Dysphagia (2011) 26:311–317
DOI 10.1007/s00455-010-9313-1

ORIGINAL PAPER

Effects of Repeated Volitional Swallowing on the Excitability of Submental Corticobulbar Motor Pathways

Aamir K. Al-Toubi · Ali Abu-Hijleh · Maggie-Lee Huckabee · Phoebe Macrae · Sebastian H. Doeltgen

Received: 21 April 2010 / Accepted: 22 October 2010 / Published online: 9 November 2010

Abstract The aim of this study was to examine the effects of repeated volitional saliva swallowing on corticobulbar excitability recorded during two muscle preactivation conditions of the submental muscle group. Motor-evoked potentials (MEPs), elicited by transcranial magnetic stimulation (TMS), were assessed in ten healthy volunteers prior to and at 5, 30, 60, and 90 min after 60 volitional saliva swallows (Protocol A). To control for intrinsic fluctuations in corticobulbar excitability during this assessment period, MEPs were also recorded, on a different day, at 30-min intervals across a 2-h period (Protocol B). At each assessment, 15 MEPs were recorded during two submental muscle preactivation conditions: volitional contraction and contraction associated with the pharyngeal phase of volitional swallowing. There were no significant effects of repetitive volitional swallowing or time on MEP measures ($p > 0.05$). We conclude that volitional saliva swallowing does not have immediate effects on the excitability of corticobulbar projections to the submental musculature during volitionally initiated swallowing motor tasks. These results provide no evidence for use-dependent potentiation of corticobulbar excitability through repetitive saliva swallowing. The lack of effects of time on mean MEP measures supports previous reports of good intrasession reliability of MEPs as a measure of corticobulbar excitability.

Keywords Corticobulbar excitability · Deglutition · Motor-evoked potentials · Transcranial magnetic stimulation · Deglutition disorders

A. K. Al-Toubi (✉) · A. Abu-Hijleh · M.-L. Huckabee · P. Macrae · S. H. Doeltgen
Department of Communication Disorders, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand
e-mail: akt35@uclive.ac.nz

A. Abu-Hijleh
e-mail: ahi28@uclive.ac.nz

M.-L. Huckabee
e-mail: maggie-lee.huckabee@canterbury.ac.nz

P. Macrae
e-mail: phoebe.macrae@vanderveer.org.nz

S. H. Doeltgen
e-mail: sebastian.doeltgen@adelaide.edu.au

A. K. Al-Toubi · A. Abu-Hijleh · M.-L. Huckabee · P. Macrae
Van der Veer Institute for Parkinson's and Brain Research, 66 Stewart Street, Christchurch 8020, New Zealand

S. H. Doeltgen
Neuromotor Development and Plasticity Research Group, School of Paediatrics and Reproductive Health, The Robinson Institute, The University of Adelaide, Adelaide, SA 5005, Australia

Rehabilitative exercises for disordered swallowing often actively recruit individuals' residual ability to swallow. For example, swallowing attempts performed with effort increase pharyngeal pressure generation (effortful swallow [1–4]) or improve laryngeal excursion and upper esophageal sphincter (UES) opening (Mendelsohn maneuver [5]). Placing the tongue between the incisors during swallowing poses biomechanical resistance to the pharyngeal constrictor muscles, consequently increasing posterior pharyngeal wall protraction (tonguehold maneuver [6, 7]) and UES peak relaxation pressure in healthy volunteers [8].

Volitional swallowing paired with electrical stimulation (neuromuscular electrical stimulation, NMES) of the submental musculature can bidirectionally modify corticobulbar excitability, evidenced by changes in motor-evoked potential (MEP) amplitude [9]. Similar findings were

reported after electrical stimulation of the musculature underlying the pharyngeal [10] and faucial pillar mucosa [11], with changes generally lasting for up to 60 min following stimulation. In contrast, when sensory perception was reduced by applying oropharyngeal anesthesia to the mucous membranes of the pharynx, MEP amplitude was significantly decreased [12]. Results from these studies provide evidence for the functional relevance of corticobulbar excitability in swallowing motor control in that MEP size was related to swallowing function [9–12].

