-manual interference paradigm. In this paradigm the
subject performs a motor task, such as finger tapping with the dominant and nondominant hands without interference and with interference. The interference task consists of verbal output. Because distal hand movements are mediated by the contralateral primary motor cortex, right-handed individuals activate the left primary motor cortex when tapping with the fingers of the right hand and vice versa when tapping with those of the left hand (Rao, Binder, Hammeke, Bandettini, Bobholz, Frost, Myklebust, Jacobson, & Hyde, 1995). In the baseline condition, right-handers tap faster with the right than the left hand. Concurrent verbalization (verbal-manual interference condition) typically yields a decrement in the tapping rate of the right index finger as compared to the baseline tapping rate (Kee, Bathurst, & Hellige, 1983; Dalen & Hugdahl, 1986). Several theories have been proposed to explain this decrement. The most widely accepted theory is the "functional cerebral space model" which indicates that coactivation of functionally overlapping neural substrates will yield a decline in response in one of the two concurrent activities (Kinsbourne & Hicks, 1978). Others have posited that "hemispheric overload" (Dalby, 1980) or "competition of resources" (Kee, Bathurst, & Hellige, 1984) produces the decrement in response. That is, allocation of attentional or processing resources is compromised due to two tasks sharing resources within the same hemisphere.

Here we use a modified dual task paradigm to investigate swallowing lateralization and assess whether the left hemisphere contributes significantly more to swallowing that the right hemisphere. Initially, the effect of language interference on finger-tapping rate was assessed. It was hypothesized that finger-tapping rate would be slower with repetition interference as compared to baseline tapping rates and that there would be a significant right side effect. This was posited as subjects were all right-handed, and it has been well established that language functions are lateralized to the left cerebral hemisphere in most right-handed individuals (Benson & Geschwind, 1968). Two tasks were used to activate the left hemisphere concurrently with swallowing, silent word repetition and tapping the right index finger, while tapping the left index finger was used to activate the right hemisphere concomitantly with swallowing. Using this paradigm, one may hypothesize that, if language or motor systems share neural substrates or overlap with neural systems that affect swallowing, then a decremental response will occur in the dual task (motor + swallowing, language + swallowing). Thus, if swallowing is lateralized predominantly to the left hemisphere, a competing task of finger tapping should produce a decrement in tapping response that is significantly greater with the right index finger than with the left index finger. In contrast, if swallowing is lateralized to the right hemisphere, there would be a significant decrement in motor response with tapping the left index finger but not with tapping the right index finger in the interference condition. As
language is generally lateralized to the left hemisphere in right-handers as previously discussed, it was hypothesized that, if swallowing is lateralized to the left hemisphere, a competing language task of silent repetition should interfere with swallowing.

**Method**

**Subjects**

Subjects consisted of 14 right-handed healthy young men (M age 29.9 ± 3.0 yr.). All subjects identified themselves as right-handed and right-footed and had no left-handed parents or sibling. Exclusion criteria included a history of dysphagia, neurological or gastrointestinal disorders, oropharyngeal structural damage, arthritis, or cervical spine disease affecting upper extremity movement, and developmental speech or language disorders, i.e., stuttering, dyslexia. The study was approved by the Institutional Review Board at Tulane University School of Medicine and by the Veterans Affairs Medical Center in New Orleans, and written consent was obtained from each subject.

**Materials and Procedure**

Measures of hand preference and neuropsychological assessment.—Confirmation of handedness was assessed on the Briggs and Nebes (1974) handedness inventory, which consists of questions about the hand used for each of 12 unimanual tasks adapted from Annett’s (1970) 120-item questionnaire. Consistent right-hand performance for a task was scored as +2 while consistent left-hand performance was scored as −2. A score of +24 indicated a strong right-hand preference for all tasks, whereas a score of −24 was indicative of strong left-handedness. The Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) was administered to screen cognition. Limb praxis was evaluated with a modified version of the Florida Apraxia Battery (Rothi, Raymer, & Heilman, 1997). The test consisted of transitive and intransitive gesture production upon command. An example of a limb transitive gesture is “use a key to unlock a door,” and an example of a limb intransitive gesture is “salute.” Subjects were videotaped executing pantomimes with later reviewing and scoring. The apraxia battery was scored using criteria developed by Rothi, Mack, Verfaellie, Brown, and Heilman (1988). Gestures were scored on a severity scale with anchors of 3: perfect, 2: imperfect but not apraxic, 1: degraded but recognizable, 0: degraded, frequently unrecognizable, with a maximum individual score of 60 (transitive gesture = 30; intransitive gesture = 30).

