Integrating Swallowing and Respiration: Preliminary Results of the Effect of Body Position

Bronwen N. Kelly, Ph.D.

Maggie-Lee Huckabee, Ph.D.

Van der Veer Institute for Parkinson's and Brain Research
Christchurch, New Zealand
Department of Communication Disorders, University of Canterbury, New Zealand

Richard D. Jones, Ph.D.

Van der Veer Institute for Parkinson's and Brain Research
Christchurch, New Zealand
Department of Medical Physics and Bioengineering, Christchurch Hospital, New Zealand
Department of Medicine, Christchurch School of Medicine and Health Sciences, New Zealand

Christopher M. A. Frampton, Ph.D.

Van der Veer Institute for Parkinson's and Brain Research
Christchurch, New Zealand
Department of Medicine, Christchurch School of Medicine and Health Sciences, New Zealand

Given the previously reported potential link between aberrant patterns of breathing-swallowing coordination (BSC) and aspiration in patients with neurological impairment, if a particular body position is associated with aberrant BSC this may have important clinical implications. This pilot study compared BSC and swallowing apnea duration (SAD) between horizontal (supine, side-lying, and prone) and vertical (sitting upright) body positions. Twenty healthy adults in two age groups were included: 10 young (20–35 years) and 10 elder adults (65–80 years), gender equally represented. Concurrent measurements of submental muscle activity (surface electromyography), nasal airflow (nasal cannula), and thyroid acoustics (laryngeal microphone) were used to determine BSC and SAD, while a custom-made mercury switch position monitor recorded body position. Breathing-swallowing coordination was defined by the number of swallows in each of the following categories: midinspiratory (II), midexpiratory (EE), inspiratory-expiratory (IE), and expiratory-inspiratory (EI). We found that BSC differed marginally between horizontal and vertical body positions. This suggests that BSC is subject to the position-related physiological changes that influence respiration and swallowing rather than being a purely predetermined and invariant brainstem-generated pattern. Body position also altered SAD, with SAD being longer in the supine than the prone position. This may be attributed to the position-related impact on hyolaryngeal excursion.

Journal of Medical Speech-Language Pathology
Volume 15, Number 4, pp. 347–355

There is evidence that an unusual pattern of breathing-swallowing coordination (BSC), specifically a high incidence of post-swallow inspiration, is associated with neurological disorders in which aspiration is common, such as cerebral palsy (Rempel & Moussavi, 2005), stroke (Selley, Flack, Ellis, & Brooks, 1989b), motor neurone disease, spinal cord, and peripheral nervous system disease or damage (Hadjikoutis, Pickersgill, Dawson, & Wiles, 2000). Patients with respiratory disorders such as chronic obstructive airway disease also have a higher incidence of postswallow inspiration (Shaker et al., 1992). Although a direct link between aberrant BSC patterns and adverse outcomes has yet to be established, the literature indicates a high likelihood that aberrant BSC is associated with (McPherson et al., 1992) but may not be the cause of (Hadjikoutis et al., 2000) aspiration. Thus, clinically, it is important to determine whether phenomena such as body position, influence BSC.

Research comparing the effects of vertical and horizontal body positions on BSC has produced conflicting evidence. McFarland, Lund, and Gagner (1994) compared BSC in the upright position to resting on the hands and knees (quadruped position) and found that swallowing apnea shifted from early to late expiration in the upright position. Conversely, using a slightly different definition of BSC, Shaker et al. (1992) found no change in BSC between vertical and horizontal positions.

Evidence to support a likely impact of position on BSC comes from the respiratory and swallowing literature. On the whole, the effect of body position on respiration, such as lung capacity, compliance, and maximal expiratory pressure, is most apparent between vertical and horizontal positions, with a detrimental effect observed in the latter (Badr, Elkins, & Ellis, 2002; Behrakis, Baydur, Jaeger, & Milic-Emili, 1983; Manning, Dean, Ross, & Abboud, 1999). In terms of swallowing, a change in body position from vertical to horizontal may alter upper esophageal sphincter (Castell, Dalton, & Castell, 1990; Johnsson, Shaw, Gabb, Dent, & Cook, 1995) and distal esophageal functioning (Chang, Lee, Yeh, & Lee, 1996), as well as pharyngeal transit times (Ingervall & Lantz, 1973). Given the latter effect on swallowing duration measures, it is therefore possible that a similar vertical-horizontal dichotomous effect is observed for the duration of swallowing apnea (SAD).