Taken together, these studies suggest that volitional swallowing paired with rehabilitative modalities transiently affects swallowing biomechanics and underlying neural mechanisms. However, a potential confound in studies pairing rehabilitative approaches with volitional swallowing is that repeated volitional swallowing may itself alter swallowing biomechanics or neurophysiology. It is, therefore, unclear whether changes observed in swallowing biomechanics and neurophysiology result from the combined application of swallowing and rehabilitative intervention or from repeated swallowing alone. In fact, it has previously been shown that 200 repetitions of volitional water swallows increase the excitability of pharyngeal corticobulbar motor projections in the short term [12]. However, in that study it was not clear whether the sensory stimulation of the water bolus, the repeated performance of swallowing, or a combination of both yielded the changes in corticobulbar excitability in this study.

In the present study, we examined whether repeated saliva swallowing, which provides minimal extrinsic behavioral or sensory modulation of swallowing, has short-term effects on the excitability of submental corticobulbar motor projections. Corticobulbar excitability was assessed in the functional context of two swallowing-related preactivation conditions: submental muscle contraction during volitional pharyngeal swallowing and volitional contraction of the submental muscle group. Evaluation of corticobulbar excitability during swallowing is of significant clinical relevance, and, in addition, it has previously been shown that preactivation of the target muscle is necessary to elicit distinguishable MEPs in the facial muscles [13, 14].

Given that swallowing is a highly automated motor response that is heavily controlled by the central pattern generator in the brainstem [15–17], it was hypothesized that repeated volitional saliva swallowing would not affect submental corticobulbar excitability. This hypothesis was based on studies that have identified larger cortical activation during the initiation of swallow-related motor tasks, e.g., volitional tongue movement, when compared to volitional swallowing [18, 19], suggesting that while the primary motor cortex may play a role in the initiation of the oral phase of swallowing, the remaining phases of the swallowing process may be more heavily controlled by subcortical swallowing regions [18, 19].

Methods

Subjects

Ten subjects with identifiable submental MEPs [5 females, mean age = 24.5 years (SD = 5.9 years)] completed the study. Subjects provided written informed consent and reported no relevant medical history or current symptoms of dysphagia. This study was approved by the appropriate Regional Health and Disability Ethics Committee.

Experimental Protocol

The procedures followed in this study have been reported to allow reliable measurement of corticobulbar excitability during pharyngeal swallowing within and across sessions [20]. Subjects were seated in a comfortable chair. Two surface electrodes (BRS-50K, Blue Sensor^{TM}, Ambu, Denmark) were placed approximately 1 cm apart at midline over the submental musculature. A reference electrode was placed over the bony aspect of the mandibular ramus. All electrodes were connected to an amplifier (Dual Bio Amp, ML 135^{TM}, ADInstruments, Castle Hill, Australia) and a recording system (Powerlab 8/30^{TM}, ML 870, ADInstruments). Data were stored on a personal computer for offline analysis.

Subjects completed two research protocols on separate days in counterbalanced order.

Experimental Protocol A: Repeated Volitional Saliva Swallowing

After baseline assessment, subjects were asked to swallow volitionally 60 times in response to a visual cue. Once 60 swallows were completed, corticobulbar excitability was reassessed at 5, 30, 60, and 90 min following the swallowing trials.

Experimental Protocol B: No Experimental Modulation (Rest)

After baseline assessment, subjects rested in a comfortable chair for 25 min before corticobulbar excitability was reassessed at 5, 30, 60 and 90 min following the rest period. This experimental protocol served as a control condition to assess intrinsic fluctuations of corticobulbar excitability across a 2-h period in the absence of any experimental modulation of corticobulbar excitability. For both experimental protocols, blocks of 15 MEPs were recorded during each of two muscle preactivation conditions: volitional contraction of the submental muscle group and contraction of these muscles during volitional pharyngeal saliva swallowing (Fig. 1), at baseline and 5, 30,

