AGE (2014) 36:9735
DOI 10.1007/s11357-014-9735-z

Age and gender effects on submental motor-evoked potentials

Oshrat Sella · Richard D. Jones · Maggie-Lee Huckabee

Received: 8 April 2014 / Accepted: 19 November 2014 / Published online: 11 December 2014

Abstract It is not known whether there are age- and/or gender-related differences in magnitude of motor-evoked potentials (MEPs) of the submental muscles. Knowledge of this is important in investigations of neurophysiological aspects of swallowing. Forty healthy participants (20 males, 20 females; 20 young [21–35 years], 20 old [53–88 years]) were recruited. Surface electromyography (EMG) electrodes were placed at midline underlying the submental muscle group. Age- and gender-related differences were evaluated in two neurophysiologic measures of swallowing: MEPs stimulated by single-pulse transcranial magnetic stimulation (TMS) over the motor cortex and surface electromyography (sEMG) recorded from the same submental muscle group during non-stimulated swallows. The older participants had larger MEPs during saliva swallowing than the young participants (p=0.04, d=0.86). Conversely, the older participants had lower amplitude submental EMG activity during non-stimulated swallows (p=0.045, d=0.67). Gender had no significant effect on MEP magnitude and on submental activity during saliva swallowing. There were no effects of age or gender on MEP latencies. These findings suggest deterioration in muscle function with age in a sample of healthy adults presenting with functional swallowing. We speculate that muscular decline is partially ameliorated by increased cortical activity—i.e., increased submental MEPs—so as to preserve swallowing function in healthy older subjects. These findings emphasize the need for different reference points for evaluation of submental MEPs of different age groups.

Keywords MEP · Age · Gender · Submental muscles · Swallowing

O. Sella (✉) · R. D. Jones · M.-L. Huckabee
New Zealand Brain Research Institute,
66 Stewart St, Christchurch 8011, New Zealand
e-mail: oshrat.sella@nzbri.org

R. D. Jones
e-mail: richard.jones@nzbri.org

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

O. Sella · R. D. Jones · M.-L. Huckabee
Department of Communication Disorders,
University of Canterbury,
Christchurch 8140, New Zealand

R. D. Jones
Department of Psychology, University of Canterbury,
Christchurch 8140, New Zealand

R. D. Jones
Department of Electrical & Computer Engineering,
University of Canterbury,
Christchurch 8140, New Zealand

R. D. Jones
Department of Medical Physics and Bioengineering,
Christchurch Hospital,
Christchurch 8011, New Zealand

Present Address:
O. Sella
Department of Communication Sciences and Disorders,
University of Haifa,
Mount Carmel, 31905 Haifa, Israel

Introduction

Normal swallowing enables liquids and solids to pass from the mouth to the stomach (Donner et al. 1985; Gleeson 1999). To protect the airway, the swallowing event must be executed with a high level of coordination and precision (Dodds et al. 1990). Age-related changes in swallowing biomechanics (Butler et al. 2011; Logemann 1990; Robbins et al. 1992; Robbins et al. 1995) may predispose older subjects to dysphagia (swallowing impairment). Age-related changes at the neural level have also been reported, but there are conflicting results from functional magnetic resonance imaging (fMRI) studies. Malandraki et al. (2011) found that older subjects had decreased blood-oxygen-level dependence (BOLD) responses in both primary sensory areas and the posterior BA4 than younger subjects during a water swallowing task. In contrast, Humbert et al. (2009) found greater BOLD responses in several areas, including the primary motor cortex (i.e., BA4 or M1) during swallowing in older subjects compared to younger subjects. The discrepancy between the results of Humbert et al. (2009) and Malandraki et al. (2011) might be explained by difference in bolus size or by differences in statistical analysis. Teismann et al. (2010) compared the somatosensory cortical activation measured from the parietal cortex between younger and older subjects, using magnetoencephalography (MEG). They found that during water swallowing, younger subjects had only beta-frequency band (14–30 Hz) event-related activation, bilaterally, whereas older subjects had alpha-, beta-, and gamma-frequency band (8–100 Hz) event-related activation, bilaterally. Hence, older subjects had a broader neural activity, involving additional neural populations. The older subjects also had greater activation of the somatosensory area (Teismann et al. 2010). Thus, both the somatosensory and the primary motor cortices have been shown to have higher activations in older subjects (Humbert et al. 2009; Teismann et al. 2010).

Exploring M1 function in swallowing is of importance as M1 has been suggested to have a role in initiating the swallowing sequence and in modulating and priming the pharyngoesophageal components of swallowing (Ertekin and Aydogdu 2003; Fraser et al. 2002; Hamdy et al. 1999; Kern et al. 2001; Martin et al. 2001; Martin et al. 2004; Mosier and Bereznaya 2001; Mosier et al. 1999; Suzuki et al. 2003). A simple and non-invasive method for assessing M1 excitability is transcranial magnetic stimulation (TMS). TMS works painlessly by magnetically inducing currents in the brain which, if sufficiently strong, can stimulate and activate cortical neurons. Changes in the excitability of the primary motor cortex can be quantified by measuring the level of activation. This capacity of TMS to measure neural excitability and changes in excitability derives from its ability to access and record synaptic responses and synaptic plastic changes (Monfils et al. 2005). A larger motor response produced by TMS stimulation indicates greater activation of excitatory interneurons, reduced excitability of the inhibitory interneurons, or a greater number of recruited motor neurons (Wassermann et al. 2008). Motor-evoked potentials (MEPs) are measured at the muscle level by either intramuscular or surface electromyography (sEMG) electrodes (Gooden et al. 1999) and represent the muscle activity induced by TMS stimulation of the primary motor area.