Thus, the present pilot study investigated whether BSC differs between four body positions: three in the horizontal plane (supine, side-lying, and prone) and one in the vertical plane (sitting upright) in healthy adults. The presence of a position effect would imply that BSC is subject to the position-related physiological changes that influence respiration and swallowing and is not a robust, predetermined, and invariant pattern. Only "dry" swallows were included to specifically address the effect of body position on BSC without introducing possible confounding effects of sensory stimulation provided by an ingested bolus. Since there is no prior research on the influence of these four body positions on SAD, the present pilot study also aimed to determine whether this feature of BSC is subject to a position effect.

METHODS

Participants

Five healthy young males (mean age of 28.2 ± 6.1 years), five healthy young females (mean age of 27.8 ± 5.7 years), five healthy elder males (mean age of 69.6 ± 3.8 years), and five healthy elder females (mean age of 71.6 ± 3.7 years) were recruited by advertisement following approval by the Canterbury Regional Health Ethics Committee. No participant reported a medical history of myocardial infarct, breathing disorder (e.g., asthma, chronic obstructive pulmonary disorder, and sleep apnea), swallowing difficulties, severe head and/or neck injury, head and/or neck surgery, neurological disorder (e.g., stroke, multiple sclerosis, Parkinson's disease), gastroesophageal reflux disease, paralysis of the diaphragm, chronic fatigue syndrome, or psychiatric disorder (e.g., anxiety, depression).

Instrumentation

Simultaneous time-locked recordings of submental muscle activity, thyroid acoustics, direction of nasal airflow, and body position were captured and sampled at 250 Hz by an integrated hardware-software system (Kay Elemetrics Swallowing Workstation, KayPENTAX, Lincoln Park, NJ) to allow for the analysis of temporal relationships between measures. Submental surface electromyography (SEMG) was used to detect swallowing (Hiss, Treole, & Stuart, 2001; Preiksaitis & Mills, 1996). The collective submental muscle group was located by palpation. The two bipolar 2 cm silver chloride SEMG electrodes (Thought Technology Triode™, Thought Technology, Montreal, Canada) were positioned over this muscle group, with the positive and negative electrodes placed in the midline between the superior border of the thyroid cartilage and the mandibular spine, and the reference electrode by default was positioned lateral to the active electrodes (Huckabee & Pelletier, 1999). This electrode array measures the activity of the anterior suprahyoid and lingual muscles (Huckabee & Pelletier, 1999). The electrodes remained in situ for the entire procedure. Further confirmation of swallowing activity was obtained using a laryngeal microphone to detect thyroid acoustics (Klahn & Perlman, 1999). Thyroid acoustics were measured using a laryngeal microphone positioned lateral to the thyroid (Takahashi, Groher, & Michi, 1994), which was located by palpation and taped in position with standard surgical tape. The microphone was a modified omnidirectional condenser microphone with a sensitivity of –62 ± 3 dB, an impedance of < 2.0 kΩ, and a frequency response of 50–12,500 Hz. The microphone was connected to a preamplifier (Rolls mini-mic preamplifier MP13, gain of 6–50 dB). Nasal airflow, using a commercially available adult-size nasal cannula, was recorded to determine the respiratory phase cycle preceding and following each swallow and to determine the duration of swallowing apnea (Hiss et al., 2001). Prior to positioning the nasal prongs, calibration procedures recommended by Kay Elemetrics Swallowing workstation user manual were followed. Nasal prongs were positioned at the entrance to the nostrils, taped to the cheek using surgical tape, and secured firmly around the head. Body position was measured by a custom-made mercury switch position monitor (Figure 1) consisting of a generic mercury switch housed in a small plastic casing that was attached to an elasticized band fitted around the chest with Velcro© at the level of the xiphisternum. Each body position resulted in a unique output voltage: side-lying (left = 1.02 V, right = 0.69 V), upright (1.55 V), supine (0.35 V), and prone (1.33 V). The mercury switch position monitor was connected to a custom-made sensor box, which also acted as an external battery-operated power source, and the output fed into the auxiliary channel of the swallowing workstation. Compatibility of this switch with the swallowing workstation was defined as confirmation of consistent and appropriate voltage output for each body position.