Radiographic procedure.—Videofluoroscopic swallowing samples were recorded on a Super-VHS videocassette recorder that was coupled to a counter timer that encoded digital time in hundredths of a second on each video.
frame. Lateral radiographic views of swallowing were obtained with the fluoroscopic tube focused on the region bounded by the lips anteriorly, the palate superiorly, and the upper esophageal sphincter inferiorly. On all swallowing trials, 300 ml of diluted liquid barium (2:1, sugar-free juice to barium) was placed in a cup and ingested through a straw, with the examiner holding the cup and straw. Interruption in consecutive swallowing due to possible adverse taste was not evident in any subjects.

Baseline and interference tasks were completed by each subject. Baseline conditions, performed separately, were Continuous Swallowing, Right Index Finger Tapping, Left Index Finger Tapping, and Word Repetition. The Interference Condition Without Swallowing used a verbal-manual interference paradigm. The Interference Conditions with Swallowing included a swallowing-manual interference paradigm and a swallowing-language interference paradigm. Duration of each trial was 10 sec., measured with a stopwatch. Each subject completed two 10-sec. trials for each task with a 15-sec. rest between trials. For all trials, the order of presentation of task was counterbalanced, and order of hand for the finger-tapping section was randomized within task. Subjects practiced each task before experimental trials for each condition began.

Baseline conditions: (a) Swallowing.—Subjects continually ingested diluted liquid barium through a straw. The amount of liquid ingested during each swallowing period during all trials was obtained by measuring the amount not swallowed and subtracting this from the initial total (300 ml). The total Volume Swallowed was averaged across the two trials for each task. The Number of Swallows during continual ingestion across all conditions was summed using the video recordings and was averaged across trials for each task. The Volume per Swallow was calculated by dividing the total amount ingested across the two 10-sec. periods by the number of swallows with averaging across the two trials. The Volume Swallowed per Second was derived for each trial by dividing the total volume ingested by 10 sec. (the duration of each trial). Results were averaged across the two trials.

(b) Finger tapping.—Using their index fingers, subjects tapped on a board that had a counter attached to register the number of taps. Subjects were instructed to tap as quickly as possible. The number of finger taps was obtained from the counter and averaged across the two trials. Hand order was randomized within subjects and across tasks.

(c) Repetition.—Subjects continually repeated the three-word set “wolf-butterfly-duck.” Subjects were instructed to repeat the word set as fast as possible. The baseline repetition tasks were recorded to obtain the number of repetitions. The total number of word sets was obtained for each 10-sec. period and averaged across trials.

Interference condition without swallowing: Verbal-manual interference
paradigm.—Subjects repetitively tapped with the left and right index finders as they repeated the three-word set “wolf-butterfly-duck.” The number of finger taps for each finger was obtained from the counter and averaged across the two trials. To obtain the percentage reduction in tapping rate for the entire sample, the following formula was used \[ \frac{(BTR-ITR)}{BTR} \times 100 \], where BTR was the mean Baseline Finger-tapping Rate and ITR was the mean Finger-tapping Rate with the Word Repetition Interference (Kee, et al., 1983).

Interference conditions with swallowing: (a) Swallowing–manual interference paradigm.—Subjects continuously ingested diluted liquid barium through a straw as they repetitively tapped with the index fingers. Total Volume Swallowed, Number of Swallows, Volume per Swallow, and Volume per Second data were obtained in the same fashion as for baseline swallowing. The number of finger taps for each hand was obtained from the counter and averaged across trials. Interference effects were examined in two conditions, the effects of swallowing on finger-tapping rates and the effects of finger tapping on swallowing parameters.

(b) Swallowing–language interference paradigm.—Subjects silently and continuously repeated the three-word set while ingesting diluted liquid barium through a straw. Subjects were instructed to not vocalize the words in this condition but to rapidly and repeatedly think the three-word set. Confirmation of repetition via self-report was ascertained after each trial; however, subjects were not expected to calculate mentally the number of repetition sets as this would have involved language processes other than repetition. Total Volume Swallowed, Number of Swallows, Volume per Swallow, and Volume per Second were calculated and averaged across the two trials.

