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Effects of chin-up posture on the sequence of swallowing events

Irene Calvo, MSc^{1,2,4,*}, Kirstyn L. Sunday, BS^{2,4}, Phoebe Macrae, PhD³, and Ianessa A. Humbert, PhD^{2,4}

¹Department of Neurorehabilitation Sciences, Casa Cura Policlinico, Milano, Italy ²Department of Speech, Language, and Hearing Sciences, University of Florida, Gainesville, Florida ³Department of Communication Disorders, University of Canterbury, Christchurch, New Zealand ⁴Swallowing Systems Core, University of Florida, Gainesville, Florida

Abstract

Background—Chin-up posture is frequently used to manage oral dysphagia after head and neck cancer. This prospective study investigates the effects of chin-ups on the sequence of pharyngeal swallowing events.

Methods—Twelve healthy young adults performed 45 consecutive swallows of 5 mL water across 3 phases on videofluoroscopy: 5 swallows in the neutral head position; 30 swallows during chin-up posture; and 10 swallows in the neutral head position. Swallowing kinematic and bolus flow measures for 9 swallowing events were recorded. Linear trends were analyzed across 30 chin-up swallows; pairwise comparison was used to compare the 3 phases.

Results—Time to hyoid peak and laryngeal vestibule closure changed abruptly during chin-up swallowing compared to the initial neutral position. No measure changed across 30 chin-up swallows. Time of hyoid burst decreased upon returning to the neutral position.

Conclusion—Our findings indicate that chin-up posture challenges the pharyngeal sequence of events for both swallowing kinematics and bolus flow.

Keywords

swallowing; dysphagia; chin-up; head and neck cancer; adaptation

INTRODUCTION

The chin-up posture is a compensatory strategy utilized in the management of dysphagia after head and neck cancer.^{1,2} To perform this posture, the head and neck are extended backward and the chin is lifted before initiation of the swallow. The chin-up posture is also referred to as head back, head extension, neck extension, or neck hyperextension. It was first described by Logemann³ as a procedure to be used in patients with difficulties in the oral phase of the swallow, because hyperextension of the head facilitates posterior bolus transit using the force of gravity.⁴ Thus, the chin-up posture is commonly used in head and neck

*Corresponding author: I. Calvo, Casa Cura Policlinico, Department of Neurorehabilitation Sciences, Via Giuseppe Dezza, 48, 20144 Milano, Italy. calvoi@tcd.ie.

cancer populations and especially in patients who have undergone a glossectomy in order to facilitate the transit of the bolus.^{5,6}

Halczy-Kowalik et al⁵ investigated the use of “self-applied” compensatory postures in a cohort of 95 patients after total or partial glossectomy and found that 16.8% of patients spontaneously tilted their head backward. They noted that the spontaneous use of the chin-up posture significantly correlated with both difficulties in tongue movements and glosso-palatal closure seen on the videofluoroscopic swallowing study (VFSS). Solazzo et al⁴ examined the effectiveness of 3 compensatory postures using both VFSS and pharyngeal manometry in a cohort of 321 patients with oropharyngeal dysphagia with different clinical diagnoses. Among 5 patients who presented with difficulties in bolus transit, the use of the chin-up posture improved swallowing in all of them. Furia et al⁶ examined 15 patients who underwent partial, total, or subtotal glossectomy and found that each of them moved their head backward during swallowing. Moreover, many patients with other types of head and neck cancers have trouble in the oral phase of swallowing because of radiotherapy and/or chemotherapy effects. Oral pain, mucositis, fibrosis caused by radiation, and chemoradiation are responsible for reduction in base of tongue movements,^{7,8} prolonged oral transit time,^{2,8,9} and reduced tongue strength.^{10,11}