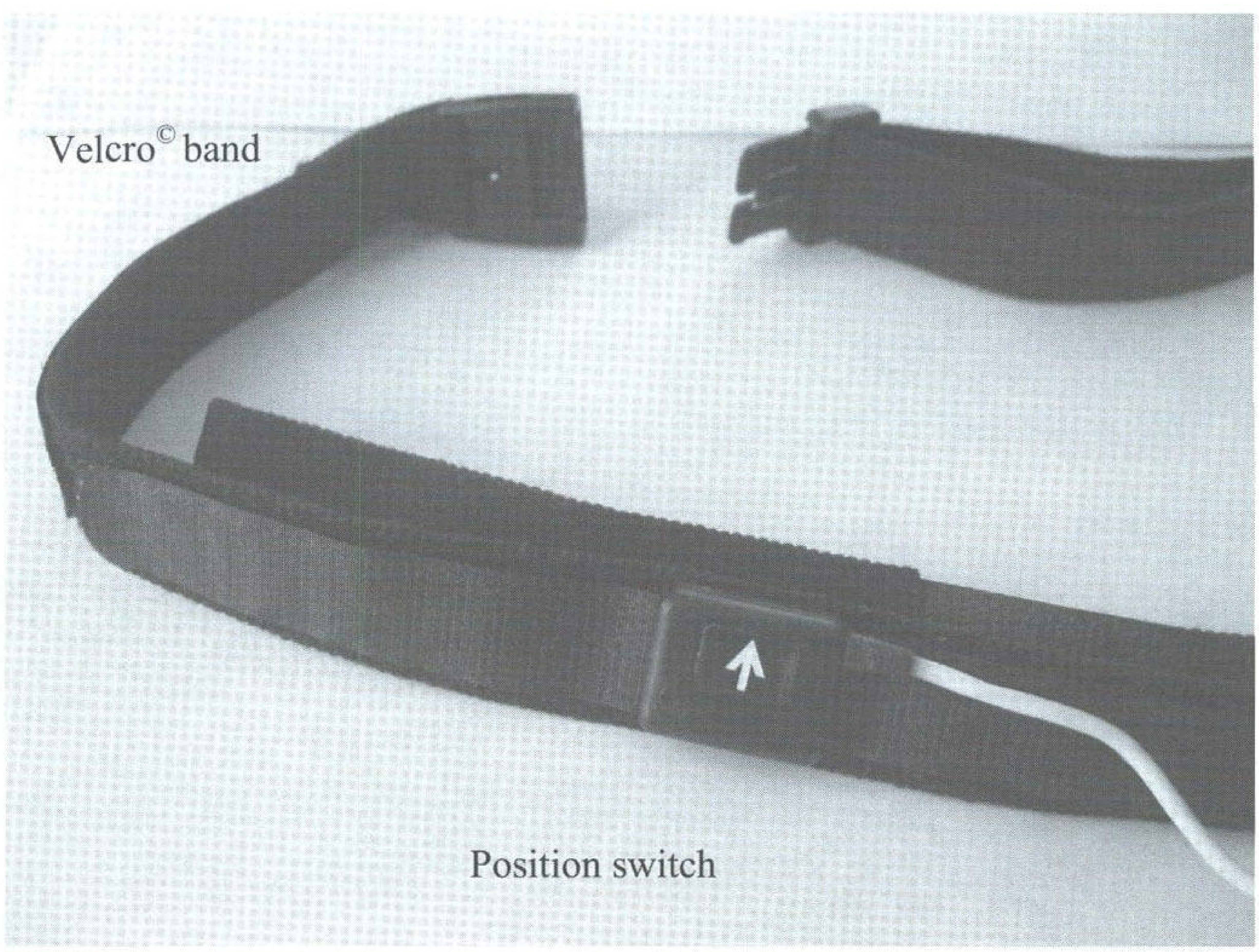

Figure 1. The mercury switch position monitor fitted to an elasticized Velcro© band.