Design.—Effects of language on manual tasks were assessed via a two-way repeated-measures analysis of variance, with independent variables Finger Tapping Side (Left, Right) and Interference (Baseline, Repetition). The dependent variable for this analysis was Tapping Rate. The a priori hypothesis that the effect of Word Repetition Interference on Finger Tapping would be greater for Right Index Finger Tapping than for Left was tested via paired-sample t tests.

Effects of swallowing on manual tasks were assessed via a two-way repeated measures analysis of variance, with independent variables Finger Tapping Side (Left, Right) and Interference (Baseline, Swallowing). The dependent variable for this analysis was Tapping Rate.

The effects of finger tapping and language on swallowing were assessed via a one-way repeated-measures multivariate analysis of variance, with independent variable Interference (Baseline, Right Index Finger Tapping, Left Index Finger Tapping, Silent Word Repetition). The dependent variables for this analysis were Number of Swallows, Volume Swallowed, Volume per Second.
Swallow, and Volume per Second. It is important to note that perfect multicollinearity exists among the first three of the dependent variables listed, i.e., any one of the variables Number of Swallows, Volume Swallowed, and Volume per Swallow can be computed if one knows the values of the other two. Because all three measures were of theoretical interest, we were willing to accept the inflation of the error term associated with the inclusion of multicollinear measures (Tabachnik & Fidell, 1996) to allow examination of all variables.

Data are reported as mean ± standard deviation unless stated otherwise. Alpha was set at .05.

**RESULTS**

*Hand Preference and Neuropsychological Assessment*

Subjects had a mean score on the handedness inventory of 21.21 ± 3.04 indicating they were strongly right-hand dominant. The baseline finger-tapping rates for all subjects was greater for the right index finger ($M=55.0±4.8$) than the left ($M=46.7±5.2$; $t_{13}=6.57$, $p<.005$), as expected for right-hand dominance. The subjects had a mean score of 29.6 ± 9 on the Mini-Mental State Examination (Folstein, et al., 1975), and all of their scores were greater than or equal to 27. Paired $t$ tests indicated no significant differences in gesture production between the right hand ($M=54.6±4.4$) and the left hand ($M=52.9±5.0$; $t_{13}=1.91$, $p=.08$).

*Effects of Language on Manual tasks*

Mean rates of the manual tasks (Right Index Finger Tapping, Left Index Finger Tapping) across conditions are shown in Table 1. Right Index Finger-tapping Rate was significantly faster than Left Index Finger-tapping Rate ($F_{1,13}=36.60$, $p<.005$). Finger-tapping Rate significantly decreased with the Word Repetition Interference ($F_{1,13}=5.16$, $p=.04$). The Finger Tapping Side by Interference interaction was not significant ($F_{1,13}=2.29$, ns). As the expected significant interaction was not obtained, two $t$ tests were completed to investigate further the interaction effect. Analysis gave a significant effect of Word Repetition Interference on Right Index Finger-tapping Rate.

**TABLE 1**

<table>
<thead>
<tr>
<th>Task</th>
<th>Condition</th>
<th>Baseline</th>
<th>Word Repetition</th>
<th>Swallowing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Right Index Finger Tapping</td>
<td>Baseline</td>
<td>55.0</td>
<td>4.8</td>
<td>50.8</td>
</tr>
<tr>
<td>Left Index Finger Tapping</td>
<td>Word Repetition</td>
<td>46.7</td>
<td>5.2</td>
<td>45.3</td>
</tr>
<tr>
<td></td>
<td>Swallowing</td>
<td>51.1</td>
<td>7.9</td>
<td>43.5</td>
</tr>
</tbody>
</table>

the Word Repetition Interference ($F_{1,13}=5.16$, $p=.04$). The Finger Tapping Side by Interference interaction was not significant ($F_{1,13}=2.29$, ns). As the expected significant interaction was not obtained, two $t$ tests were completed to investigate further the interaction effect. Analysis gave a significant effect of Word Repetition Interference on Right Index Finger-tapping Rate.
(t₁,₃ = 3.21, p = .007) but not on Left Index Finger-tapping Rate (t₁,₃ = .78, ns). The mean percentage in reduction of Tapping Rate from Baseline with Word Repetition Interference was 7.8 for the Right Index Finger and 3.0 for the Left Index Finger.