Despite accepted chin-up posture use in patients with oral dysphagia, its use in the pharyngeal dysphagia population raises safety concerns and, as a result, was recommended only in patients with intact laryngeal and pharyngeal function.³ We agree that the original goal of the chin-up posture was not intended to address the pharyngeal swallow. Nonetheless, although clinicians might be recommending chin-up swallowing in patients with poor posterior oral transit, ultimately the bolus will be swallowed and it is unknown what aspects of pharyngeal swallowing are more likely to be facilitated versus inhibited while in the chin-up position. Recently, Halczy-Kowalik et al⁵ showed that 4 of 10 patients who have undergone partial and total glossectomy presented with aspiration while performing the chin-up position before swallowing, leading to predeglutition leakage into the airway. In a study by Badenduck et al,¹² instructed chin-up position led to 1 silent aspiration event with thin liquids and penetration events and significant residue with puree consistency in healthy individuals. Ertekin et al^{13,14} noted that the chin-up position decreased the “dysphagia limit” (maximum amount of a bolus swallowed before piecemeal swallowing occurred) in a cohort of adults with oropharyngeal dysphagia and in healthy subjects when swallowing volumes less than 20 mL. Castell et al¹⁵ found that chin-up swallows decreased upper esophageal sphincter relaxation time, increased upper esophageal sphincter residual pressure, and narrowed the pharyngoesophageal junction in a cohort of 9 healthy subjects. Therefore, we can infer that although chin-up swallowing might help oral transit, it is highly likely that it is impacting pharyngeal events. As chin-up swallowing is spontaneously executed by patients with oral swallowing difficulties, the effect of the chin-up position is especially important to examine. Furthermore, in patients treated for head and neck cancer, chemoradiotherapy to the oral cavity is likely to impact the surrounding areas² (ie, pharyngeal and laryngeal muscles), also affecting the pharyngeal phase of swallowing and possibly compromising the safety of a chin-up swallow.

Although each of these aforementioned studies could substantiate recommendations that the chin-up position should be avoided in patients with swallowing impairments because of laryngeal or pharyngeal dysfunction, some limitations should be considered. First, many of these studies did not compare physiological differences between the head in the neutral position and chin-up swallowing. This is critical in order to determine which underlying swallowing impairments are more likely to be improved, worsened, or unchanged by the posture and why. Second, few bolus presentations were administered in previous studies, which limits the understanding of (a) whether the underlying impairment is consistent or transient in the neutral head position and (b) whether chin-up swallowing effects are consistent or transient across multiple trials. Third, it is unclear whether chin-up posture swallowing effects continue after returning to neutral head position swallowing (also known as after-effects or exaggerated movements). The stability of a treatment's effects on swallowing as well as the presence or absence of after-effects have been studied using electrical stimulation, mode of bolus presentation, and chin-down swallowing¹⁶⁻²¹ and could shed light on chin-up swallowing outcomes as well.

The purpose of this study was to address each of these limitations and improve our understanding on the effects of chin-up swallowing. To address the limited number of swallow trials, the current study includes 45 consecutive swallows (5 swallows in the neutral head position; 30 swallows in the chin-up position; and then 10 swallows post chin-up neutral head position swallows). Because of concerns of laryngeal compromise previously documented, only healthy adults were included in this investigation. The sequence of 9 swallowing events was determined for all swallows to determine: (a) the immediate physiological effects of chin-up swallowing; (b) the presence and stability of chin-up swallowing effects across 30 chin-up swallows; and (c) whether after-effects occur when returning to neutral head position swallowing.

We hypothesized that: (a) the sequence of events during chin-up swallowing would be altered compared to the neutral position swallowing. We expected to find differences both in events related to hyolaryngeal kinematics and bolus flow. Compared to the neutral position, hyperextending the neck results in increased distance between the hyoid bone and the mental protuberance of the mandible.²² Thus, the time of peak hyoid elevation might occur at a different point in the swallow relative to other events. Additionally, bolus flow into the pharynx is likely facilitated by gravity during chin-up swallows. Thus, swallowing events that are impacted by bolus flow (ie, hyoid burst and time of upper esophageal sphincter opening) might change relative to other nonbolus related swallowing events. (b) The sequence of events will change over the course of several chin-up swallows. Previous studies have shown that applying a perturbation or manipulation to swallowing can gradually impact swallowing kinematics across 20 to 30 consecutive swallows.^{16,17,20} Specifically, the swallowing system gradually adapted to overcome the effect of the perturbation or adapted to the novel experience. We expected that during 30 consecutive chin-up swallows the system would gradually change to accommodate any effects of hyolaryngeal or bolus flow changes. (c) When returning to the neutral position swallowing after several chin-up swallows, we expected to find after-effects on the sequence of swallowing events. In particular, events that were harder to achieve during chin-up swallowing might become

easier when the perturbation is suddenly eliminated, and thus, might occur earlier in the swallow (ie, peak hyoid elevation) relative to other events.