Procedure

Participants were made comfortable on a bed in the Swallowing Rehabilitation Research Laboratory at the Van der Veer Institute for Parkinson's and Brain Research where the submental SEMG electrodes, nasal cannula, microphone, and mercury switch position monitor were fitted and connected to the Kay Elemetrics Swallowing Workstation. Participants were required to swallow saliva when prompted by the examiner in order to ensure that swallows were highly volitional in nature, at a rate of approximately one swallow every 15 s. Five dry swallows were performed in this manner in each of four positions in random order (totaling 20 swallows): in supine, in prone, on either their right or left side (the participants' choice) and in an upright, sitting position on a bed. All subjects were able to perform all 20 swallows.

Data Analysis

Swallows were identified by simultaneous bursts of SEMG activity and thyroid acoustics and absent nasal airflow as per previous research published from our laboratory (Kelly, Huckabee, & Friend, 2006; Kelly, Huckabee, Jones, & Frampton, 2007). All swallows were assigned to one of four respiratory-phase categories based on the phase of respiration preceding and following the SA: inspiration-SA-inspiration (II), inspiration-SA-expiration (IE), expiration-SA-expiration (EE), and expiration-SA-inspiration (EI). SAD was measured manually for all swallows using the computer cursor to highlight and Kay Elemetrics software to quantify the duration of respiratory cessation as previously reported (Kelly et al., 2006; Kelly, Huckabee, Jones, & Frampton, 2006) and the mean SAD for each individual for each body position was calculated.

Data Processing and Preparation

The data from four participants (20%), one from each age and gender group, were reanalyzed by the primary and independent raters to calculate intraclass correlation coefficients for intra- and interrater reliability on measures of swallow categorization and SAD. Repeated-measures ANOVA was used to analyze the effect of body position on the number of swallows in each respiratory-phase category. Respiratory-phase category (dependent variable) and body position (independent variable) were entered as within-subject factors, with age and gender as between-subject factors. Similarly, repeated-measures ANOVAs were used to analyze the effect of body position on SAD (dependent variable) with body position (independent variable) entered as a within-subject effect and age and gender as between-subject factors. The sphericity assumption for all repeated-measures ANOVAs was tested using Mauchly's test (Mauchly, 1940). The Greenhouse-Geisser correction was applied when this assumption was not met. Where significant main or interaction effects were found, they were further explored using Fisher's Least Significance Difference (LSD) tests. Statistics were performed using the Statistical Package for the Social Sciences (SPSS, version 13.0, 2004). An alpha significance level of .05 was adopted.

RESULTS

A total of 400 swallows (5 swallows in each of the four body positions, for all 20 participants) were recorded and analyzed. Intraclass correlation coefficients demonstrated satisfactory inter- and intrarater reliability for swallow categorization ($r = .904$ and $r = .974$, respectively) and SAD ($r = .985$ and $r = .967$, respectively).

Effect of Body Position on Breathing-Swallowing Coordination

The repeated-measures ANOVA revealed a main effect of respiratory-phase category [$F(1.96, 31.3) = 56.1$, $p < .001$] but no main age or gender effect. LSD testing revealed that EE swallows ($M = 3.2$, $SE \pm 0.2$) occurred more frequently than IE ($M = 0.9$, $SE \pm 0.2$), EI ($M = 0.8$, $SE \pm 0.2$) and II ($M = 0.1$, $SE \pm 0.1$). There was also a marginally significant interaction between respiratory-phase category and body position [$F(4.40, 70.3) = 2.28$, $p = .063$]. Although not significant at a rigorous $p < .05$ level, the approximation to significance justified further evaluation with Fisher's LSD testing. LSD testing revealed that this body position effect was characterized by differences between the vertical (upright) and horizontal positions (prone, supine, and side-lying). Specifically, there were fewer IE swallows in the upright position compared to supine and side-lying (Figure 2). There were more EE swallows in the upright position than in the side-lying position. There was no interaction of respiratory-phase category with age or gender.

