The Coordination of Respiration and Swallowing for Volitional and Reflexive Swallows: A Pilot Study

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This pilot project evaluated breathing-swallowing coordination during sleep and wakefulness via concurrent measurements of submental surface electromyographic activity, swallowing acoustics, and nasal airflow of 16 young and elderly healthy participants (gender equally represented). Swallowing occurred more frequently in the midexpiratory phase and less frequently at the expiratory-inspiratory cusp during wakefulness than during sleep. There was a significant interaction of age and gender on the frequency of occurrence of midexpiratory swallows for males only. The mean duration of swallowing apnea was significantly shorter for midexpiratory swallows than for any other respiratory phase category but was not influenced by condition, age, or gender. Decreased variability in breathing-swallowing coordination during wakefulness compared to sleep suggests that cortical influences play a substantial role in organizing swallowing respiratory behaviors.

The cessation of respiration during swallowing is known as swallowing apnea and was noted as early as 1920 (Clark, 1920). Swallowing apnea may occur at one of the following four stages in breathing: during expiration, during inspiration, at the transition (cusp) between inspiration and expiration, or between expiration and inspiration. Swallowing apnea typically occurs during the expiratory phase of respiration in alert humans (Hiss, Treole, & Stuart, 2001; Klahn & Perlman, 1999). Up to 100% thin liquid swallows are followed by expiration (Klahn & Perlman, 1999; Martin, Logemann, Shaker, & Dodds, 1994; Preiksaitis & Mills, 1996), with expiration resuming approximately 0.5 seconds before the swallow is completed (Martin, et al., 1994). Postswallow expiration is regarded as a likely protective mechanism involved in the prevention of bolus residue in the pharynx from entering the lungs (McPherson et al., 1992).

The brainstem exerts significant influence over breathing and swallowing (Horn & Waldrop, 1998; Miller, 1999), as well as the integrative process of the coordination of the two (Feroah et al., 2002; Saito, Ezure, Tanaka, & Osawa, 2003). There is evidence that the cortex is also involved in breathing (Horn & Waldrop, 1998) and swallowing (Hamdy et al., 1999), but the exact nature of cortical influence is unclear. Some research suggests that conscious

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cortical input may influence breathing-swallowing coordination (Nishino & Hiraga, 1991). Although the specific neural pathways utilized by descending cortical input are unclear, determining the presence or absence of cortical input at a behavioral level is considered a precursor to further investigation of these pathways.

To determine whether the cortex is involved in breathing-swallowing coordination, the comparison of volitional and reflexive swallowing conditions may be a valid approach. "Since there is no volitional input for initiation of a reflexive swallow, comparison of its cortical representation with that of a volitional swallow can provide a study model that can potentially increase our understanding of the non-sensory/motor cortical control of swallowing" (Kern, Jaradeh, Arndorfer, & Shaker, 2001, p. 354). It appears that this study model has not been well addressed. Some studies have compared the breathing-swallowing coordination during conditions in which "subconscious" (spontaneous/naïve) and volitional swallows were performed (Nishino & Hiraga, 1991; Paydarfar, Gilbert, Poppel, & Nassab, 1995; Shaker et al., 1992). Unfortunately the precise methodological approaches to this question may be problematic as it is unlikely that truly reflexive swallows were elicited. Shaker et al. (1992) compared volitional swallows with subconscious swallows that were performed during rest but not sleep (Shaker et al., 1992). The level of consciousness and the degree of reflexivity during rest is debatable given that the participants were awake.

Paydarfar et al. (1995) compared self-syringed liquid swallows on cue to spontaneous liquid swallows. Spontaneous swallows were elicited in two ways: by slow infusion of water and by water injection at various points in the respiratory cycle through a flexible straw positioned in the oral cavity. It could be argued that the former swallowing task is not truly representative of spontaneous subconscious swallowing, given the likelihood of participant anticipation and oral preparation.

One pair of researchers postulated that the "coordination of swallowing and breathing would depend on behavioural control and might be lost in the unconscious state" (Nishino & Hiraga, 1991, p. 988). Under anesthesia, swallowing apnea occurred during expiration and during inspiration, with no preponderance of either respiratory phase category (Nishino & Hiraga, 1991). Thus, anesthetized subjects demonstrated increased variability in breathing-swallowing coordination compared to the less variant coordination produced by conscious subjects (Hiss et al., 2001; Klahn & Perlman, 1999). This finding suggests that conscious cortical input may have a significant influence over the coordination of breathing and swallowing. Unfortunately, these authors did not provide specific values for those swallows occurring at either respiratory cusp. Instead, the authors classified these swallows as "undefined" and did not submit those to further analyses. Furthermore, the application of these data (Nishino & Hiraga, 1991) to the healthy population is problematic for two reasons: first, their participants were intubated and, second, sleep was anesthesia-induced.