TMS is frequently used in research to measure brain physiology (Hallett 2000). Specific to swallowing, TMS has been used to document changes in excitability in M1 as a result of natural recovery of swallowing following stroke (Hamdy et al. 1997, 1998) and to document changes in excitability in M1 following swallowing-related training in healthy adults (Svensson et al. 2006). Thus, single-pulse TMS has the capacity to capture changes in excitability as a result of neural recovery or intervention. It is also likely that TMS can also capture age-related changes in M1.

Increased activation with aging could indicate a more diffuse, less specific, neural response during swallowing. This might serve as a compensatory mechanism to offset what would otherwise be decreased swallowing function with age (Robbins et al. 1992). This is supported by findings from the limb literature, with overactivation of additional brain areas correlating with decreased motor performance in older subjects (Langan et al. 2010). Decreased activation in older subjects could account for a decline in swallowing biomechanics associated with age (Humbert and Robbins 2008; Robbins et al. 1995).

Age- and gender-related differences in MEPs from the submental muscle group during swallowing have not been investigated, while age effects have been indicated in submental muscle activity during swallowing (Vaiman et al. 2004). The question of age and gender effects on MEPs was explored as a by-product of analyzing data for another research hypothesis. The aim of

Table 1 Subjects with swallowing MEPs (n=28): age in years (mean±SD) in each age group, by gender in each age group, and by age group in total

Age group	Gender	Handedness	Age by gender (range)	Age by age group (range)
Young (n=14)	Female (n=9)	Right n=8, left n=1	24.7±4.6 (21–35)	24.9±4.3 (21–35)
	Male (n=5)	Right n=4, left n=1	25.2±4.0 (21–30)	
Old (n=14)	Female (n=6)	Right n=4, left n=2	65.2±8.7 (53–77)	67.1±9.9 (53–85)
	Male (n=8)	Right n=6, ambi n=2	68.5±11.1 (54–85)	

Ambi ambidextrous

the current study was to determine the presence and extent of age and gender effects on submental MEPs during swallowing, as any such effects would likely have methodological ramifications on the measurement of neurophysiological changes following swallowing rehabilitation.

Methods

This study was approved by a regional health ethics committee. Written informed consent was obtained from the subjects. The study conformed to the standards of the *Declaration of Helsinki*.

Participants

Forty healthy adults were recruited (younger group: mean±standard deviations (SD)=25±4, range=21–35, 11 females, 9 males; older group: mean±SD=69±9.5, range=53–88, 9 females, 11 males). Participants had no medical history of dysphagia or neurological disorders. Submental sEMG and submental MEPs were recorded on the same day, with task order counter-balanced across subjects. MEPs were elicited in 29 subjects during volitional saliva swallowing; inability to elicit submental MEPs in some healthy subjects has been previously reported (Abdul Wahab et al. 2010; Doeltgen et al. 2010). One subject from the older group (88-year-old female) had an MEP magnitude larger than 3 SD that of her age group mean and, hence, was excluded as an outlier. Thus, MEP data were analyzed from 28 subjects (Table 1), and submental sEMG data were recorded from all subjects (n=40). MEPs were not available from one young female, six young males, four older females, and two older males.

Instrumentation

A Magstim 200™ transcranial magnetic stimulator (Magstim Company Limited, Whitland, Wales, maximal output of 2.2 T) with a figure-of-eight coil (outer wing diameter 70 mm) was used. Three surface electrodes (neonatal solid gel electrodes, BRS-50K, Blue Sensor™, Ambu, Denmark) were used to collect the MEP data. A shielded cable connected the electrodes to an EMG amplifier (Dual Bio Amp™, ML135, ADInstruments, Castle Hill, Australia). The EMG amplifier was connected to a custom-built triggering device, which was connected to the data acquisition system (Powerlab™ 8/30, ML870, ADInstruments, Castle Hill, Australia) that recorded the data and consequently transferred it to the data analysis software (Scope™ version 3.9.1, ADInstruments, Castle Hill, Australia). Data were acquired at 10 kHz, using a high-pass filter at 10 Hz and a low-pass filter at 2 kHz.

As a point of comparison to stimulated swallows, an additional data set of submental sEMG signals were obtained post hoc during non-stimulated swallows using a single disposable circular patch containing three silver/silver chloride electrodes (disposable pre-gelled electrode pad, Multi-BioSensors Inc., El Paso, TX, USA) arranged in a triangular configuration. Two electrodes were designated for recording and the third was used as ground. The sEMG signals were recorded and processed using the KayPENTAX Swallowing Signals Lab (KayPENTAX Inc., Lincoln Park, NJ, USA). Sampling frequency for sEMG signals was 500 Hz. The raw signal was band-pass filtered (50–250 Hz), rectified, and then smoothed by integration with a 50-ms time constant.

Procedure

Submental MEPs and submental sEMG were collected in a single session but separately. Participants were

seated in a comfortable chair in the examination room. For submental MEP recording, two surface electrodes were placed externally, in the midsagittal plane, overlying the floor-of-mouth muscle group. Hence, electrical activity was collectively registered primarily from right and left anterior belly of digastric, right and left mylohyoid, and right and left geniohyoid muscles (Athukorala et al. 2014). The electrodes were placed between the posterior, midline aspect of the mandible, and the superior palpable edge of the thyroid cartilage, with an inter-electrode distance of 10 mm. During positioning of the electrodes, the participant was asked to maintain a neutral head position and avoid neck extension. The ground electrode was placed over the bony prominence of the zygomatic bone.