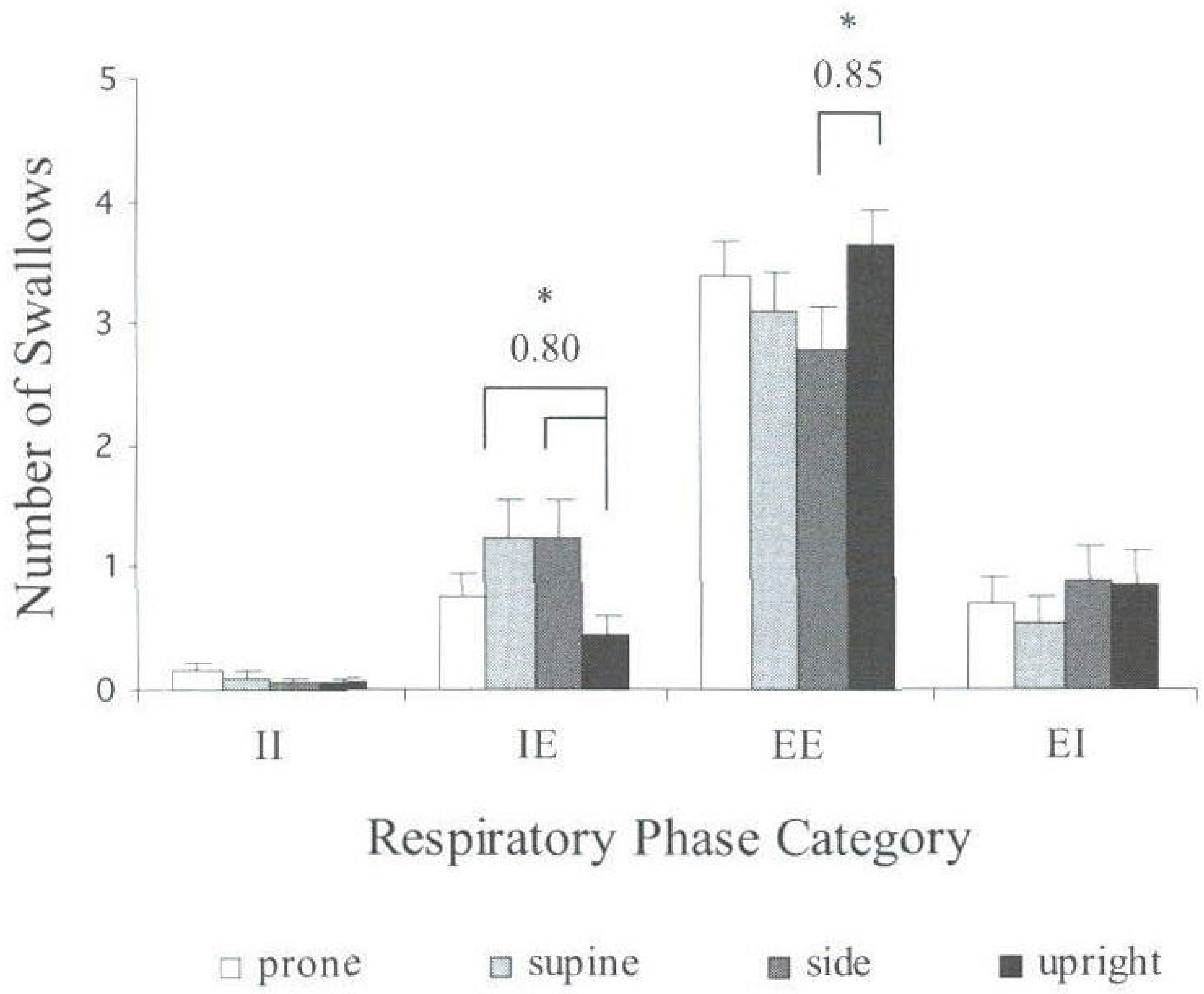

Figure 2. The number of swallows (mean and standard error) in each respiratory-phase category for all body positions. *Note:* * = significant difference determined by Fisher's LSD testing, 0.80 is the difference in the number of IE swallows between the upright position and both supine and side lying positions, 0.85 is the difference in the number of EE swallows between side-lying and upright positions, II = inspiration-SA-inspiration, IE = inspiration-SA-expiration, EE = expiration-SA-expiration, EI = expiration-SA-inspiration.