It is clear that endotracheal tubes alter swallowing and respiratory reflexes. The prolonged presence of an endotracheal tube adversely affects the swallowing reflex (de Larminat, Montravers, Dureuil, & Desmonts, 1995), and endotrached patients also demonstrate a marked difference in the type of airway reflex response between pre- and postsurgical conditions (Hasegawa & Nishino, 1999). It is feasible that these effects may, in turn, affect or coexist with alterations of breathing-swallowing coordination. The effect of anesthesia on the neural controls of breathing-swallowing coordination is unknown; however, its effect on brain functioning is obviously dramatic. It is likely that the neurophysiologic impact of anesthesia is not comparable to that of natural sleep.

This study compared the breathing and swallowing coordination during natural sleep and wake conditions. In the wake condition, participants were required to swallow water in order to make a comparison between a highly volitional swallowing task and a reflexive one (during sleep). Younger and older adults of both genders were included to determine whether the condition effect on the coordination of breathing and swallowing is dependent on age and gender.

METHOD

Participants

Eight young (between the ages of 20 and 29 years, mean = 26 years) and eight elderly healthy (60 to 79 years, mean = 72 years) adults, gender equally represented, participated in this study. None of the participants met the exclusion criteria: a history of stroke, heart attack, asthma and/or any other breathing disorder, chronic obstructive pulmonary disorder (COPD), swallowing difficulties, severe head and/or neck injury, head and/or neck surgery, sleep apnea and/or other sleep disorders, neurological disorders (e.g., stroke, multiple sclerosis, Parkinson's disease), gastroesophageal reflux disease (GORD/GERD), paralysis of the diaphragm, chronic fatigue syndrome, or psychiatric disorders (e.g., anxiety, depression). Potential participants, who were taking medication that affected their alertness or sleep, were also excluded.

Participants' Tasks

Breathing-swallowing coordination of each participant was monitored under two conditions: during 6 to 8 hours of natural sleep and during the self-administration of twenty 15-milliliter water boluses from a cup while sitting in an upright position. In the former condition, spontaneous swallows were performed, and in the latter condition volitional swallows on command were performed and recorded using the same equipment.

Instrumentation

Simultaneous time-locked recordings of submental muscle activity (Hiss et al., 2001; Preiksaitis & Mills, 1996), nasal airflow (Hiss et al., 2001; Tarrant, Ellis, Flack, & Selley, 1997), and swallowing acoustics (Klahn & Perlman, 1999; Preiksaitis & Mills, 1996) determined the coordination of breathing and swallowing for each participant. All signals were recorded by an integrated hardware-software system (Kay Elemetrics, Lincoln Park, NJ). Time-locked SEMG, acoustics and respiratory measures were stored as amplitude by time waveforms.

The collective submental muscle group was recorded using surface electrodes (1-centimeter diameter silver chloride triode electrode, Thought Technology, Montreal, Canada) adhered on the skin surface between the palpable superior edge of the thyroid and the spine of the mandible. The rectified and averaged SEMG signals were collected at a sampling rate of 250 Hz. Submental EMG was used to confirm swallowing onset.

Thyroid acoustics using a modified Littmann™ Pediatric stethoscope (KOA 28703) was used to rule out submental EMG artifact and confirm swallowing onset. The bell and diaphragm of the stethoscope were attached to a soft cervical collar. The tubing was cut 4 centimeters from the chest piece and attached to an omnidirectional impedance microphone (Optimus 33-3003). The acoustic signals were collected at a sampling rate of 250 Hz.

Nasal airflow was recorded at the nares using a commercially available adult-size nasal canula. Respiratory tracings were used to categorize respiratory phase cycle in which swallowing apnea occurred and to determine the duration of swallowing apnea. The nasal prongs were situated at the entrance to each nostril and secured firmly around the head.

Procedure

Each participant was made comfortable in a single bed in a private room at a subacute rehabilitation hospital. Following the positioning of the submental SEMG electrodes, nasal canula, and modified stethoscope, participants were left to sleep in a position they felt most comfortable. Participants were instructed to notify the researcher when they awoke by ringing a hand-held electronic bell next to their bed. Recording was initiated once participants failed to respond to a verbal prompt and continued overnight. Recording was discontinued during periods of wakefulness. The following morning, participants were required to perform twenty 15-milliliter water bolus swallows while sitting in an upright position on the edge of the bed. The water boluses were self-administered from a cup. Participants were given a verbal prompt to initiate each swallow, with a minimum of 1 minute allowed between swallows.

Data Analysis

Swallows in both conditions were categorized into one of four phases based on the site of the swallowing apnea within the respiratory phase; midinspiratory (II), inspiratory-expiratory (IE), midexpiratory (EE), and expiratory-inspiratory (EI) by the authors (ML and NF). The duration of apnea during each swallowing event was measured manually.