Single-pulse TMS data were collected over the M1 submental-related hotspot during volitional saliva swallowing. To time lock the MEP to muscle activation, TMS was triggered at a threshold that represented 75 % of each participant's mean submental sEMG peak amplitude during ten non-effortful saliva swallows recorded using the same system and settings. To localize the M1 area that sends corticobulbar projections to the submental muscles, TMS was activated at 50–60 % of the maximal output while the subjects were asked to contract the submental muscles. The researcher discharged the TMS over the scalp across an area that extended 4 cm anteriorly and 8–10 cm lateral to the vertex, since this area overlays M1. The hotspot was defined as the scalp site from which the largest and most consistent MEP was stimulated. This procedure was repeated for both hemispheres.

Once the hotspot for each hemisphere was identified, increasing stimulation levels were applied over this location to determine the maximal peak to peak MEP magnitude during volitional submental muscle contraction. Stimulation started from 30 % of the maximal output and was increased in 5 % increments to a level at which no additional increase was seen in MEP amplitude. Three stimulation trials were administered at each level. After reaching a plateau in the MEP response, the maximal MEP amplitude was identified from the recorded traces by measuring the peak-to-peak amplitude. An MEP response with an amplitude approximately half of the maximal MEP was identified among the collected traces, and the level of stimulation needed to elicit this half-sized MEP was noted and confirmed by further stimulation.

For both tasks, a light signal was used to prompt the subject to activate the submental muscles every 30 s. For the volitional saliva swallowing task, the subjects were asked to "Swallow your saliva; try to swallow with no effort, as you usually swallow." The task consisted of 15 repetitions.

A custom-designed software package (UC Evoked Potentials Analysis software) was used to measure the onset and magnitude of the MEPs. Latency and magnitude were quantified based on the rectified ensemble-average waveform from the 15 sweeps. The MEP onset latency was determined as the time point (in ms) at which the waveform departed the baseline followed by a rapid constant raise toward a peak. In order to avoid EMG activity which was non-MEP-related, the onset had to be equal to or greater than 2 SD above the pre-stimulus background EMG level. The pre-TMS stimulation EMG was integrated over the time period 55 ms to 5 ms (50-ms duration) prior to the magnetic stimulation. This was used to determine the averaged background EMG level, and the 2 SD were automatically calculated by the software based on this information. If the onset latency chosen was less than 2 SD above the background EMG level, the time cursor was moved to the closest time point at which this criterion was met. MEP magnitude was determined as the area (in μV ms) between the onset latency cursor and the offset cursor, automatically placed 15 ms after the onset cursor, as suggested in a study that measured MEPs from anterior digastric muscle (Sowman et al. 2009).

For submental sEMG recording, the skin under the chin was cleaned with alcohol swabs prior to electrode placement. Surface EMG electrode placement, underlying the floor-of-mouth muscle group, was similar to that used for MEP recordings. The participants were instructed to "Swallow your saliva with no effort; try to perform a regular swallow." The participants repeated the swallow five times with 30 s rest between trials. Analysis was based on the averaged peak amplitude of the five trials.

It is important to recognize that although sEMG and MEPs were recorded separately, there was no difference between the volitional saliva swallows used to record sEMG and those used to trigger and record TMS-stimulated MEPs.

Statistical analysis

Statistical analyses were conducted using the SPSS statistics package (IBM SPSS Statistics version 19.0).

To evaluate differences in MEPs and sEMG amplitude between younger and older subjects, a Student's *t* test for unpaired samples was used to examine age effects. Significance was set at $\alpha \leq 0.05$ (two-sided). Confidence intervals (95 % CI) are reported for means and mean differences.

Results

Effects of age on MEP magnitude

During volitional saliva swallowing, the older group ($n=14$) demonstrated larger MEP magnitudes ($M=3{,}357$ μV ms, SD=1,239) than the younger group ($n=14$, $M=2{,}510$ μV ms, SD=725) ($t_{21}=2.2$, $p=0.04$, CI=−48–1,644, $d=0.86$). Example MEPs from one of the older participants and one of the younger participants are shown in Fig. 1.

Since a difference was found between the two age groups, a regression analysis was used to examine age-related effects on MEP magnitude. A simple linear regression line was fit to the data as a secondary investigation, acknowledging that data were missing for the age group between 36 and 52 years of age. During volitional saliva swallowing, age significantly predicted MEP magnitude, with an increase in MEP magnitude of 23.6 μV ms for each year of age ($F_{1,26}=8.47$, $p=0.007$, R^2(Adj.)=0.22, $B=23.6$, CI=6.9–40.4, standardized $\beta=0.50$) (Fig. 2).

Effects of age on MEP latency

During volitional saliva swallowing, there was no significant difference in onset latency between the older group ($n=14$, $M=8.76$ ms, SD=1.97) and the younger group ($n=14$, $M=8.25$ ms, SD=1.59) $t_{26}=0.73$, $p=0.46$, CI=−0.89–1.89, $d=0.30$.

Effects of gender on MEP magnitude

For volitional saliva swallowing, there was no significant difference in MEP magnitude between males ($n=13$, $M=3{,}056$ μV ms, SD=1,195) and females ($n=15$, $M=2{,}827$ μV ms, SD=1,010) $t_{26}=0.55$, $p=0.59$, CI=−627–1,085, $d=0.11$.

Effects of gender on MEP latency

During volitional saliva swallowing, there was no significant difference in onset latency between males ($n=13$, $M=8.06$ ms, SD=1.24) and females ($n=15$, $M=8.89$ ms, SD=2.11; $t_{26}=1.24$, $p=0.22$, CI=−0.53–2.20, $d=0.49$).