Effect of Body Position on Swallow Apnea Duration

The mean SAD value for all swallows was 942.1 ms (SD ± 286.5 ms). Repeated-measures ANOVA showed a body position effect on SAD [$F(3, 48) = 2.79$, $p = .050$]. Further exploration of the position effect using LSD testing revealed that the mean SAD of swallows performed in supine was longer than those performed in prone body position (Figure 3). There were no effects for age or gender, nor were there interactions of any combinations thereof.

DISCUSSION

These preliminary findings indicate that changes in vertical-horizontal position alter both BSC and SAD. The effect of body position on BSC is supported by earlier findings by McFarland et al. (1994) but not Shaker et al. (1992). Although the effect on BSC was only marginal and future research with a larger N size is encouraged to confirm this effect, it is important to consider that "there is no sharp border between 'significant' and 'non-significant,' only increasingly strong evidence as the P-value decreases" (Moore & McCabe, 1989, p. 486). Thus the effect, albeit marginal, may have important implications for the neurophysiology of BSC and, therefore, potentially the clinical management of patients with breathing and/swallowing disorders.

The exact mechanisms underlying the marginal position effect on BSC are unclear but as both respiration and swallowing are affected by position, they may contribute indirectly to the modification of BSC. The effects of body position on respiration may be largely attributed to biomechanical forces (review by Hoit, 1995), such as the degree of abdominal compression (Badr et al., 2002; Hough, 1984) and diaphragmatic displacement (Manning et al., 1999), the activity of the muscles of expiration (Badr et al., 2002; Hoit, 1995), respiratory recoil mechanisms (Manning et al., 1999), or airway patency (Behrakis et al., 1983; Manning et al., 1999; Yates, Billig, Cotter, Mori, & Card, 2002). In terms of swallowing, a change in body position from vertical to horizontal may alter pharyngeal transit times (Ingervall & Lantz, 1973) and esoph-