MATERIALS AND METHODS

Participants

The local institutional board approved the study design and procedures. Participants were 12 young healthy adults (mean age, 20.6 years; age range, 18–29 years; 7 women; 5 men). Written informed consent was obtained from each participant; no history of speech, swallowing, or neurological disorders was reported by any participant.

Procedure

Before the study, participants performed 2 head neutral swallows, 2 chin-up swallows, and then 2 head neutral swallows in order to familiarize participants with the study procedure and the cues for position change (Figure 1). For the study procedure, every subject performed 45 consecutive swallows of 5 mL Varibar thin liquid barium. A 5-mL bolus was used because it was the largest bolus size that participants could swallow 45 times without feeling too full and asking to terminate the study and/or use the toilet before the end of the study. The 45 swallows were performed in the following order: 5 swallows in the head neutral position (phase 1); 30 swallows in the chin-up position (phase 2); and 10 swallows in the head neutral position (phase 3). Approximately 30 trials with a swallowing perturbation or manipulation have already been shown to cause gradual changes on swallowing kinematics in previous studies.^{16,18,19}

The chin-up swallows were performed without controlling the head angle, but generic instructions were given to the participants to maintain the chin-up posture until they received a cue to return to the neutral position (which occurred after 30 consecutive swallows). Volunteers were seated upright and each bolus was delivered by the investigator with a syringe through a 66-inch flexible tube taped to the participant's chin. This allowed maintenance of the chin-up posture for consecutive swallows including the 7-second inter-swallow interval. The participants were instructed to hold the bolus in their mouth and were cued to swallow with an auditory prompt. A PowerPoint presentation was used to prompt the participant to swallow, with a 5-second countdown before the swallow, followed by a 2-second presentation of a visual and audio cue in which the participant was to perform the swallow.

Videofluoroscopy

All swallows were recorded with continuous videofluoroscopy (Axiom Sireskop SD, Siemens, Munich, Germany) in the sagittal plane with a video capture rate of 30 frames per second. The field of view included the oral cavity, pharynx, hyolaryngeal structures, subglottal air column (trachea), upper esophageal sphincter, and the upper esophagus. A time code was recorded simultaneously to facilitate data analysis.

Data analysis

Measures—Nine measures were used to investigate the sequence of swallowing events in each swallow, previously described by Young et al¹⁶ as follows: (1) bolus head enters the pharynx: the first frame when the head of the bolus passes the ramus of the mandible; (2) bolus tail enters the pharynx: the first frame when the bolus tail passes the ramus of the mandible; (3) bolus head into the upper esophageal sphincter: the first frame of bolus entry into the upper esophageal sphincter (frequently the same frame as upper esophageal sphincter open). When barium rests on top of a closed upper esophageal sphincter, it is shaped like a “U.” When the upper esophageal sphincter opens, the bolus head is funneled in and is shaped like an elongated “V.” Thus, we identified the frame of the bolus head in the upper esophageal sphincter as the first frame in which the bolus head appears as an elongated “V” shape. (4) Hyoid burst: the first superior and/or anterior burst of motion of the hyoid that results in a forward/upward loop of the hyoid during a swallow. (5) Peak hyoid elevation: maximum superior displacement of the hyoid bone (at or after hyoid burst). (6) Laryngeal vestibule closure (LVC): the first frame when the laryngeal vestibule is closed and no airspace can be seen through the hyolaryngeal structures. (7) Laryngeal vestibule open (LVO): first frame when the laryngeal vestibule reopens and airspace can be visualized as the epiglottis begins its return to the rest position. (8) Upper esophageal sphincter open: the first frame when the upper esophageal sphincter opens, identified by the presence of either airspace just before bolus entry into the upper esophageal sphincter or by bolus head entry into the upper esophageal sphincter. (9) Bolus tail exit upper esophageal sphincter: the first frame when the bolus tail passes the upper esophageal sphincter.