**Effects of Swallowing on Manual Tasks**

Table 1 presents the mean Finger-tapping Rates at Baseline and with the Swallowing Interference. Tapping Rate with the Right Index Finger was significantly faster than with the Left Index Finger (F₁,₁₃ = 25.96, p < .005). Finger-tapping Rates during the Swallowing Interference were significantly lower than Baseline Finger-tapping Rates (F₁,₁₃ = 8.45, p = .01). The Interference by Finger Tapping Side interaction was not significant (F₁,₁₃ = .12, ns).

**Effects of Interference on Swallowing**

Mean rates and volumes for swallowing at baseline and with manual and language interference are shown in Table 2. At the multivariate level there was a significant main effect for Interference (Wilks lambda = .640, F₉,₉₀ = 2.01, p = .05). Univariate tests were then performed for each of the four swallowing parameters. A significant effect of Interference was found only for the Volume per Swallow variable (F₁,₁₀ = 4.39, p = .009). To examine which Interference variable affected swallowing, post hoc pairwise comparisons were performed for Volume per Swallow. The Volume per Swallow was significantly lower in the Silent Repetition condition than Right Finger Tapping (p = .02) and Left Finger Tapping (p = .02) conditions and was not significant as compared to Baseline swallowing (p = .06).

**TABLE 2**

<table>
<thead>
<tr>
<th>Swallowing Parameter</th>
<th>Interference Condition</th>
<th>Baseline</th>
<th>Right Finger Tapping</th>
<th>Left Finger Tapping</th>
<th>Silent Word Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>No. of Swallows</td>
<td></td>
<td>0.25</td>
<td>2.11</td>
<td>9.43</td>
<td>1.65</td>
</tr>
<tr>
<td>Volume Swallowed, ml</td>
<td></td>
<td>111.25</td>
<td>52.90</td>
<td>113.39</td>
<td>62.28</td>
</tr>
<tr>
<td>Volume per Swallow, ml</td>
<td></td>
<td>11.28</td>
<td>6.05</td>
<td>12.02</td>
<td>6.77a</td>
</tr>
<tr>
<td>Volume per Second, ml/sec</td>
<td></td>
<td>11.12</td>
<td>5.29</td>
<td>11.34</td>
<td>6.23</td>
</tr>
</tbody>
</table>

a,bFor the interference effect within the Volume per Swallow row, means with like superscripts are not significantly different (p = .05).

**Discussion**

Lateralization of swallowing is controversial, and findings are contradictory. This study was undertaken to identify possible lateralization of swallowing using a dual task paradigm in a group of healthy right-handed subjects. Analysis indicates that Swallowing interferes bilaterally with a concurrent
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manual task of Finger Tapping. Furthermore, Silent Word Repetition significantly interfered with Volume per Swallow in a concurrent swallowing task. While a portion of our findings support a model of bilateral cerebral hemisphere activation of swallowing, a specific left hemispheric contribution to swallowing also appears evident based on decrements in the volume per swallow that occurred with the language task.

Previous research has found interference of verbalization on right-hand finger-tapping rates in both right-handed and left-handed subjects (Murphy & Peters, 1994; Fearing, Browning, Corey, & Foundas, 2001). Our sample consisted of self-professed right-handed subjects all of whom demonstrated right-hand dominance on a handedness questionnaire and a motor task. We initially tested the effects of Verbal Interference on Finger-tapping Rates to confirm the activation of the left hemisphere. All subjects showed the expected right-hand advantage for finger-tapping rate and declines in tapping rates for both hands were evident with verbal interference. We expected to observe a significant difference in the magnitude of interference for right and left index fingers; however, this expected significant interaction was not found. When examining the means, the effect of verbal interference was in the expected direction. That is, the decline in Right Index Finger-tapping Rate with Word Repetition Interference was greater than the decline in Left Index Finger-tapping Rate. Moreover, the percentage reduction difference between Finger Tapping Sides was similar to previous results (Kee, et al., 1983). Although there was no significant interaction in the repeated-measures analysis, analyses of manual tasks indicated a significant Right Side effect of concurrent verbalization but not a Left Side effect.