TMS output (intensity) and hemispheric asymmetry by age group

Additional analyses were undertaken to determine if the TMS output (intensity) used to record the MEPs was different between the age groups and to determine if the hemisphere of the hotspot (right or left) was different between the age groups. Student's unpaired *t* test revealed no significant difference in TMS output between the older subjects ($n=14$, $M=52.1$ %, SD=1.6, CI=48.8–55.5) and younger subjects ($n=16$, $M=54.1$ %, SD=1.5, CI=50.9–57.2) ($t_{28}=0.88$, $p=0.38$, CI=−2.6–6.5). Fisher's exact test revealed no significant differences ($p=1.00$) in the side of the hotspot between older subjects ($n=14$, 7 left, 7 right) and younger subjects ($n=16$, 9 left, 7 right).

Effects of age on sEMG peak amplitude

During volitional saliva swallowing, the older group ($n=20$) demonstrated smaller sEMG peak amplitude ($M=37.3$ μV, SD=16.9) than the younger group ($n=20$, $M=59.5$ μV, SD=44.7) ($t_{38}=2.1$, $p=0.045$, CI=0.5–43.8, $d=0.67$).

Effects of gender on sEMG peak amplitude

For volitional saliva swallowing, there was no significant difference in sEMG peak amplitude between males ($n=20$, $M=41.2$ μV, SD=20.7, CI=31.5–50.9) and females ($n=20$, $M=55.6$ μV, SD=44.8, CI=34.6–76.5) ($t_{38}=1.29$, $p=0.20$, CI=−8.0–36.6, $d=0.42$).

Discussion

This is the first study to investigate the effects of age and gender on the magnitude and latency of MEPs recorded from the submental muscles during volitional swallowing of saliva. The study revealed that older subjects produced larger submental MEPs than younger

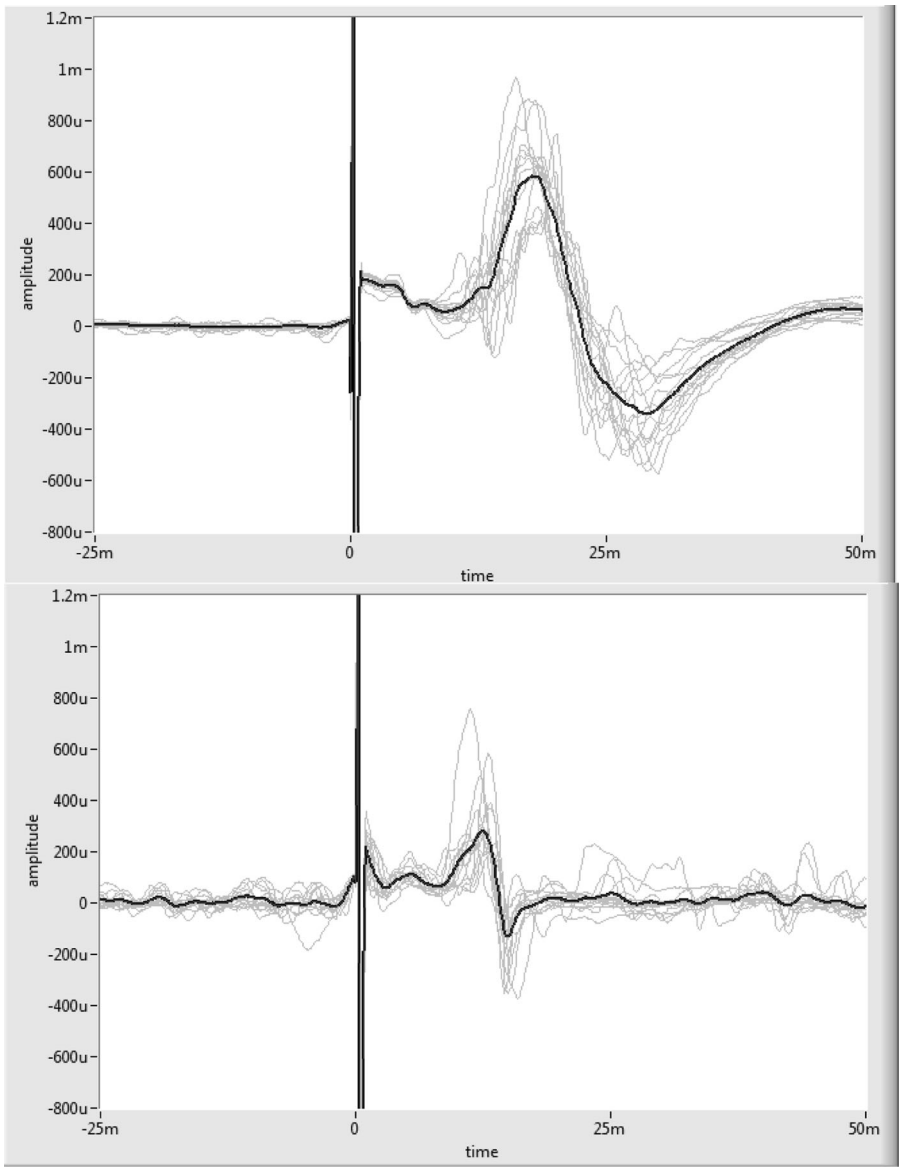

Fig. 1 Illustration of swallowing MEP waveforms from two representative healthy participants. *Top panel*: Female, 72 years old; *lower panel*: female, 23 years old. *Y axis*: Amplitude in microvolts. *X axis*: Time in milliseconds. Displayed are 15 MEPs, with mean MEPs highlighted in *bold*. The *vertical line* at 0 ms displays the magnetic stimulus artifact

subjects but with no difference in latencies. However, for non-stimulated submental activity recorded from the same participant pool, older subjects had smaller amplitude than younger subjects. The study also found no differences in MEP magnitudes, MEP latencies, and sEMG peak amplitude between males and females. Previous research has found no clear relationship between handedness and side of M1 dominancy related to swallowing (Hamdy et al. 1996) and, thus, the imbalance in the distribution of handedness among subjects should have had no impact on results.