In addition to swallowing kinematics, Penetration-Aspiration scores²³ were derived for each swallow.

Analysis

Each swallow was measured with frame-by-frame analysis by 2 experienced researchers blinded from the study. Then, a third unblinded researcher arranged all the swallowing events into chronological order. Two different formats were used to analyze the swallows: 3 phases and 4 stages (see Figure 1). The 3 phases corresponded to the sequence of 45 swallows: 5 neutral head swallows (phase 1); 30 chin-up swallows (phase 2); and 10 neutral head swallows (phase 3). Comparing outcomes among the 3 phases allowed us to determine differences without consideration for changes within any phase. However, to examine changes within each phase (ie, hypothesis 2 = to assess if swallowing events change across the 30 chin-up swallows within phase 2), 4 stages were also defined. The 4 stages included: (1) the first 5 neutral swallows (N1); (2) the first 5 chin-up swallows (P1); (3) the last 5 chin-up swallows (P2); and (4) the first 5 neutral head swallows upon returning to the neutral position after the chin-up posture (N2). We determined the sequence of swallowing events in 2 different ways. First, we derived the millisecond that each swallowing event occurred, relative to 2 different reference swallowing events, including (a) the frame of hyoid burst and (b) the frame that the bolus head entered the pharynx. This method of sequencing was classified as the ratio data method, as milliseconds are interval data with a natural zero point. We chose these 2 reference points as (a) hyoid burst is the physiological event that traditionally marks the onset of the pharyngeal phase of swallowing,^{24,25} and because we

believe chin-up would alter the bolus position by gravity, and (b) the bolus head entering the pharynx was chosen as an onset point of bolus flow-related events. Second, we derived the order of each swallowing event as it occurred for each individual swallow, and numbered them from 1 through 9. This method was classified as the ordinal data method, as it described the order of events unrelated to absolute timing.

Comparison and statistical analysis

Parametric statistics were used to determine differences in ratio data (milliseconds relative to a reference event), whereas nonparametric statistics were used to investigate differences in ordinal data (absolute order of each swallowing event). For each method (ratio and ordinal), comparisons were made among the 3 different phases (phase 1, phase 2, and phase 3) as well as among the 4 different stages (N1, P1, P2, and N2) in separate analyses.

To answer question 1 (Are there physiological effects of chin-up swallowing on the sequence of swallowing events?), the means between phase 1 (first 5 head-neutral swallows) and phase 2 (30 chin-up swallows) were compared. We were able to determine if there are immediate physiological effects of chin-up swallowing on the sequence of swallowing events by comparing the means of N1 (first 5 head neutral swallows) and P1 (first 5 chin-up swallows).

To answer question 2 (Does the sequence of swallowing events change over the execution of multiple chin-up swallows?), the presence of a linear trend throughout phase 2 was determined. In addition, P1 (first 5 chin-up swallows) was compared to P2 (last 5 chin-up swallows).

To answer question 3 (Are there immediate aftereffects on the swallowing sequence of events when returning to the neutral head position after performing chin-up swallows?), the means of phase 1 (first 5 head neutral swallows) and phase 3 (10 head neutral swallows performed after the chin-up posture) were compared. Because after-effects may decrease over time, we also compared the means of N1 (first 5 head neutral swallows) and N2 (first 5 head neutral swallows performed after the chin-up posture).

Statistical analyses were conducted with SPSS version 23. A linear mixed-effects model²⁶ (parametric test) was used to analyze data derived in milliseconds. "Subjects" were entered as random effects to deal with heterogeneity across the participants. Factors included the time period (ie, phase or stage), which were the fixed effects and the intercept of each person varied. Trial number was used as a covariate to estimate trends in the data (changes across 30 chin-up swallows in phase 2). Confidence intervals (95%) were calculated to indicate the degree of uncertainty in the estimation of the parameters. Pairwise comparisons generated by the software were used in the case of statistically significant fixed effects with Sidak correction for multiple comparisons (p values of $< .05$ were considered statistically significant). Reliability was determined by deriving interrater reliability on 20% of the data and intrarater reliability on 5% of the data using single-measure intraclass correlation coefficients. A Friedman test was used to detect differences in the ordinal data ($\alpha < 0.05$). The statistical measure, Cohen's d , was used to determine the effect size when comparing

the means that were statistically significant (effect sizes of 0.4 or greater were considered relevant effects).