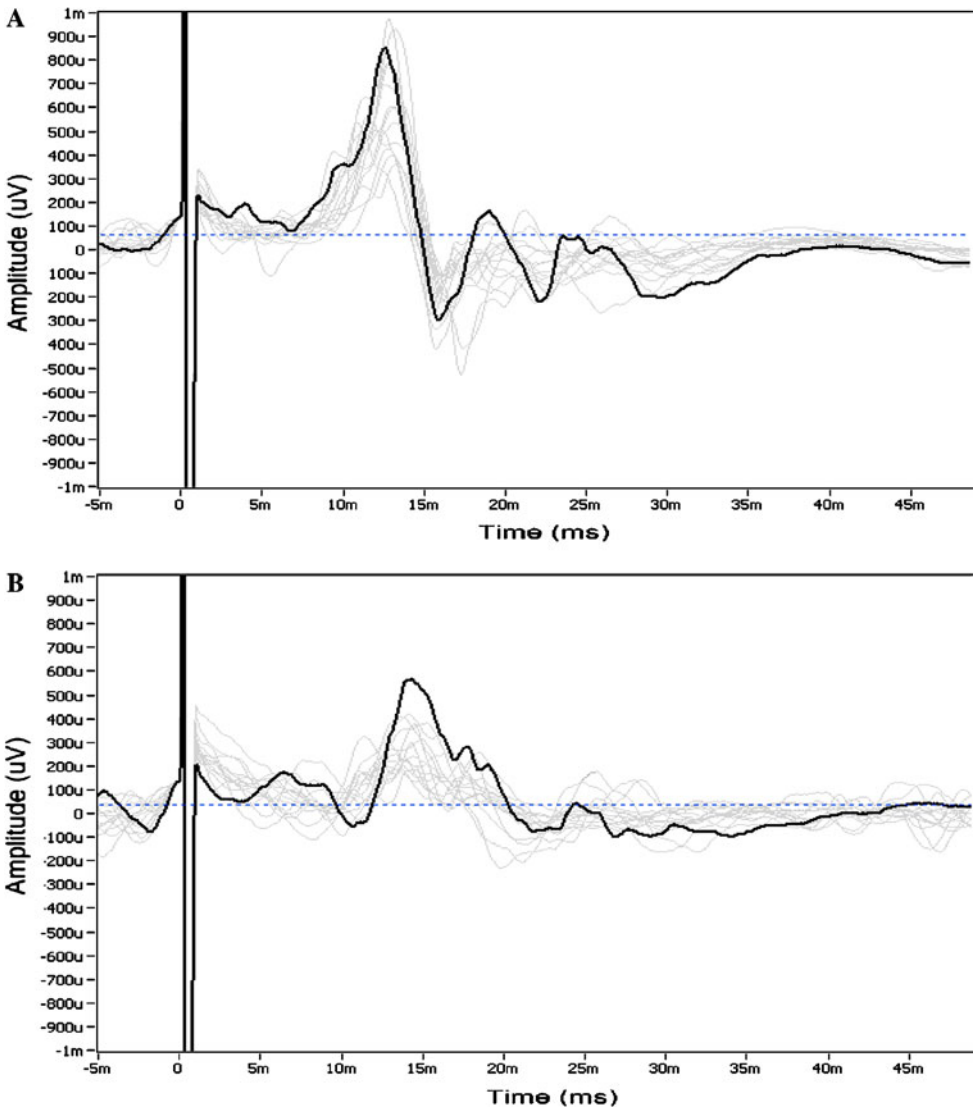

Fig. 1 MEP waveforms of one representative participant recorded during **a** volitional contraction and **b** volitional pharyngeal swallowing. Fifteen overlaid MEP traces are displayed, with one MEP waveform *highlighted in bold*

60, and 90 min after subjects had completed the experimental protocol.