The percentage of swallows in each respiratory phase category was calculated for each individual and entered into a database to be analyzed statistically. All statistics were performed using a commercially available statistical software package (SPSS for Windows, 1997) at $p < .05$. A two-tailed paired samples t-test was performed to determine whether swallowing occurred more frequently in a particular respiratory phase category. A multivariate analysis of variance (MANOVA) was performed to determine whether there was a condition effect on the coordination of breathing and swallowing, irrespective of age and gender. A repeated measures analysis of variance (ANOVA) was then performed to determine the effects of age and gender on condition. A paired samples t-test was performed to determine whether the duration of apnea was different between the four respiratory phase categories. A repeated measures ANOVA was performed to determine the effects of condition, age and gender on the duration of apnea. The sample size of 16 participants provided sufficient power (80% for a two-tailed analysis with an alpha value of .05). Effect size for between-subject effects was $\gamma > 1.5$; for within-subject effects it was $\gamma > 1.2$.

RESULTS

Breathing-Swallowing Coordination

Irrespective of condition, age, and gender, swallowing occurred most frequently in the EE respiratory phase category followed by IE, EI, and II categories (Table 1). A two-tailed paired samples *t*-test revealed that the percentage of the total number of swallows in each respiratory phase category was significantly different between all categories: II-EI (t (31) = –3.376, $p < .001$), II-EE (t (31) = –15.851, $p < .001$), II-IE (t (31) = –3.926, p = 0.002), IE-EE (t (31) = 9.158, $p < .001$), EE-EI (t (31) = 11.675, $p < .001$)], except between IE and EI (t (31) = 1.113, p = .274).

The Effect of Condition on Breathing-Swallowing Coordination

Swallows were more common in the EE respiratory phase category for both conditions (see Table 1). Swallowing in the wake condition occurred most frequently during the EE respiratory phase category, followed by IE, then EI, and finally the II category (see Table 1). During the sleep condition, swallowing occurred most frequently during the EE respiratory phase category followed by EI, then IE, and finally in the II category (see Table 1). During the wake condition, 84.9% and 94.3% of swallows were preceded (the sum of EI and EE categories) and followed (the sum of IE and EE categories) by expiration, respectively. During sleep, 83% and 82.1% of swallows were preceded and followed by expiration, respectively.

A MANOVA indicated that the effect of condition was dependant on the respiratory phase category in which swallowing occurred [F (1, 3) = 4.746, p = .006]; thus, an individual ANOVA for each phase was performed. The individual ANOVAs revealed a significant difference between conditions in the occurrence of swallows in the EE respiratory phase category [F (1, 15) = 7.34, p = .016], with a greater proportion in wake than in sleep condition (Figure 1). There was a significantly higher occurrence of swallows in the EI respiratory phase category during sleep than during wake [F (1, 15) = 12.452, p = 0.003] (see Figure 1). There were no condition effects for swallows occurring in the II or IE respiratory phase categories.

The Effects of Age and Gender on Breathing-Swallowing Coordination

Both male and female groups swallowed predominantly in the EE respiratory phase category irrespective of age and condition (see Table 1). Similarly, both age groups swallowed more frequently in midexpiration than in any other phase (see Table 1). A repeated measures ANOVA revealed no interaction effects of gender and age on the frequency of swallows in the II, IE, and EI respiratory phase categories. However there was a gender and age interaction for swallows in the EE respiratory phase category [F (1, 51) = 6.492, p = 0.026]. Another repeated measures ANOVA revealed that elderly males swallowed less frequently in midexpiration during sleep than wake [F (1, 3) = 56.888, p = 0.005]. The results of another repeated measures ANOVA showed the difference between conditions was almost significant for young females as well [F (1, 3) = 10.096, p = 0.05] (Figure 2). There were also no significant condition effects for young males and elderly females.

Duration of Swallowing Apnea

Irrespective of condition, age, or gender, the duration of swallowing apnea during the II respiratory phase category was the longest, followed by EI, then IE, with the shortest in the EE category (Table 2). A two-tailed paired samples *t*-test revealed that swallows in the EE respiratory phase category were significantly shorter than swallows in all other categories irrespective of condition, age, and gender: II (t (12) = 3.074, p = 0.01), IE (t (23) = –3.173, p = 0.004) and EI (t (20) = –2.733, p = 0.013). There were no significant differences in the duration of swallowing apnea between the II and IE, II and EI, or IE and EI categories.

The Effect of Condition on the Duration of Swallowing Apnea

Irrespective of age and gender, the mean duration of swallowing apnea in the wake condition was

TABLE 1. Mean and standard deviation of percentage swallows in each respiratory phase category for both age groups, genders, and conditions.