RESULTS

A total of 540 swallows were recorded on VFSS. In 33 swallows, the images were too dark and were excluded from the analysis. A total of 507 swallows were analyzed. Interrater and intrarater reliability held excellent agreement; all p values were $> .95$ for each swallowing event. Penetration-Aspiration scores were 1 in 58% of the swallows, 2 in 26% of the swallows, and 3 in 16% of the swallows. The results are reported below by the 2 different groupings (3 phases and 4 stages) when appropriate. The following results are also discussed by data type, including ordinal data (order of events from 1–9) as well as ratio data (milliseconds when each measure is relative to the hyoid burst time or the time of the bolus head in the pharynx). Fixed effects are reported for ratio data and pairwise comparisons are reported for both ratio and ordinal data. Ordinal data means for each event are reported in Table 1 for phases and Table 2 for stages.

Fixed effects

Phases—For differences in milliseconds (events relative to the bolus head entering the pharynx) only the head into the upper esophageal sphincter event was different ($p = .03$; $F = 3.537$). Mean values for this event were 162 msec in phase 1 ($SD = 132$); 153 msec in phase 2 ($SD = 72$); and 183 msec in phase 3 ($SD = 132$). No other significant differences were found.

Stages

For differences in milliseconds (events relative to hyoid burst), only the peak hyoid elevation was different ($p = .011$; $F = 3.277$). Mean values for this event were 151 msec in the N1 head neutral swallows ($SD = 87$); 224 msec in phase 1, early chin-up swallows ($SD = 78$); 215 msec in phase 2, late chin-up swallows, ($SD = 78$); and 151 msec in N2, late head neutral swallows ($SD = 90$). No other significant differences were found.

Pairwise comparisons

Research question 1: Does chin-up swallowing alter the sequence of swallowing events compared to the neutral position?

Phases

When comparing head neutral swallows (phase 1) to chin-up swallows (phase 2), differences were found for the following specific events.

Ordinal

Peak hyoid elevation—Chin-up swallowing caused the peak hyoid elevation to occur later in the swallow ($p = .001$; Table 3). In the head neutral swallows of phase 1, the peak hyoid elevation was the first or second event 72% of the time and the third or fourth event in 28% of the swallows. Whereas, in the chin-up swallows (phase 2), the peak hyoid elevation

was the first or second event 45% of the time and the third or fourth event 55% of the time (Table 4).

Laryngeal vestibule closure—Chin-up swallowing caused the LVC to occur earlier in the swallow ($p = .04$; Table 3). In the head neutral swallows (phase 1) the LVC was the third or fourth event in 20% of the swallows, and the fifth, sixth, or seventh event in 80% of the swallows. Whereas, in the chin-up swallows (phase 2), the LVC was the third or fourth event in 38% of the time, and the fifth or sixth event in 62% of the time (Table 4).

Ratio

No statistically significant differences were found.

Stages

Research question 1 was answered in the stages data by comparing the first 5 head neutral swallows (N1) to the first 5 chin-up swallows (P1).

Ordinal

Peak hyoid elevation—Similar to the phase comparisons, the chin-up swallowing caused the peak hyoid elevation to occur later in the swallow than in the neutral head position swallows ($p = .001$; Table 5). In the head neutral swallows (N1), the peak hyoid elevation was the second or third event 72% of the time, and the fourth and fifth event 28% of the time. In the early chin-up swallows (P1), the peak hyoid elevation was the second or third event 39% of the time, and the fourth and fifth event 61% of the time (Table 6).

Laryngeal vestibule closure—Similar to the phase comparison, the chin-up swallowing caused LVC to occur earlier in the swallow than in the neutral head position swallows ($p = .041$; Table 5). In the head neutral swallows (N1), LVC was the second or third event 20% of the time, and the fourth, fifth, or sixth event 83% of the time. In the chin-up swallows (P1), LVC was the second or third event 28% of the time and the fourth or fifth event 72% of the time (Table 6). However, this difference had a small effect size ($d = 0.241$).

Ratio

No statistically significant differences were found.