Age effects on MEP magnitude and latency and on sEMG amplitude

The current results regarding age-related MEP differences are supported by an fMRI study that found increased hemodynamic M1 activation with increased age

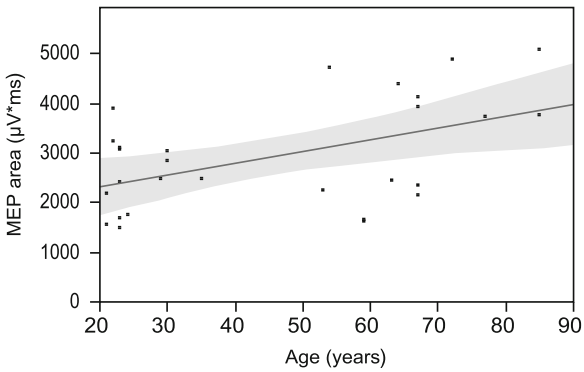

Fig. 2 *Linear regression*: the effects of age (in years) on MEP area (μV ms) during volitional swallowing. The *black line* represents the linear fit, and the *shaded gray* areas around it represent 95 % confidence intervals around the *linear line*

during different swallowing tasks, including saliva swallowing (Humbert et al. 2009). In addition, the results are supported by an MEG study that found increased somatosensory cortical activation in older subjects during water swallowing (Teismann et al. 2010), although their study measured post-central gyrus (S1) activity, rather than M1 activity as measured in the current study. The results from the current study are also consistent with a study that found larger MEPs in hand muscles of older subjects when compared to younger subjects (Bernard and Seidler 2012).

The difference in trends of age effects on stimulated and non-stimulated submental activity is interesting and unexpected. We found that, in comparison to younger subjects, older subjects have lower sEMG amplitude in the non-stimulated condition but have greater magnitude in the stimulated one. Increased MEP magnitude in older subjects might reflect the recruitment of additional cortical areas during task performance, representing a possible compensatory mechanism, without which the non-stimulated submental activity would have been even lower in older subjects. Another possible explanation for the age-related differences in MEP magnitude is cortical disinhibition. This mechanism has not been explored during neural activation of swallowing-related muscles in older subjects, but it has been explored during neural activation limb muscles. Increased MEP magnitude measured from limb muscles has been postulated to be due to decreased excitability of intracortical inhibitory neurons and subsequent enhanced neural activation (McGregor et al. 2011; Peinemann et al. 2001).

Another explanation is that increased MEP magnitude in older subjects might reflect the cortical response to single-pulse TMS, where older subjects had greater gains than younger subjects. The increased MEP magnitude might represent recruitment of additional cortical areas during swallowing in response to the TMS pulse. Indeed, Hamdy et al. (2001) found that cortical stimulation by TMS evoked mylohyoid and oesophageal muscle activation in an anesthetized cat. Thus, single-pulse TMS has already been shown to cause changes in muscle activation. This raises the possibility of using TMS as a therapeutic tool to increase cortical excitability. However, this would need to be confirmed by way of a future study in which functional swallowing data is collected concurrently with the application of single-pulse TMS in humans. Such a study would also ensure that the increased activation and recruitment of additional cortical areas do not actually lead to a disruption of one or more aspects of the precise execution of the sequence and co-occurrence of motor events involved in swallowing.

The current study found age-related differences in sEMG activity. Kleim and Jones (2008) found no age effects in submental muscle activity during various swallowing tasks consisting on different textures and tastes of liquids and solids. However, Vaiman et al. (2004) found a non-significant trend toward a decrease in submental activity during swallowing with age, which supports the current results. Age-related changes in muscle properties, known as sarcopenia (Evans 1995), can affect MEP and sEMG magnitude, since they are recorded from peripheral muscles. It is not clear whether age-related changes exist in submental musculature. However, other swallowing-related muscles were reported to be affected by sarcopenia. For example, reduction of the muscle thickness of the tongue has been reported (Tamura et al. 2012), together with a reduction in the tongue's muscle reserve (Nicosia et al. 2000; Robbins et al. 2005). In addition, changes to slower-contracting motor units in the laryngeal muscles have been reported in aging rats (Suzuki et al. 2002). In humans, age-related changes in pharyngeal muscle composition have been documented, along with decline in endurance (van Lunteren et al. 1995). The submental muscle group might be influenced by age-related changes documented in limb muscles, including the loss of larger motoneurons leading to atrophy (Faulkner et al. 2007; Johnson and Duberley 1998; Mittal and Logmani 1987), re-innervation of muscle fibers by neighboring

motoneurons, and creation of motor units that consist of a large number of slow twitching muscle fibers (Fling et al. 2009). Thus, our finding of lower sEMG amplitude in older subjects agrees with other age-related changes in the oropharynx.