Transcranial Magnetic Stimulation

Focal transcranial stimulation of the motor cortex was achieved with a magnetic stimulator connected to a figure-8 coil with an outer diameter of 90 mm and a maximal output of 2.2 T (Magstim 200^{TM}, Magstim Company Limited, Whitland, Wales). The coil was positioned laterally over the scalp with the handle pointing backward at an approximate angle of 45° to the sagittal plane. The location over which maximal submental MEPs could be evoked consistently was marked on the scalp. Subsequently, TMS intensity was increased until MEP amplitude did not increase or maximal stimulator output was reached. For all subsequent experiments, data were recorded at a TMS intensity that evoked approximately half-maximal MEPs. This procedure was performed over the subject's left and right hemispheres in counterbalanced order to identify the hemisphere over which largest motor responses could be evoked. All subsequent measurements were recorded from this hemisphere.

For the *volitional contraction* condition, subjects were instructed to "Imagine you are stifling a yawn. Try to open your mouth, but at the same time, contract your cheek muscles to prevent the jaw from opening." For the *volitional pharyngeal swallowing* condition, subjects were instructed to "Swallow your saliva and keep the tongue as relaxed as possible during swallowing." Single swallows were performed with a rest period of at least 10–15 s in between swallows. If multiple swallows occurred inadvertently, the trial was excluded and repeated. Online surface electromyographic (sEMG) activity was displayed on a computer screen for visual feedback. Subjects matched the amplitude of muscle activation during the

contraction task to that displayed during the pharyngeal swallowing task.

TMS was triggered automatically from submental sEMG. Trigger threshold was defined as 75% of the average sEMG amplitude of ten volitional saliva swallows. In all experiments, this threshold was maintained for both muscle preactivation conditions to ensure TMS triggering at matched sEMG levels.

Statistical Analysis

For each muscle preactivation condition, each block of 15 MEPs was averaged for each subject and each assessment time. Mean MEP amplitude at each postintervention assessment was expressed as the percentage of the subject's mean MEP recorded at baseline. Separate repeated-measures analyses of variance (ANOVAs) were performed on these measures of change for MEP amplitude and onset latency, with the within-subject variable of time (baseline and 5, 30, 60, and 90 min).

Results

Group mean MEP amplitudes and onset latencies at baseline did not differ between the two experimental sessions ($p > 0.05$) (Fig. 2).

MEP Amplitude

There were no significant main effects of time after repeated swallowing (protocol A) on MEP amplitudes recorded during volitional contraction [$F_{(4,36)} = 0.283$, $p = 0.887$] or volitional pharyngeal swallowing [$F_{(4,36)} = 0.609$, $p = 0.659$]. Likewise, there were no significant main effects of time after the resting condition (protocol B) on