Stages

Research question 2: Does the sequence of swallowing events change over the executions of multiple chin-up swallows?

No linear trends were found across the 30 chin-up swallows during phase 2, and no differences were found in the means of swallowing events of P1 (first 5 chin-up swallows) compared to P2 (last 5 chin-up swallows).

Research question 3: Are there immediate after-effects on the swallowing sequence of events when returning to the neutral position?

Phases

Research question 3 was answered in the phase data comparing phase 1 and phase 3.

Ordinal

In the neutral position swallows after the chin-up swallows (phase 3), the hyoid burst occurred later compared to the neutral swallows that occurred before chin-up swallows (phase 1; $p = .025$; Table 3). Whereas in phase 3, the hyoid burst was the first event 79% of the time and the second event 21% of the time (Table 4). However, this difference had only a small effect size ($d = 0.337$).

Ratio

No significant differences were found.

Stages

Research question 3 was answered in the stages data comparing N1 (first 5 head neutral swallows) and N2 (first 5 head neutral swallows upon returning to the neutral position).

Ordinal

Upon returning to the neutral position after the chin-up swallows, the hyoid burst occurred later in the swallow compared to the neutral swallows that occurred before chin-up swallowing ($p = .025$; Table 5). In N1 swallows, the hyoid burst was the first event 91% of the time and the second event 9% of the time. Whereas in N2 swallows, the hyoid burst was the first event 77% of the time and the second event 23% of the time (Table 6). However, this difference did not have a large effect size ($d = 0.381$).

Ratio

No significant differences were found.

Additional findings

Additional findings were found when looking at the pairwise comparisons of the ordinal data for comparisons that were not originally hypothesized.

Phase 2 versus phase 3

Kinematics involving the upper esophageal sphincter and LVC occurred later in phase 3 swallows (return to neutral head position), compared to the 30 chin-up swallows (phase 2). In particular, upper esophageal sphincter open, bolus head in upper esophageal sphincter, and LVC all occurred later after chin-up swallowing ($p < .001$; $p < .001$; and $p = .003$; Table 7).

Phase 1 versus swallows upon returning to the neutral position

Four events were different when comparing the first 5 chin-up swallows (P1) to the first 5 swallows upon returning to the neutral position (N2). Three events happened later in N2 swallows compared with P1 swallows: hyoid burst ($p = .013$), upper esophageal sphincter open ($p = .019$), and bolus head into the upper esophageal sphincter ($p = .019$; Table 7).

Conversely, peak hyoid elevation happened earlier in N2 swallows compared with P1 swallows ($p = .014$; Table 8).

Phase 2 versus swallows upon returning to the neutral position

Three events were different when comparing the last 5 chin-up swallows (P2) to the first 5 swallows upon returning to the neutral position (N2). Similarly to P1 versus N2, the hyoid burst ($p = .008$), upper esophageal sphincter open ($p = .022$), and bolus head into the upper esophageal sphincter ($p = .033$) occurred later in the head neutral swallows compared with the chin-up swallows (Table 8).

Swallows upon returning to neutral position versus phase 2

When comparing the first 5 head neutral swallows (N1) to the last 5 chin-up swallows (P2), the hyoid maximum peak hyoid elevation occurred significantly later in the chin-up position ($p = .014$; Table 8).

DISCUSSION

The purpose of this study was to examine the effects of the chin-up posture on the sequence of swallowing events and to investigate the presence of motor learning adaptation during and immediately after chin-up swallowing. Overall, we found that chin-up swallowing leads to later time of peak hyoid elevation and earlier time of laryngeal vestibule closure. No changes were found in swallowing kinematics over the course of 30 chin-up swallows. In addition, the time of the hyoid burst was later after returning to the head neutral position. Additional findings showed upper esophageal sphincter-related events happening later in the swallow after returning to the neutral position, compared to upper esophageal sphincter events occurring during chin-up posture.