Respiratory Phase Category	Males		Females		Young Adults		Elderly Adults		Sleep		Wake		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
II	2.8%	5.2%	2.0%	4.9%	2.8%	5.3%	2.5%	3.1%	2.5%	3.2%	2.3%	5.2%	2.4%	4.2%
IE	12.6%	17.1%	14.3%	25.3%	10.6%	15.3%	14.3%	10.3%	14.3%	10.6%	12.6%	20.6%	13.4%	16.1%
EE	73.7%	24.1%	73.8%	16.1%	76.2%	22.6%	67.0%	14.7%	67.0%	15.2%	80.4%	28.0%	73.7%	23.1%
EI	8.6%	11.2%	9.9%	10.6%	9.1%	11.2%	15.2%	13.8%	15.2%	14.3%	3.3%	5.4%	9.3%	12.2%

Note: II = swallows in mid-inspiration, IE = swallows at the inspiratory-expiratory cusp, EE = swallows in midexpiration, EI = swallows at the expiratory-inspiratory cusp, SD = standard deviation.

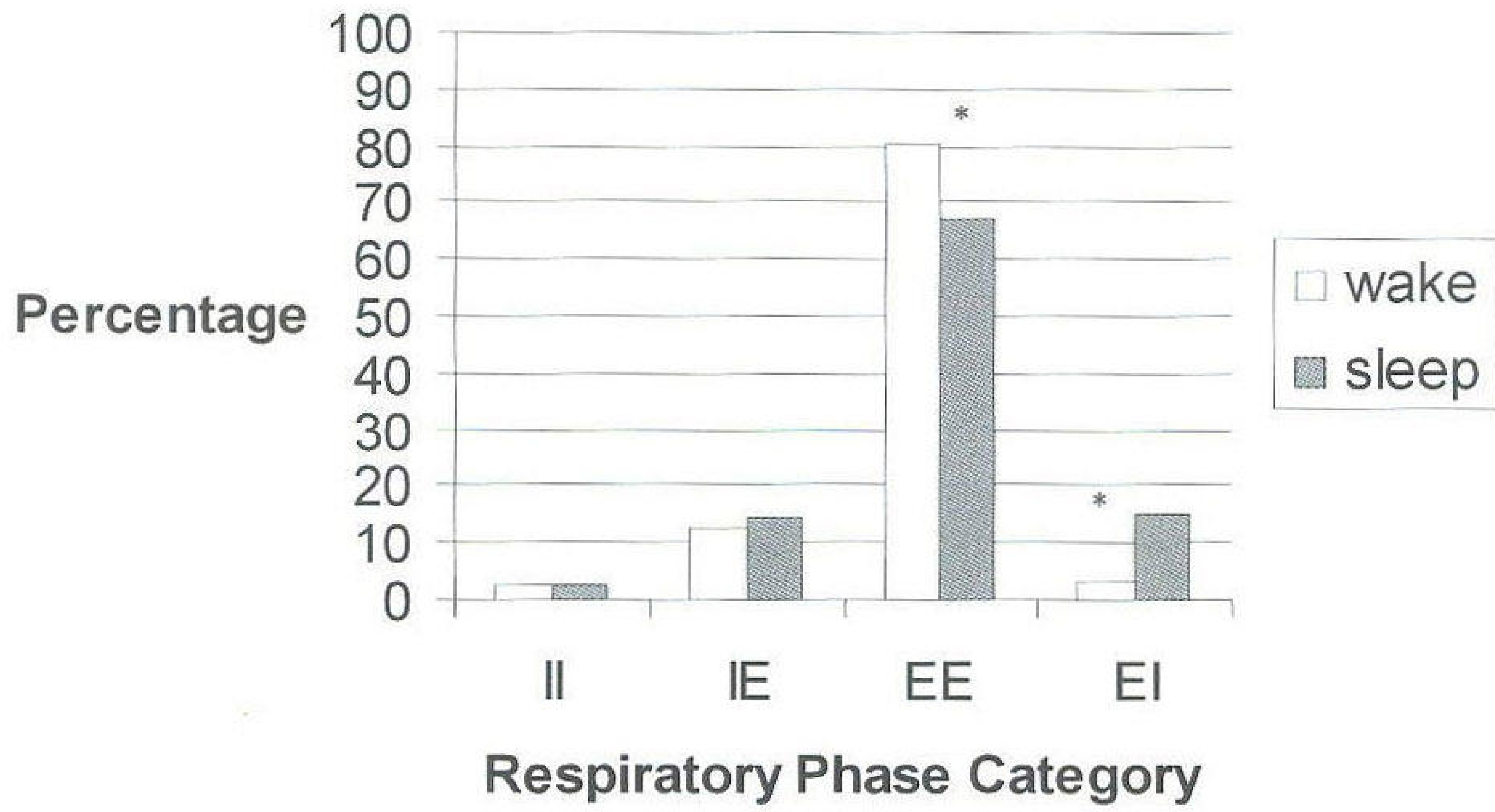

Figure 1. The percentage of swallows within each respiratory phase category for sleep and wake conditions irrespective of age and gender. *Note:* II = swallows in mid-inspiration, IE = swallows at the inspiratory-expiratory cusp, EE = swallows in mid-expiration, EI = swallows at the expiratory-inspiratory cusp. *Denotes a significant difference at $p < .05$.