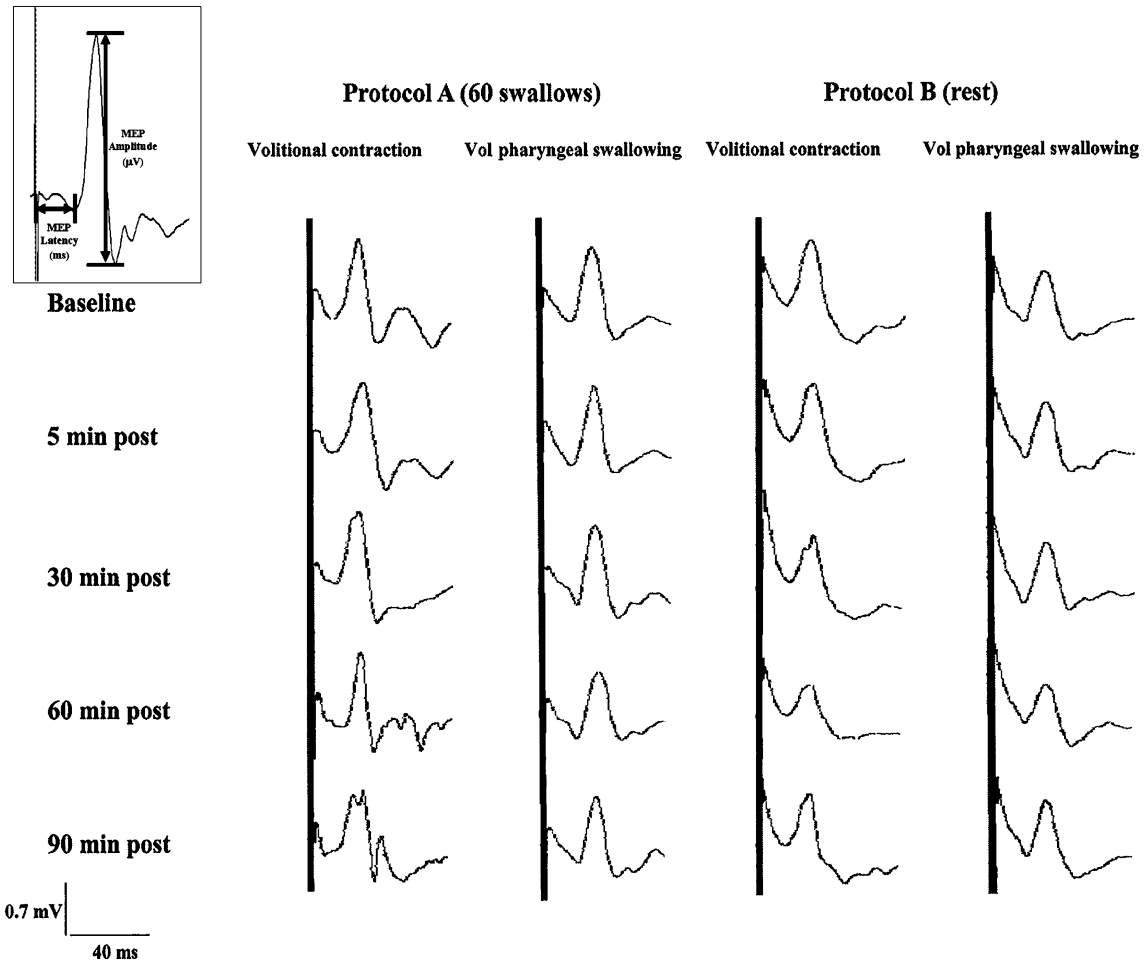

Fig. 2 Mean motor-evoked potential (MEP) waveforms of one representative subject recorded during two muscle preactivation conditions: volitional contraction and contraction associated with pharyngeal swallowing. The illustration *inset* in *top left-hand corner* indicates the MEP measures analyzed in this study. Specifically, these are MEP amplitude, defined as the difference between the first positive and first negative peak of the MEP waveform, and MEP onset latency, defined as the latency between stimulus onset and the onset of the MEP

Table 1 MEP amplitudes (in μV) recorded at baseline and at four post-treatment assessments during the VC and VPS contraction conditions

Assessment time	Protocol A		Protocol B	
	VC	VPS	VC	VPS
Pretreatment baseline	764.5 (326.4)	641.87 (472.88)	757.83 (307.6)	583.4 (193.6)
5-min post-treatment trial	692.95 (331.07)	603.43 (309.38)	847.4 (339.54)	600.9 (252.8)
30-min post-treatment trial	767.2 (438.4)	586.9 (359.17)	746.63 (327.53)	566.7 (231.94)
60-min post-treatment trial	827.05 (510.7)	635.32 (354.5)	704.87 (363.6)	618.8 (266.75)
90-min post-treatment trial	721.75 (430.4)	596.5 (354.46)	737.1 (308.85)	577.87 (208.42)