Although no significant difference in TMS output to elicit a MEP was found between the two age groups, this does not necessarily indicate that the level of excitability was the same for both age groups. Threshold testing for submental MEPs was not conducted in the present study. If the older subjects had been found to have a lower threshold than the younger subjects, this would have supported the view of increased excitation in the older group (Matsunaga et al. 1998; Rossini et al. 1992). MEP thresholds during rest and activity (10 % of maximal contraction) have been reported for anterior belly of digastric using both intramuscular and sEMG recording electrodes (Gooden et al. 1999; Jaberzadeh et al. 2007; Sowman et al. 2009). However, MEP thresholds for the submental muscle group, composed of anterior belly of digastric, mylohyoid, and geniohyoid, have not been previously reported. The ability to record MEP threshold from this group of muscles with sEMG should be assessed in future studies.

MEP normalization was not conducted in the current study; thus, control for muscle-related effects on the elicited response cannot be ruled out. Normalization of MEPs is conducted by calculating a ratio between the raw EMG data collected from a muscle during a task and a reference value recorded from the same muscle. The reference EMG value can be the EMG value recorded during a maximal voluntary isometric muscle contraction (Burden 2010). Alternatively, the reference value can be the maximal response recorded by electrically stimulation the muscle itself, called the M-max, and has been used for limb muscles (Keenan et al. 2006; Kidgell and Pearce 2010). Normalization of MEPs by peripheral nerve stimulation and acquisition of M-waves has not been conducted in swallowing research, and it is not clear if it is feasible to do so with the muscles of swallowing.

Finally, age did not influence MEP latency. This finding is consistent with a study that found no effects of age on the latency of MEP from ipsilateral hand, although there was a trend toward longer latencies in older subjects when the contralateral hand was measured (Bernard and Seidler 2012).

Gender effects on MEP magnitude and latency and on sEMG amplitude

Gender did not influence the magnitude and latency of the MEP nor the sEMG amplitude. This supports an earlier study that found no gender effects on limb MEP magnitude (Pitcher et al. 2003). Another study measured MEPs from the upper limb and found no gender effects on MEP magnitude and latency in younger subjects, after correcting the latencies for the subject's arm length (Livingston et al. 2010). Previous research also found no gender effects on non-stimulated submental sEMG amplitude during swallowing (Vaiman et al. 2004).

Using MEPs as an outcome measure in swallowing-related interventions

Since MEPs are a commonly used outcome measure in swallowing-related intervention studies in healthy subjects (Abdul Wahab et al. 2010; Doeltgen et al. 2010; Fraser et al. 2003), it is important to consider the characteristics of a desirable result following intervention. Rehabilitation-related studies consider increased MEP magnitude to be a positive outcome following therapy (Hamdy et al. 1997) and an absent or decreased MEP magnitude a negative predictor for motor improvement (Koski et al. 2004; Piron et al. 2005).

Dysphagia recovery has been related to expansion of the pharyngeal cortical area in the intact hemisphere as measured by increased MEP amplitude from additional areas in M1 (Hamdy et al. 1997). Limb movement recovery has been found to be positively correlated with MEP magnitude, but this correlation was dependent on the severity of the impairment, with larger MEPs immediately post-injury serving as a positive predictor for recovery (Koski et al. 2004; Piron et al. 2005). Hence, increasing MEP magnitude and expanding M1 areas from which MEPs can be recorded are a positive outcome following rehabilitation in persons with motor impairments. However, it is not known if MEP changes in healthy subjects should be interpreted in the same way. Indeed, it was found in healthy subjects that changes to MEP magnitude did not directly translate to changes in swallowing function, following short intervention (Power et al. 2004). This raises the question: Could larger swallowing-related MEPs be a positive outcome in one population (e.g., younger subjects) but not in another (e.g., older subjects)? Improved understanding

of the underlying mechanism leading to increased swallowing-related MEP magnitudes in older subjects will be valuable for improved interpretation of intervention results.

Submental MEP elicitation

In the current study, MEPs could not be elicited in 25–27 % of the subjects recruited. This inability to elicit submental MEPs has been previously reported. In one study, 50 % (8 of 16) had swallowing MEPs (Abdul Wahab et al. 2010). In another study from the same group, only 16 of 35 participants had recordable swallowing-related MEPs (Doeltgen et al. 2011). It has been postulated that the inability to record swallowing-related MEPs from all subjects is the result of non-optimal orientation of possible TMS coil angles to the underlying neuronal field, producing a low to immeasurable MEP output (Teismann et al. 2010). To clarify, the distance between the coil and the motor cortex changes the ability to elicit strong enough stimulation; this distance is dependent on skull thickness and can be increased due to cerebral atrophy (Wassermann et al. 2008), which is known to occur with increased age (Gur et al. 1991).

Conclusions

The current finding regarding age effects on MEP magnitude is consistent with fMRI findings reported by Humbert et al. (2009). The nature of increased MEP magnitude in older subjects should be further investigated. Possibly, the decline in submental activity demonstrated by decreased sEMG peak amplitude is partially ameliorated by increased cortical activity demonstrated by increased submental MEPs. This mechanism likely serves to preserve swallowing function in healthy older subjects. In addition, the finding regarding decreased submental activity in older subjects is reported for the first time and is likely to represent the effects of sarcopenia. Lastly, age-related differences in submental MEP magnitude need to be taken into account when designing future studies, by selecting participants who represent the targeted population age group.

Acknowledgments The work was supported by a research grant from Canterbury Medical Research Foundation.

Conflict of interest The authors declare that there are no conflicts of interest.