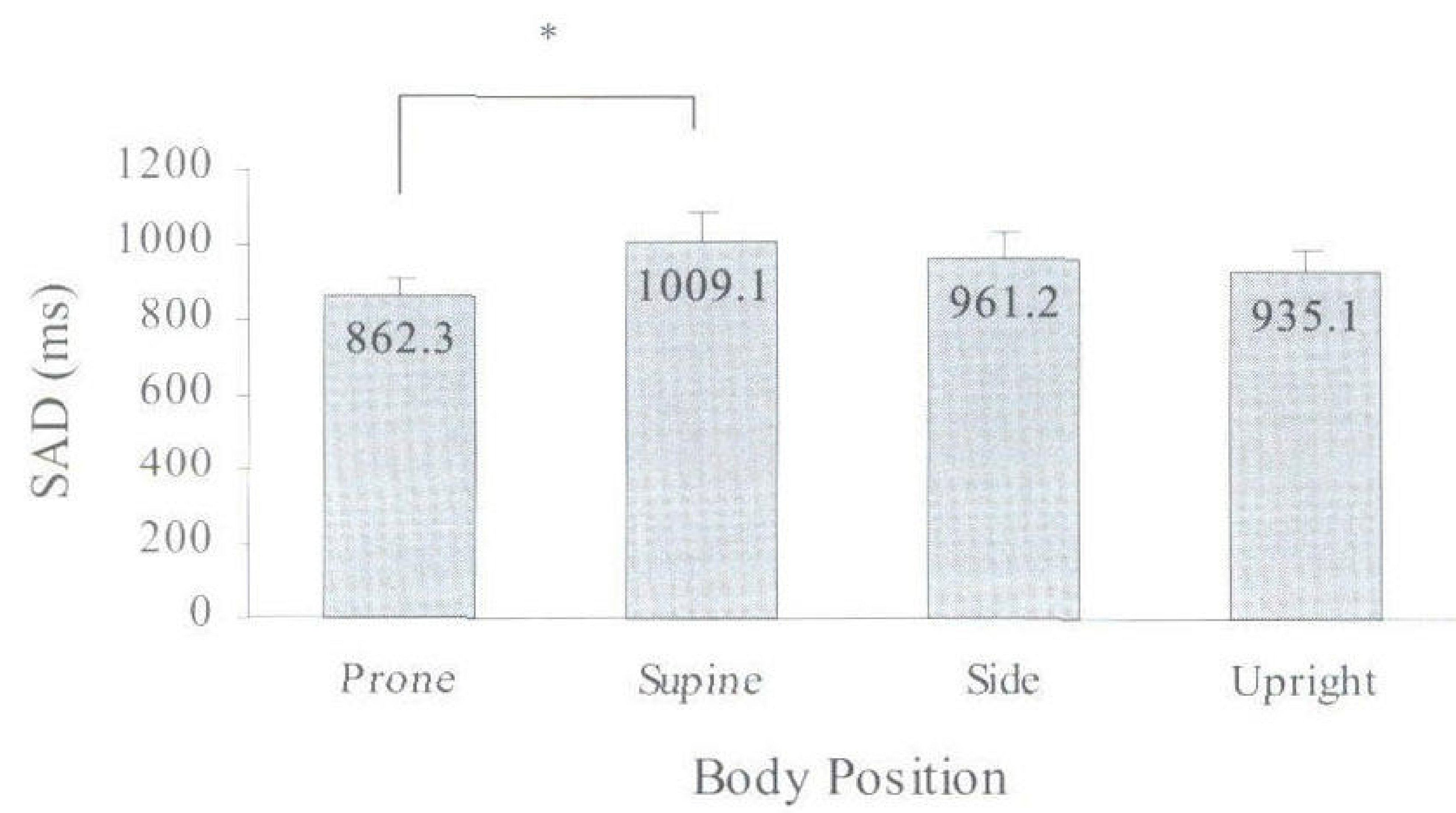

Figure 3. Means and standard error scores of swallowing apnea duration (SAD) for all four body positions, irrespective of gender and age. *Note:* * = significant difference determined by Fisher's LSD testing.

ageal functioning (Castell et al., 1990; Chang et al., 1996; Johnsson et al., 1995). The timing of maximal cricopharyngeus muscle relaxation relative to the contraction of the pharynx is increased in the vertical compared to the horizontal plane (Castell et al., 1990). Thus, the coordination of swallowing (Castell et al., 1990) as well as the coordination of swallowing and breathing is influenced by body position (present study).

Since the brainstem is the key central nervous system structure involved in BSC in humans and animals (Dick, Oku, Romaniuk, & Cherniack, 1993; Feroah et al., 2002; Miller & Sherrington, 1916; Saito, Ezure, & Tanaka, 2002), it is possible that the position-related changes in respiration may indirectly influence the interaction of respiratory and swallowing brainstem central pattern generators. Central to the control of swallowing is the nucleus tractus solitarius, which receives afferent neural information from chemoreceptors and baroreceptors that are sensitive to oxygen and carbon dioxide blood levels and blood pressure, respectively (Miller, 1999). This afferent information is also received by parts of the brainstem that control the diaphragm, the primary muscle involved in inspiration (Miller, 1999). Since body position alters ventilation in animals (Izumizaki, Pokorski, Ishihara, Iwase, & Homma, 2005) and blood pressure in humans (Jones & Dean, 2004), it is conceivable that this is detected by and influences the interaction of respiratory and swallowing central pattern generators and, hence, alters the pattern of BSC.

Given that these results have important implications for the neurophysiology of BSC, it is necessary to consider the potential implications for the clinical management of patients with breathing and/swallowing disorders. A position-induced alteration of BSC suggests that BSC is sensitive to altered respiratory or swallowing biomechanics or peripheral neural feedback rather than being a purely predetermined and invariant brainstem-generated pattern. Patients with neurological damage or breathing and/or swallowing disorders may therefore also experience altered BSC associated with a change in body position. Although the vertical-horizontal dichotomy offers some support for the upright position to be assumed during feeding, further investigation of the impact of a semireclined position on the BSC of the patient population is warranted.

The effect of body position on SAD is likely due to the known position-related changes in biomechanical forces on swallowing given that SAD was sensitive to a change in position only on a horizontal plane. SAD was shorter in prone than in supine position. One likely explanation for this is the comparative impact of these positions on the hyoid bone excursion during swallowing that may indirectly influence SAD. The exact relationship of hyolaryngeal excursion and SAD is not known; however, it is conceivable that an elevated hyolaryngeal complex may impinge upon continued respiration. Furthermore, swallowing biomechanics are tightly linked in a largely predetermined pattern that is governed by the brainstem central pattern generator. Thus, it is possible that the neural network governing the duration of laryngeal excursion and those governing SAD interact to synchronize these two activities, supported by research that demonstrates that an increase in one is mirrored by an increase in the other (Martin, Logemann, Shaker, & Dodds, 1994). The fact that a position effect on SAD but not BSC was observed suggests that SAD and BSC are controlled by independent neural networks or that only SAD is affected by position-related influences on the biomechanics of swallowing.