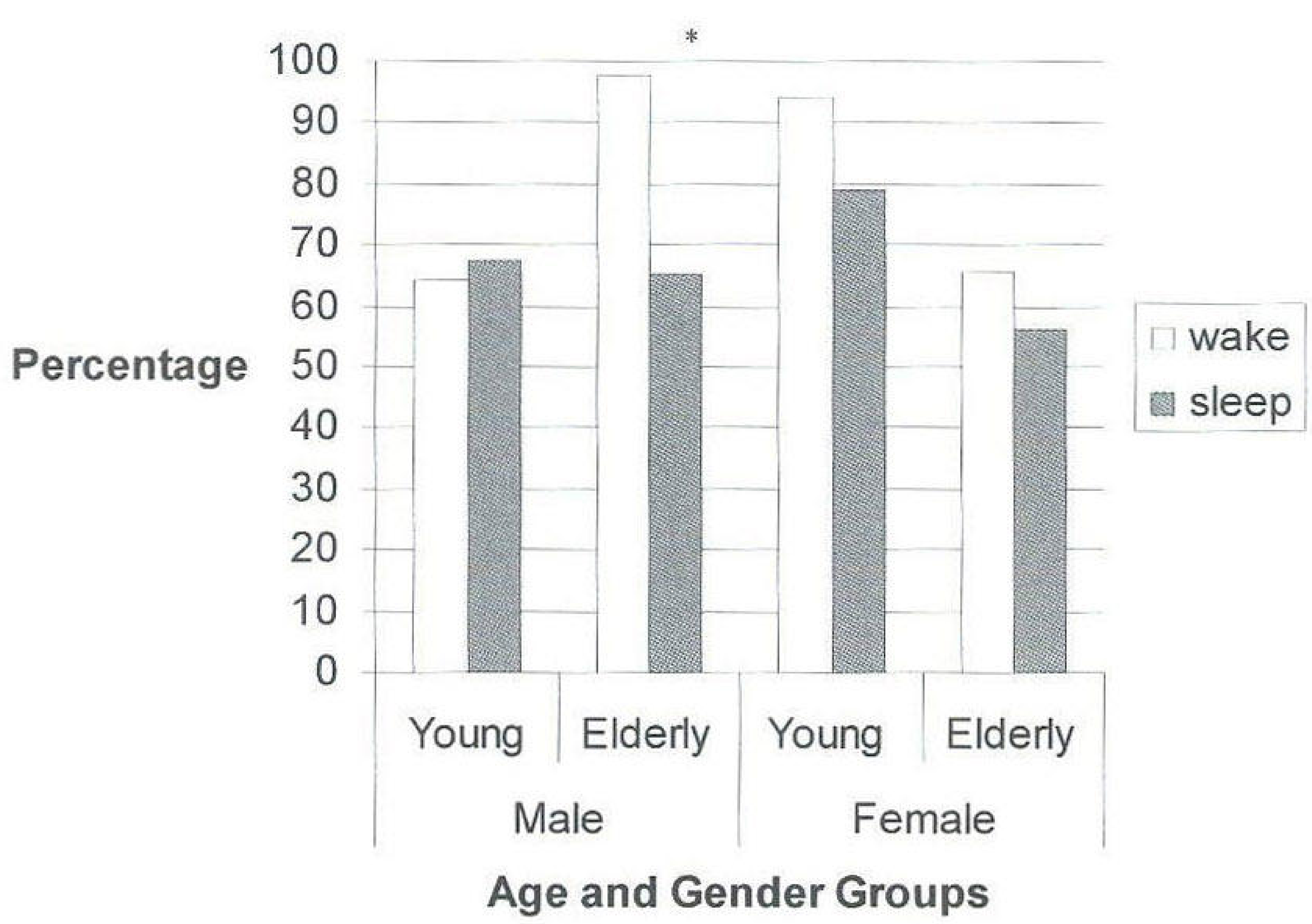

Figure 2. The percentage midexpiratory swallows during sleep and wake conditions for young and elderly, male and female groups. *Denotes significant difference at $p < .05$.

greatest for swallows in the IE respiratory phase category, followed by II, then EI, and finally the EE category (see Table 2). During sleep, the mean duration of swallowing apnea was greatest for swallows in the II category, followed by EI, then IE, and finally the EE category (see Table 2). A repeated measures ANOVA revealed no condition effects for the duration of swallowing apnea in any of the four respiratory phase categories.