References

Abdul Wahab N, Jones RD, Huckabee ML (2010) Effects of olfactory and gustatory stimuli on neural excitability for swallowing. Physiol Behav 101:568–575

Athukorala RP, Jones RD, Sella O, Huckabee ML (2014) Skill training for swallowing rehabilitation in patients with Parkinson's disease. Arch Phys Med Rehabil 95(7):1374–1382

Bernard JA, Seidler RD (2012) Evidence for motor cortex dedifferentiation in older adults. Neurobiol Aging 33:1890–1899

Burden A (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol 20:1023–1035

Butler SG, Stuart A, Leng X, Wilhelm E, Rees C, Williamson J, Kritchevsky SB (2011) The relationship of aspiration status with tongue and handgrip strength in healthy older adults. J Gerontol A Biol Sci Med Sci 66:452–458

Dodds WJ, Stewart ET, Logemann JA (1990) Physiology and radiology of the normal oral and pharyngeal phases of swallowing. AJR Am J Roentgenol 154:953–963

Doeltgen SH, Dalrymple-Alford J, Ridding MC, Huckabee ML (2010) Differential effects of neuromuscular electrical stimulation parameters on submental motor-evoked potentials. Neurorehabil Neural Repair 24:519–527

Doeltgen SH, Ridding MC, Dalrymple-Alford J, Huckabee ML (2011) Task-dependent differences in corticobulbar excitability of the submental motor projections: implications for neural control of swallowing. Brain Res Bull 84:88–93

Donner MW, Bosma JF, Robertson DL (1985) Anatomy and physiology of the pharynx. Gastrointest Radiol 10:196–212

Ertekin C, Aydogdu I (2003) Neurophysiology of swallowing. Clin Neurophysiol 114:2226–2244

Evans WJ (1995) What is sarcopenia? J Gerontol A Biol Sci Med Sci 50:5–8

Faulkner JA, Larkin LM, Claflin DR, Brooks SV (2007) Age-related changes in the structure and function of skeletal muscles. Clin Exp Pharmacol Physiol 34:1091–1096

Fling BW, Knight CA, Kamen G (2009) Relationships between motor unit size and recruitment threshold in older adults: implications for size principle. Exp Brain Res 197:125–133

Fraser C et al (2002) Driving plasticity in human adult motor cortex is associated with improved motor function after brain injury. Neuron 34:831–840

Fraser C, Rothwell J, Power M, Hobson A, Thompson D, Hamdy S (2003) Differential changes in human pharyngoesophageal motor excitability induced by swallowing, pharyngeal stimulation, and anesthesia. Am J Physiol Gastrointest Liver Physiol 285:G137–G144

Gleeson DC (1999) Oropharyngeal swallowing and aging: a review. J Commun Disord 32:373–395

Gooden BR, Ridding MC, Miles TS, Nordstrom MA, Thompson PD (1999) Bilateral cortical control of the human anterior digastric muscles. Exp Brain Res 129:582–591

Gur RC et al. (1991) Gender differences in age effect on brain atrophy measured by magnetic resonance imaging. Proc Natl Acad Sci U S A 88: 2845–2849

Hallett M (2000) Transcranial magnetic stimulation and the human brain. Nature 406:147–150

Hamdy S et al (1996) The cortical topography of human swallowing musculature in health and disease. Nat Med 2:1217–1224

Hamdy S, Aziz Q, Rothwell JC, Crone R, Hughes D, Tallis RC, Thompson DG (1997) Explaining oropharyngeal dysphagia after unilateral hemispheric stroke. Lancet 350:686–692

Hamdy S, Aziz Q, Rothwell JC, Power ML, Singh KD, Nicholson DA, Tallis RC et al. (1998) Recovery of swallowing after dysphagic stroke relates to functional reorganization in the intact motor cortex. Gastroenterology 115(5):1104–1112

Hamdy S, Mikulis DJ, Crawley A, Xue S, Lau H, Henry S, Diamant NE (1999) Cortical activation during human volitional swallowing: an event-related fMRI study. Am J Physiol 277:G219–G225

Hamdy S, Xue S, Valdez D, Diamant NE (2001) Induction of cortical swallowing activity by transcranial magnetic stimulation in the anaesthetized cat. Neurogastroenterol Motil 13: 65–72

Humbert IA, Robbins J (2008) Dysphagia in the elderly. Phys Med Rehabil Clin N Am 19:853–866

Humbert IA et al (2009) Neurophysiology of swallowing: effects of age and bolus type. Neuroimage 44:982–991

Jaberzadeh S, Pearce SL, Miles TS, Turker KS, Nordstrom MA (2007) Intracortical inhibition in the human trigeminal motor system. Clin Neurophysiol 118:1785–1793

Johnson IP, Duberley RM (1998) Motoneuron survival and expression of neuropeptides and neurotrophic factor receptors following axotomy in adult and ageing rats. Neuroscience 84: 141–150

Keenan KG, Farina D, Merletti R, Enoka RM (2006) Influence of motor unit properties on the size of the simulated evoked surface EMG potential. Exp Brain Res 169:37–49

Kern MK, Jaradeh S, Arndorfer RC, Shaker R (2001) Cerebral cortical representation of reflexive and volitional swallowing in humans. Am J Physiol Gastrointest Liver Physiol 280: G354–G360

Kidgell DJ, Pearce AJ (2010) Corticospinal properties following short-term strength training of an intrinsic hand muscle. Hum Mov Sci 29:631–641

Kleim JA, Jones TA (2008) Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res 51:S225–S239

Koski L, Mernar TJ, Dobkin BH (2004) Immediate and long-term changes in corticomotor output in response to rehabilitation: correlation with functional improvements in chronic stroke. Neurorehabil Neural Repair 18:230–249

Langan J, Peltier SJ, Bo J, Fling BW, Welsh RC, Seidler RD (2010) Functional implications of age differences in motor system connectivity. Front Syst Neurosci 4:17