Values are mean and standard deviation in parentheses

VC volitional contraction, *VPS* volitional pharyngeal swallowing

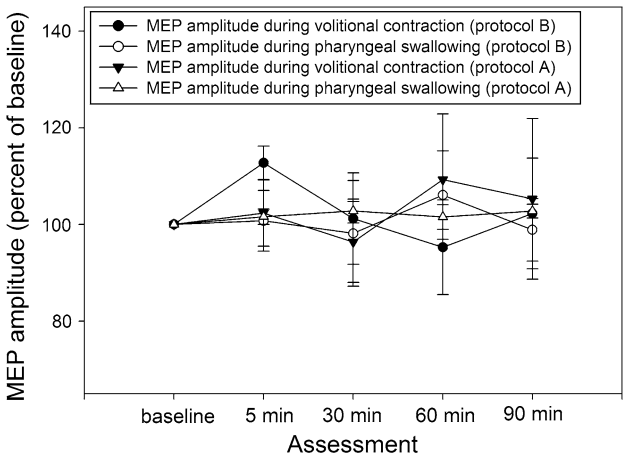

Fig. 3 MEP amplitude relative to baseline and standard error of the mean (SEM) following 60 volitional saliva swallows (protocol A) and 25 min of rest (Protocol B). MEPs were recorded during two muscle preactivation conditions (volitional contraction and volitional pharyngeal swallowing)

MEP amplitudes recorded during volitional contraction [$F_{(4,36)} = 1.223$, $p = 0.313$] or volitional pharyngeal swallowing [$F_{(4,36)} = 0.261$, $p = 0.901$] (Table 1; Fig. 3).

MEP Onset Latency

There were no significant main effects of time after repeated swallowing (protocol A) on MEP onset latencies recorded during volitional contraction [$F_{(4,36)} = 0.609$, $p = 0.659$] or volitional pharyngeal swallowing [$F_{(4,36)} = 1.566$, $p = 0.204$]. There were also no significant main effects of time after the resting condition (protocol B) on MEP onset latencies recorded during volitional contraction [$F_{(4,36)} = 2.383$, $p = 0.07$] or volitional pharyngeal swallowing [$F_{(4,36)} = 0.513$, $p = 0.727$] (Table 2).

Table 2 MEP onset latencies (in ms) recorded at baseline and at four post-treatment assessments during the VC and VPS contraction conditions

Assessment time	Protocol A		Protocol B	
	VC	VPS	VC	VPS
Pretreatment baseline	7.8 (0.42)	8.2 (0.94)	8.3 (0.96)	8.5 (0.93)
5-min post-treatment trial	7.9 (0.6)	8.4 (0.84)	7.9 (0.71)	8.5 (1.08)
30-min post-treatment trial	8.0 (0.75)	8.6 (0.74)	8.14 (0.66)	8.7 (0.73)
60-min post-treatment trial	7.9 (0.77)	8.5 (0.82)	7.9 (0.89)	8.6 (0.84)
90-min post-treatment trial	8.0 (0.53)	8.6 (0.78)	7.9 (0.83)	8.5 (0.84)

Values are mean and standard deviation in parentheses

VC volitional contraction, *VPS* volitional pharyngeal swallowing

Discussion

This study documents that a period of repeated volitional saliva swallowing does not affect the excitability of corticobulbar pathways to the submental musculature when assessed during volitional contraction or volitional pharyngeal saliva swallowing. In addition, these results show that mean corticobulbar excitability does not significantly fluctuate across a 2-h period, as evidenced by stable average MEP amplitudes.

A number of techniques [e.g., magnetic resonance imaging (MRI), positron emission tomography (PET), transcranial magnetic stimulation (TMS)] have identified cerebral activation during swallowing, including the primary sensorimotor cortices. Some researchers have suggested that cortical areas might be activated primarily in the initiation of swallow-related motor tasks, with the rest of the swallowing process heavily controlled by subcortical swallowing regions [18, 19]. In addition, significantly greater activation of cortical and subcortical brain volume during volitional tongue movement compared to a volitional swallowing task has been reported [18, 19]. Differences in cortical activation during swallowing and tongue movement support the notion that parts of the swallowing process, in particular, the reflexive, pharyngeal phase, are heavily controlled by central pattern generators in the

brainstem [15–17]. In contrast, the regulation of voluntary swallowing-related motor tasks such as tongue movement may rely more heavily on upper cortical motor networks [18, 19]. In the context of these previous findings, the lack of changes in corticobulbar excitability in response to repetitive volitional saliva swallowing in this study supports the notion that cortical motor networks may not be as heavily involved in the motor control of pharyngeal swallowing. Similarly, repetitive saliva swallowing paired with electrical stimulation did not affect MEPs recorded during a volitionally initiated pharyngeal swallowing task [9]. In contrast, repetitive performance of the more cortically driven motor task of thumb abduction has been documented to affect corticospinal excitability [21].