Our data appear consistent with bilateral interference of concurrent swallowing on the motor task, thus offering support for bilateral hemisphere activation for swallowing. Bilateral activation of the sensorimotor cortex during swallowing has been identified using the functional imaging methodologies of PET and fMRI (Hamdy, Mikulis, Crawley, Xue, Lau, Henry, & Diament, 1999; Zald & Pardo, 1999). Moreover, certain studies of focal lesions in stroke patients have found no association between hemisphere lesioned and dysphagia (Chen, et al., 1990; Alberts, et al., 1992; Johnson, et al., 1992; Daniels, et al., 1999; Daniels & Foundas, 1999). If one assumes a bilateral representation for swallowing, the bilateral decline in finger-tapping rates with concurrent verbalization supports the cerebral space model. Swallowing and finger tapping are both predominantly driven by the motor cortices. The motor-hand representation is anatomically close to the representation of the face, larynx, and pharynx, thus coactivation of these anatomically close neural substrates may have yielded the decline in right and left finger-tapping rates with concurrent swallowing. Unilateral distal hand movements, like those used in the right and left index finger-tapping task, are mediated
by the contralateral motor representation of the hands located along the length of the primary motor cortex. Oromotor functions are also mediated by areas of the contralateral motor cortex, so the right sides of the face and oral cavity are controlled by the left primary motor cortex and vice versa. However, there is greater coactivation of the oromotor cortex to initiate swallowing, as coordinated bilateral motor functions are required to produce a swallow. Thus, the requisite motor programs that activate and instruct oral motor units to initiate a swallow are mediated by bilateral motor systems. Our findings support this model of swallowing.

The measure of Volume per Swallow was significantly decreased with the language task of Silent Word Repetition as compared with Right or Left Index Finger Tapping but was nonsignificant when compared with Baseline Finger Tapping. These results suggest that the left hemisphere contributes to swallowing and may be interpreted as consistent with some aspects of swallowing being lateralized. Neural regions activated in swallowing and silent repetition are anatomically close and functionally overlapping. Speech and swallowing share the same musculature with close proximity of the mouth, pharynx, and larynx on the primary motor cortex. Functional imaging studies have identified activation of the left dorsolateral prefrontal cortex and the left supplementary motor cortex in “silent” generation of verbs (Wise, Chollet, Hadar, Friston, Hoffner, & Frackowiak, 1992) and activation of the left primary motor cortex during “silent” repetition (Warburton, Wise, Price, Weiller, Hadar, Ramsay, & Frackowiak, 1995). These same areas are activated during swallowing (Hamdy, Mikulis, Crawley, Xue, Lau, Henry, & Diamont, 1999; Hamdy, Rothwell, Brooks, Bailey, Aziz, & Thompson, 1999; Zald & Pardo, 1999).

When inspecting the means for the effect of Interference on Swallowing, the Number of Swallows decreased with manual interference but was maintained with language interference as compared to baseline. Conversely, the Volume Swallowed was generally maintained as compared to baseline with the manual tasks but declined with the language interference. This finding is interesting; however, the basis driving it is unclear. Finger Tapping, which is a motor task, may set the pace for swallowing rate by influencing the rhythm and timing of the suck-swallow pattern. As one focuses on the distal motor task, the proximal motor task, Number of Swallows, may show a decrement in response. Silent Word Repetition involves activation of motor speech regions, which suggests output to articulatory musculature (Warburton, et al., 1995). It may be that less volume is required to initiate oral transfer given this subvocalization stimulation of the tongue and other oral muscles during Silent Word Repetition.

Although these data suggest that the left hemisphere motor and language systems are associated with some swallowing behavior, other processes
such as overload of attentional demands and allocation of resources may be contributing to the observed interference in the dual task paradigm. Furthermore, we cannot conclude that the left hemisphere is more important than the right hemisphere in mediating swallowing because we did not study the effect of a higher-order right hemisphere task on swallowing. In further studies, researchers should explore right hemisphere contributions to swallowing behavior via a dual task paradigm with tasks that selectively activate the right hemisphere.

REFERENCES


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