Effects of Age and Gender on Duration of Apnea

The mean duration of apnea for each gender group (irrespective of age and condition) and each age group (irrespective of gender and condition) are reported in Table 2.

A repeated measures ANOVA revealed no age effects on the duration of swallowing apnea of any of

TABLE 2. The mean duration of swallowing apnea (in seconds) for each phase of respiration under sleep and wake conditions.

Respiratory Phase Category	Males		Females		Young Adults		Elderly Adults		Wake		Sleep	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
II	1.91	1.31	2.27	1.17	1.91	1.49	2.23	1.0	1.82	0.83	2.2	1.37
IE	1.52	0.84	1.93	1.08	1.58	1.04	1.87	0.94	2.21	1.16	1.41	0.74
EE	1.23	0.46	1.22	0.48	1.16	0.5	1.29	0.45	1.16	0.37	1.28	0.57
EI	2.01	1.41	1.68	1.06	1.99	1.46	1.67	0.94	1.52	1.42	1.94	1.18

Note: II = swallows in midinspiration, IE = swallows at the inspiratory-expiratory cusp, EE = swallows in midexpiration, EI = swallows at the expiratory-inspiratory cusp, SD = standard deviation.

the respiratory phases. Similarly, there were no gender effects on the duration of swallowing apnea for any of the respiratory phase categories.

DISCUSSION

The coordination of breathing and swallowing was more variable during reflexive (sleep) swallowing than volitional (bolus ingestion) swallowing in healthy individuals irrespective of age or gender. Although swallowing typically occurred during midexpiration during both conditions, midexpiratory swallows were less common during reflexive swallows. A decrease in midexpiratory reflexive swallows was particularly evident in elderly males. The increased variability in respiratory phase cycling for reflexive swallowing suggests that conscious cortical influences may play a substantial role in organizing swallowing-respiratory behaviors and thereby facilitating airway protection.

A similar pattern of increased variability was observed in the unconscious state of anesthetized patients (Nishino & Hiraga, 1991) compared to the typically midexpiratory pattern observed for volitional swallowing (Hiss et al., 2001; Klahn & Perlman, 1999; Perlman, Ettema, & Barkmeier, 2000). In anesthetized patients, swallowing occurred just as frequently during inspiration as during expiration (Nishino & Hiraga, 1991). This study revealed that, during natural sleep, 67% of swallows occurred in midexpiration and only 2.5% in midinspiration. It is possible that the effects of the anesthesia on breathing-swallowing coordination are profound, thereby accounting for the discrepancy between the results of the present study and that of Nishino and Hiraga. On the other hand, it is also possible that the participants in the present study were not always asleep. Although participants were instructed to inform the researchers when they awoke, objective confirmation of sleep (with the use of electroencephalography) was not obtained. The possible inclusion of wake (volitional) swallows may also account for the similarity in the occurrence of midexpiratory swallowing in the reflexive condition in the present study (67%) and that of Hiss et al. (2001) during volitional swallowing (62%).

Another variable that may have contributed to the condition effect can be attributed to the ingestion of a liquid bolus in the wake condition. Although liquid bolus ingestion is volitionally initiated, the influence of the sensory feedback of the liquid bolus in the wake condition may have contributed to the alteration of breathing-swallowing coordination. Although prior research indicates there is no difference in the breathing and swallowing coordination between spontaneous dry swallows and water-induced reflexive swallows (Nishino, Yonezawa, & Honda, 1985), the comparison of dry volitional swallows with that of reflexive sleep swallows may provide a better comparison of the influence of volitional input on breathing-swallowing coordination.

It is also acknowledged that the participants' posture differed between the two conditions. Volitional swallows were performed sitting upright, and reflexive swallows were not. McFarland, Lund, and Gagner (1994) found a difference in the coordination of breathing and swallowing between upright positioning and resting on hands and knees; swallowing apnea occurred later in the expiratory phase in the former position. However, other research has indicated no difference in breathing-swallowing coordination between sitting and supine position (Shaker et al., 1992). Although the specific effect of side-lying and prone positioning remains unknown, it is doubtful that a change in body position could account for the differences observed between the conditions in the present study given the results of the study conducted by Shaker et al.

Expiration was most closely associated with swallowing. During bolus ingestion 84.9% of swallows were preceded by expiration, and 94.3% were followed by expiration. During sleep 83% of swallows were preceded by expiration, and 82.1% were followed by expiration. The pattern of predominantly midexpiratory swallowing during volitional bolus ingestion (80.4%) is consistent with prior literature (Hiss et al., 2001; Klahn & Perlman, 1999). However, the pattern of predominantly midexpiratory reflexive swallowing (67%) is not. Prior research indicated that spontaneous swallows in adult humans typically occur at the inspiratory-expiratory cusp and in midexpiration (Paydarfar et al., 1995). The discrepancy between these results and those of the present study may be attributed to the methodological approach adopted by Paydarfar et al. These authors elicited spontaneous swallows by water infusion, which may not be representative of reflexive swallowing given the likelihood of anticipation and oral preparation on behalf of the participant. This contrived method of eliciting spontaneous swallows is not comparable to spontaneous sleep swallows given the likelihood of cortical activation as a result of anticipation. This method is also unlike volitionally initiated bolus swallows used in the present study, thus differing results are to be expected.