Interestingly, the present findings contrast with those of a previous study documenting larger pharyngeal MEPs after repetitive volitional water swallowing [12]. However, methodologies varied between studies in terms of number of swallows, swallowing rate, and bolus. Subjects in the study by Fraser et al. [12] performed 200 water swallows at a rate of one every 5 s. It is possible that the higher number and frequency of repetitions and the added sensory stimulation by the water bolus had greater influence on cortical excitability. Thus, if repetitive volitional swallowing was to be considered as a rehabilitative approach for disordered swallowing, the addition of a water bolus may yield greater effects. However, repetitive water swallowing may not be suitable for individuals who are at risk for aspiration, especially when it is performed at a high frequency.

A confound in studies evaluating the effects of rehabilitative interventions on corticobulbar excitability across a period of time is the high variability of this measure within individuals [22]. This may exaggerate, or mask, the effects induced by rehabilitative interventions. On this note, investigations assessing the reliability of MEPs in measuring excitability of corticobulbar and corticospinal motor projections suggest that averaging multiple trials minimizes the effect of intrinsic variability and improves the reliability of mean MEP measurement [20, 23, 24]. This is in agreement with the absent effect of time on mean MEP measures documented in the present study.

Conclusion

A short interval of repetitive volitional saliva swallowing has no immediate effects on corticobulbar excitability in healthy subjects and mean corticobulbar excitability is stable across a 2-h period, supporting reports of good within-session reliability. Furthermore, studies investigating the cortical excitability of the submental muscle group can rule out any effect of swallowing alone on MEP amplitude and latency. In addition, the changes observed in swallowing biomechanics and neurophysiology when volitional swallowing with rehabilitative modalities are paired could be attributed mainly to the rehabilitative modalities or the combined application of both, but not to swallowing alone. Studies in individuals with dysphagia are warranted to investigate whether a greater number of volitional saliva swallows yields neurophysiological and functional benefits.

References

1. Kahrilas PJ, Logemann JA, Krugler C, Flanagan E. Volitional augmentation of upper esophageal sphincter opening during swallowing. Am J Physiol. 1991;260:G450–6.
2. Kahrilas PJ, Logemann JA, Gibbons P. Food intake by maneuver: an extreme compensation for impaired swallowing. Dysphagia. 1992;7:155–9.
3. Huckabee ML, Butler SG, Barclay M, Jit S. Submental surface electromyographic measurement and pharyngeal pressures during normal and effortful swallowing. Arch Phys Med Rehabil. 2005;86:2144–9.
4. Huckabee ML, Steele CM. An analysis of lingual contribution to submental surface electromyographic measures and pharyngeal pressure during effortful swallow. Arch Phys Med Rehabil. 2006;87:1067–72.
5. Logemann JA, Kahrilas PJ. Relearning to swallow post CVA: application of maneuvers and indirect biofeedback: a case study. Neurology. 1990;40:1136–8.
6. Fujiu MJ, Logemann JA, Pauloske BR. Increased postoperative posterior pharyngeal wall movement in patients with oral cancer: preliminary findings and possible implications for treatment. Am J Speech Lang Pathol. 1995;4:24–30.
7. Fujiu M, Logemann JA. Effect of a tongue-holding maneuver on posterior pharyngeal wall movement during deglutition. Am J Speech Lang Pathol. 1996;5:23–30.
8. Doeltgen SH, Witte U, Gumbley F, Huckabee ML. Evaluation of manometric measures during tongue-hold swallows. Am J Speech Lang Pathol. 2009;18:65–73.
9. Doeltgen SH, Dalrymple-Alford J, Ridding MC, Huckabee ML. Differential effects of neuromuscular electrical stimulation parameters on submental motor evoked potentials. Neurorehabil Neural Repair. 2010;24(6):519–27.
10. Fraser C, Power M, Hamdy S, Rothwell J, Hobday D, Hollander I, Hollander I, Tyrell P, Hobson A, Williams S, Thompson D. Driving plasticity in human adult motor cortex is associated with improved motor function after brain injury. Neuron. 2002;34(5):831–40.
11. Power M, Fraser C, Hobson A, Rothwell J, Mistry S, Nicholson D, Thompson DG, Hamdy S. Changes in pharyngeal corticobulbar excitability and swallowing behaviour after oral stimulation. Am J Physiol Gastrointest Liver Physiol. 2004;286(1):45–50.
12. Fraser C, Rothwell J, Power M, Hobson A, Thompson D, Hamdy S. Differential changes in human pharyngoesophageal motor excitability induced by swallowing, pharyngeal stimulation, and anesthesia. Am J Physiol Gastrointest Liver Physiol. 2003;285:137–44.
13. Cruccu G, Berardelli A, Inghilleri M, Manfredi M. Functional organization of the trigeminal motor system in man. Brain. 1990;112:1333–50.
14. McMillan AS, Watson C, Walshaw G. Improved reproducibility of magnetic stimulation-evoked motor potentials in the human