Livingston SC, Goodkin HP, Ingersoll CD (2010) The influence of gender, hand dominance, and upper extremity length on motor evoked potentials. J Clin Monit Comput 24:427–436

Logemann JA (1990) Effects of aging on the swallowing mechanism. Otolaryngol Clin North Am 23:1045–1056

Malandraki GA, Perlman AL, Karampinos DC, Sutton BP (2011) Reduced somatosensory activations in swallowing with age. Hum Brain Mapp 32:730–743

Martin RE, Goodyear BG, Gati JS, Menon RS (2001) Cerebral cortical representation of automatic and volitional swallowing in humans. J Neurophysiol 85:938–950

Martin RE, MacIntosh BJ, Smith RC, Barr AM, Stevens TK, Gati JS, Menon RS (2004) Cerebral areas processing swallowing and tongue movement are overlapping but distinct: a functional magnetic resonance imaging study. J Neurophysiol 92: 2428–2443

Matsunaga K, Uozumi T, Tsuji S, Murai Y (1998) Age-dependent changes in physiological threshold asymmetries for the motor evoked potential and silent period following transcranial magnetic stimulation. Electroencephalogr Clin Neurophysiol 109:502–507

McGregor KM et al (2011) Physical activity and neural correlates of aging: a combined TMS/fMRI study. Behav Brain Res 222:158–168

Mittal KR, Logmani FH (1987) Age-related reduction in 8th cervical ventral nerve root myelinated fiber diameters and numbers in man. J Gerontol 42:8–10

Monfils MH, Plautz EJ, Kleim JA (2005) In search of the motor engram: motor map plasticity as a mechanism for encoding motor experience. Neuroscientist 11:471–483

Mosier K, Bereznaya I (2001) Parallel cortical networks for volitional control of swallowing in humans. Exp Brain Res 140: 280–289

Mosier KM, Liu WC, Maldjian JA, Shah R, Modi B (1999) Lateralization of cortical function in swallowing: a functional MR imaging study. AJNR Am J Neuroradiol 20: 1520–1526

Nicosia MA, Hind JA, Roecker EB, Carnes M, Doyle J, Dengel GA, Robbins J (2000) Age effects on the temporal evolution of isometric and swallowing pressure. J Gerontol A Biol Sci Med Sci 55:M634–M640

Peinemann A, Lehner C, Conrad B, Siebner HR (2001) Age-related decrease in paired-pulse intracortical inhibition in the human primary motor cortex. Neurosci Lett 313:33–36

Piron L, Piccione F, Tonin P, Dam M (2005) Clinical correlation between motor evoked potentials and gait recovery in poststroke patients. Arch Phys Med Rehabil 86:1874–1878

Pitcher JB, Ogston KM, Miles TS (2003) Age and sex differences in human motor cortex input-output characteristics. J Physiol 546:605–613

Power M et al (2004) Changes in pharyngeal corticobulbar excitability and swallowing behavior after oral stimulation. Am J Physiol Gastrointest Liver Physiol 286:G45–G50

Robbins J, Hamilton JW, Lof GL, Kempster GB (1992) Oropharyngeal swallowing in normal adults of different ages. Gastroenterology 103:823–829

Robbins J, Levine R, Wood J, Roecker EB, Luschei E (1995) Age effects on lingual pressure generation as a risk factor for dysphagia. J Gerontol A Biol Sci Med Sci 50:M257–M262

Robbins J, Gangnon RE, Theis SM, Kays SA, Hewitt AL, Hind JA (2005) The effects of lingual exercise on swallowing in older adults. J Am Geriatr Soc 53:1483–1489

Rossini PM, Desiato MT, Caramia MD (1992) Age-related changes of motor evoked potentials in healthy humans:

non-invasive evaluation of central and peripheral motor tracts excitability and conductivity. Brain Res 593:14–19

Sowman PF, Flavel SC, McShane CL, Sakuma S, Miles TS, Nordstrom MA (2009) Asymmetric activation of motor cortex controlling human anterior digastric muscles during speech and target-directed jaw movements. J Neurophysiol 102:159–166

Suzuki T, Connor NP, Lee K, Bless DM, Ford CN, Inagi K (2002) Age-related alterations in myosin heavy chain isoforms in rat intrinsic laryngeal muscles. Ann Otol Rhinol Laryngol 111: 962–967

Suzuki M, Asada Y, Ito J, Hayashi K, Inoue H, Kitano H (2003) Activation of cerebellum and basal ganglia on volitional swallowing detected by functional magnetic resonance imaging. Dysphagia 18:71–77

Svensson P, Romaniello A, Wang K, Arendt-Nielsen L, & Sessle BJ (2006) One hour of tongue-task training is associated with plasticity in corticomotor control of the human tongue musculature. Exp Brain Res 173(1):165–173

Tamura F, Kikutani T, Tohara T, Yoshida M, Yaegaki K (2012) Tongue thickness relates to nutritional status in the elderly. Dysphagia 27:556–561

Teismann IK, Steinstraeter O, Schwindt W, Ringelstein EB, Pantev C, Dziewas R (2010) Age-related changes in cortical swallowing processing. Neurobiol Aging 31:1044–1050

Vaiman M, Eviatar E, Segal S (2004) Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 2. Quantitative data: amplitude measures. Otolaryngol Head Neck Surg 131:773–780

van Lunteren E, Vafaie H, Salomone RJ (1995) Comparative effects of aging on pharyngeal and diaphragm muscles. Respir Physiol 99:113–125

Wassermann, EM, Epstein, CM, & Ziemann, U (2008) The Oxford handbook of transcranial stimulation. Oxford Univ Press, New York