Irrespective of the discrepancies in the literature, it appears there is a trend toward an increase in midexpiratory swallows, with an increase in volitional control over swallowing. This trend is represented in Figure 3. On one end of the spectrum, approximately half of the reflexive swallows of anesthetized patients were midexpiratory (Nishino & Hiraga, 1991) compared to 93% for volitional swallowing (Klahn & Perlman, 1999). Unfortunately, the continuum of conditions varying by degree of volitional input into swallowing is incomplete, given the different approaches to the reporting of data by authors. For example, some authors did not report the percentage midexpiratory swallows (Shaker et al., 1992), and, thus, cannot be represented in the continuum in Figure 3. Research is currently underway to complete this continuum of conditions varying by degree of volitional input into swallowing.

Midexpiratory swallows proved to be of particular interest again in terms of gender, condition, and age interaction effects on the frequency of occurrence and duration of apnea. Midexpiration was most closely associated with swallowing for males and females, which is consistent with prior research (Hiss et al., 2001; Klahn & Perlman, 1999). A condition effect was observed for midexpiratory swallows only for elderly males, with midexpiratory swallows occurring more frequently during wakefulness than sleep. Although a condition effect was not observed for young males, and young and elderly females, descriptively, the distribution patterns of the latter two groups are similar to that of the elderly men. These results are in keeping with the overall increase in the frequency of midexpiratory swallows during wakefulness shown in Figure 1. Thus it appears that the mature nervous system is hardwired to perform swallows predominantly in midexpiration irrespective of the presence or absence of an ingested bolus and irrespective of the level of consciousness.

The mean duration of swallowing apnea was significantly shorter for midexpiratory swallows than for any other respiratory phase category irrespective of condition, age, or gender. These results are