Further to this, the trajectory of the hyoid excursion during swallowing is characterized by anterior movement and to a lesser extent superior movement (Ishida, Palmer, & Hiiemae, 2002). Thus, it is conceivable that antigravitational forces on the anterior hyoid movement would be maximal in the supine and minimal in the prone position, with side-lying and upright positioning in-between. Additionally, two-dimensional hyolaryngeal excursion is not different between upright and supine positions (Johnsson et al., 1995). Both the present and a previous study (Shaker et al., 1992) demonstrate that SAD also does not differ between upright and supine positions, thereby strengthening the link between hyolaryngeal excursion and SAD. Therefore, if SAD and hyolaryngeal excursion are in fact related, this would offer a feasible explanation for longer SAD in supine than in prone position where gravitational forces on anterior hyoid excursion are polarized to the extremes.

There was no age effect on BSC, which is in agreement with earlier research (Hiss et al., 2001; Selley, Flack, Ellis, & Brooks, 1989a) but is in contrast to research indicating that the incidence of pre- and postswallow respiratory-phase categories differ between elder and younger participants (Shaker et al., 1992). However, these results and those of the present study are not directly comparable for two reasons. First, the present study did not perform analyses specifically on pre- and postswallow categories but rather on four categories determined by the *combination* of pre- and post-swallow respiratory phases. Second, the findings of Shaker et al. (1992) were obtained from a spontaneous swallowing condition unlike the volitional swallowing condition used in the present study. Whether the degree of volitional input into swallowing alters BSC is yet to be established, but it may explain the contradiction in the findings of the present study and that of Shaker et al. (1992).

Finally, the absent gender effect on SAD is supported by previous research (Martin-Harris, Brodsky, Michel, & Walters, 2003), as is the age effect (Kelly et al., 2006; Shaker et al., 1992). However, one study demonstrated an increase in nutritive SAD with age (Selley et al., 1989a), and another found that nonnutritive SAD of volitional swallows increases with age for women with the opposite effect for men (Hiss et al., 2001). Unlike the present study, the former study included nutritive swallows and thus may not be directly comparable to the present research. However, the sample sizes in the studies by both Selley et al. and Hiss et al. were substantially larger (33 and 60, respectively), thereby increasing the likelihood of detecting a small but real effect.

CONCLUSIONS

These preliminary results showed a marginal effect of body position on BSC. The presence of a body-position effect on BSC is supported by its effect on SAD and suggests that BSC is subject to the position-related physiological changes that influence both respiration and swallowing. This lends support for the upright position to be adopted during feeding in the patient population. However, future research should determine the relationship between bolus ingestion, body position, and BSC, as well as the adverse outcomes of aberrant patterns of BSC in the patient population and the contribution of a semireclined body position to these outcomes. There was evidence that a shift between the horizontal positions, prone and supine, alters SAD. This may be attributed to the position-related impact on hyolaryngeal excursion. Age did not influence either of these measures (BSC or SAD), although a larger sample size may detect small age-related decrements. Future research should aim to determine the precise reasons for the position effect on SAD. The present study offers hypotheses that, through adequate testing, may clarify these reasons.

Acknowledgment The authors wish to thank the participants and Sharon Broadmore, Elizabeth Haughey, Li Pyn Leow, and Inn Sze Low. The authors also wish to thank the Foundation for Research Science and Technology and the Tertiary Education Commission of New Zealand for financial support and the staff in the Medical Physics and Bioengineering Department of the Canterbury District Health Board for technical support.

Address correspondence to Bronwen Kelly, Van der Veer Institute for Parkinson's and Brain Research, 16 St Asaph Street, PO Box 2682, Christchurch 8020 New Zealand.
e-mail: bmk21@student.canterbury.ac.nz

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