masseter muscle by a new method for locating stimulation sites on the scalp. Arch Oral Biol. 1998;43:665–8.
15. Jean A. Brainstem control of swallowing: localization and organization of the central pattern generator for swallowing. In: Taylor A, editor. Neurophysiology of the jaw and teeth. New York: Macmillan; 1990. p. 294–321.
16. Miller RM, Chang MW. Advances in the management of dysphagia caused by stroke. Phys Med Rehabil Clin N Am. 1999;10(4):925–41.
17. Jean A. Brain stem control of swallowing: neuronal network and cellular mechanisms. Physiol Rev. 2001;81:929–69.
18. Kern M, Birn R, Jaradeh S, Jesmanowicz A, Cox R, Hyde J, Shaker R. Swallow-related cerebral cortical activity maps are not specific to deglutition. Am J Physiol Gastrointest Liver Physiol. 2001;280(4):G531–8.
19. Martin RE, MacIntosh BJ, Smith RC, Barr AM, Stevens TK, Gati JS, Menon RS. Cerebral areas processing swallowing and tongue movement are overlapping but distinct: a functional magnetic resonance imaging study. J Neurophysiol. 2004;92(4):2428–43.
20. Doeltgen SH, Ridding M, O'Beirne G, Dalrymple-Alford J, Huckabee ML. Test-retest reliability of motor evoked potentials (MEPs) at the submental muscle group during volitional swallowing. J Neurosci Methods. 2009;178(1):134–7.
21. Bütefisch CM, Davis BC, Wise SP, Sawaki L, Kopylev L, Classen J, Cohen LG. Mechanisms of use-dependent plasticity in the human motor cortex. Proc Natl Acad Sci USA. 2000;97:3661–5.
22. Wassermann EM. Inter- and intra-individual variation in the response to TMS. In: Wassermann EM, Epstein CM, Ziemann U, Walsh V, Paus T, Lisanby SH, editors. The Oxford handbook of transcranial stimulation. New York: Oxford University Press; 2008.
23. Plowman-Prine E, Triggs W, Malcolm M, Rosenbek J. Reliability of transcranial magnetic stimulation for mapping swallowing musculature in the human motor cortex. Clin Neurophysiol. 2008;119:2298–303.
24. Cacchio A, Cimini N, Alosi P, Santilli V, Marrelli A. Reliability of transcranial magnetic stimulation-related measurements of tibialis anterior muscle in healthy subjects. Clin Neurophysiol. 2009;120(2):414–9.

Aamir K. Al-Toubi BSLT

Ali Abu-Hijleh BSLT

Maggie-Lee Huckabee PhD

Phoebe Macrae BSLT

Sebastian H. Doeltgen PhD