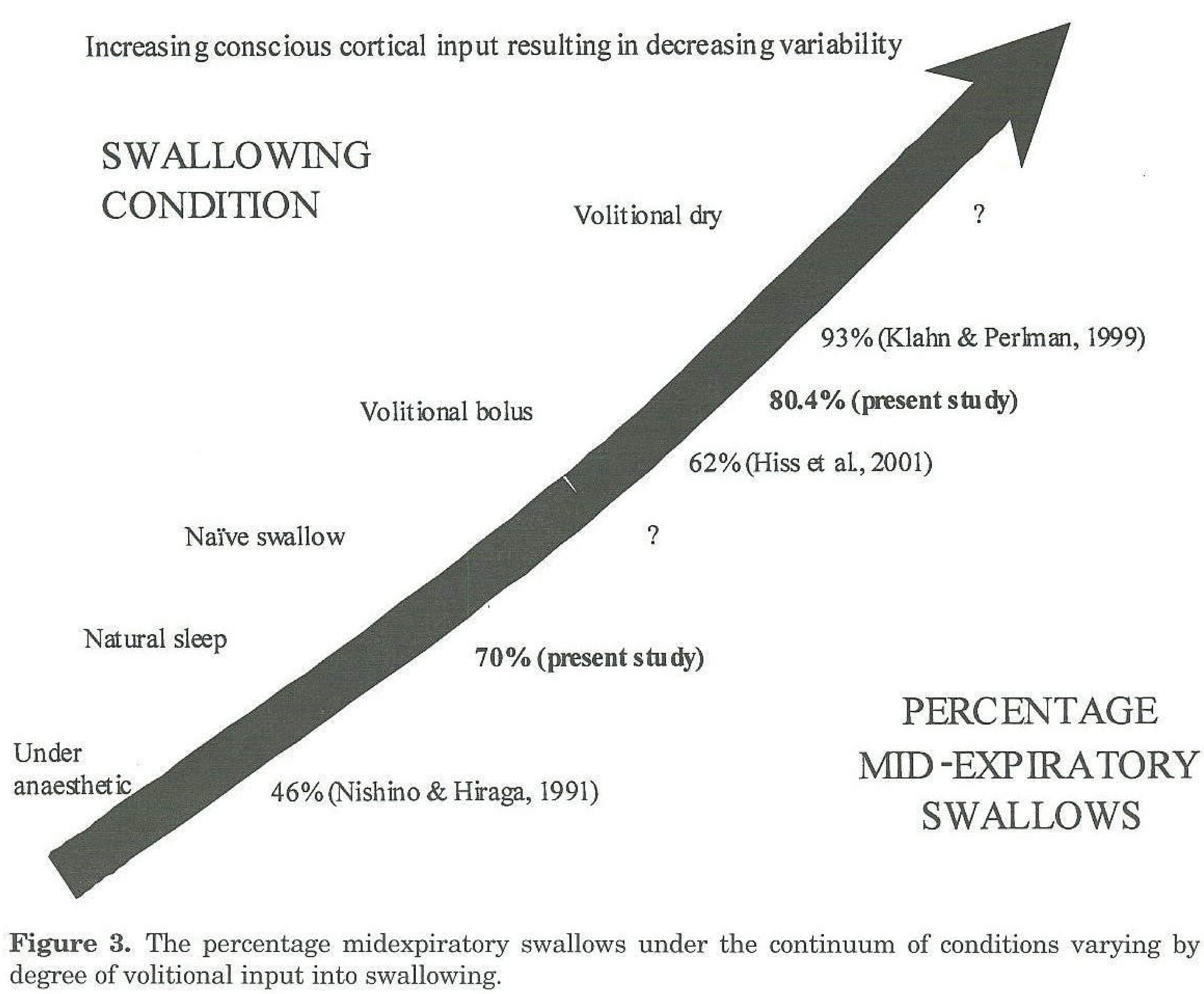

Figure 3. The percentage midexpiratory swallows under the continuum of conditions varying by degree of volitional input into swallowing.

not surprising given that midexpiratory swallows are considered most effective in airway protection, thereby eliminating the need for lengthy apnea duration. However, these results are in conflict with prior research that suggests that the duration of swallowing apnea may not be affected by the respiratory phase in which it occurs (Nishino & Hiraga, 1991; Paydarfar et al., 1995). The reason for this apparent conflict remains unclear.

The mean duration of swallowing apnea in all respiratory phase categories was not influenced by condition, age, or gender. Interestingly, a difference in the duration of swallowing apnea between the conditions was expected, as the introduction of a bolus may significantly shorten (Shaker et al., 1992) swallowing apnea duration. In the present study, liquid boluses were ingested in one condition (wake) and not the other (sleep), yet there was no difference in the duration of swallowing apnea between the conditions.

The influence of age on the duration of apnea appears debatable. Some authors argue that it is influenced by increasing age (Hiss et al., 2001; Selley, Flack, Ellis, & Brooks, 1989). The finding that duration of swallowing apnea is longer in the elderly than in young adults (Hiss et al., 2001; Selley et al., 1989) may be explained by the larger pharyngeal transit times demonstrated on videofluoroscopy (Rademaker, Pauloski, Colangelo, & Logemann, 1998). Other studies show that the influence of age on swallowing apnea duration is not clear-cut. An interaction between age and gender was reported for bolus swallows, with females demonstrating decreasing duration of swallowing apnea with increasing age and males demonstrating an increase with increasing age (Hiss et al., 2001). Hiss et al. found that the opposite was true for dry swallows, with males demonstrating a decrease in the duration of swallowing apnea with age and females demonstrating an increase. However, there was not a significant effect of age or gender in isolation for saliva swallows (Hiss et al., 2001), which is consistent with the results of the present study.

The results of the present study show differences between reflexive and volitional swallows. However, future research to determine whether descending cortical input influences breathing-swallowing coordination should take into consideration the potential variables and limitations of this pilot study that may have influenced these results. Objective confirmation of sleep status using electroencephalography is perhaps the most obvious recommendation, given that wakeful swallows may incorrectly be classified as sleep swallows. Confirmation of the age and gender interactions should be examined with a greater number of subjects. As already discussed, there is conflicting evidence of an effect of body position on breathing-swallowing coordination. Further investigation is required before it can be established whether position is a variable that needs to be controlled in future sleep-wake study designs.

CONCLUSIONS

Although expiration was most closely associated with volitional and reflexive (sleep) swallowing, significantly fewer reflexive swallows occurred during midexpiration than volitional swallows. Reflexive swallowing also occurred significantly more frequently at the expiratory-inspiratory cusp than did volitional swallowing. The increased variability in respiratory phase cycling for volitional swallowing suggests that conscious cortical influences may play a substantial role in organizing swallowing-respiratory behaviors, thereby facilitating airway protection. The authors acknowledge that there were two independent variables that may have contributed to the differences observed in this pilot research between the sleep and wake conditions. First, the participants' posture differed between the conditions. Second, and perhaps more important, was the inclusion of liquid boluses in the wake, but not in the sleep, condition. Nonetheless, this pilot study provides important data that highlight the need for future research to determine the influence of these variables and to control for their influences in order to compare volitional and reflexive swallowing conditions. Objective confirmation of sleep status and the inclusion of a greater number of participants are recommended for future research in this area. Such care will determine whether descending conscious cortical input influences breathing-swallowing coordination.

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