Peak hyoid elevation and laryngeal vestibule closure

Our findings show that peak hyoid elevation events occurred later in the swallow when performing chin-up compared to head neutral swallows (see Figure 2). We propose that this change in the sequence of events might be caused by mechanical disadvantages of the hyolaryngeal complex during the chin-up position.²² Longer time to peak hyoid elevation might occur because maintaining the chin-up position at rest increases passive tension of the suprahyoid muscles.²⁷ Adding a swallowing task to this increased passive tension could lead to fewer muscle fibers available for recruitment during hyoid excursion.^{28,29} This is consistent with findings by Sakuma and Kida³⁰ reporting that swallowing in the chin-up position requires longer duration and greater amplitude of suprahyoid and infrahyoid muscle activity as measured on surface electromyography.

Timing of LVC also changed, occurring earlier during the chin-up swallows (phase 2) when compared to the first neutral swallows (phase 1; see Figure 2). Even though remarkable variability has been found in the sequence of events in healthy swallowing, including variations in the sequence of LVC and hyoid kinematics,³¹ measures of peak hyoid velocity have previously been linked to LVC in healthy subjects swallowing thin liquids.³² In the current study, the peak hyoid elevation occurred consistently later and LVC occurred

consistently earlier in the sequence of events during chin-up swallowing compared with head neutral swallows, showing a relationship between the 2 events' occurrences. Previously, Humbert et al²⁰ showed that when peak hyoid elevation is perturbed with intermittent surface electrical stimulation causing hyoid peak to be significantly lower, the duration of LVC significantly increases. This suggests that when peak hyoid elevation is impaired, other components of the swallow might adapt to facilitate the LVC. However, in this study, contrary to previous findings in error reduction and motor learning during swallowing tasks,^{17,19} no change was seen throughout the 30 consecutive chin-up swallows, in which no attempts were made to increase the time to peak hyoid elevation. Instead, there was a quick shift in LVC and peak hyoid elevation sequence of events from the initial chin-up swallows that was maintained throughout phase 2. This further supports the idea that changes in the peak hyoid elevation and LVC during chin-up swallowing is a mechanically driven event, as LVC is related biomechanically to hyolaryngeal movements.^{33,34} Similarly, Young et al¹⁶ showed that chin-down swallowing leads to faster LVC, likely because of the mechanical advantage of the larynx and hyoid being close together when the chin is turned down toward the chest.^{35,36} The abrupt changes seen in LVC for these studies do not fit the traditional motor adaptation model for limb movements, in which gradual adaptation is seen during the perturbation period, followed by gradual deadaptation when the perturbation is ceased.³⁷ As airway protection is a primary and vital function, it might not need as much time to change and adapt as limb movements would, because airway safety is far more important to achieve than lifting an arm. Moreover, it is possible that the motor plan was changed when the chin was already up, and then maintained, as it was sufficient for protecting the airway without further involvement of feed-forward inputs. When peak hyoid elevation was perturbed during chin-up, time to peak hyoid elevation could be perceived as an error, and, as a result, the LVC was increased to accommodate. Moreover, as swallowing is a complex task involving different interrelated kinematics, it is difficult to isolate and perturb one specific movement. Therefore, other components might have been involved in facilitating onset of LVC while the hyolaryngeal elevation was perturbed. This suggests that the onset of peak hyoid elevation might not always impact the onset of LVC.

It has been shown that different bolus volumes and consistencies impact LVC and hyolaryngeal temporal kinematics^{32,38,39} and sequence of events,⁴⁰ with LVC occurring earlier compared to peak hyoid elevation if the bolus volume increases.⁴¹ Therefore, LVC might respond to both a mechanical kinematic change and a change in bolus flow and position⁴² because of gravity during chin-up swallows.

Chin-up posture has been traditionally considered to pose a threat to people with pharyngeal dysphagia,^{2,3} however, few studies have investigated its relationship to swallowing safety. In this study with healthy subjects, no deep penetration or aspiration events occurred. Nonetheless, our data in the chin-up position showed a decrease in duration to LVC that is usually considered favorable during swallowing, as a faster LVC would likely translate to a safer swallow.³²

Hyoid burst

Immediate after-effects of chin-up posture on swallowing sequence of events were found only for the timing of the hyoid burst. As this event is traditionally used to mark the onset of the pharyngeal swallow, it shows that consecutive chin-up swallowing can lead to delays in the onset of pharyngeal swallowing when returning to the neutral position (N1 compared with N2). We propose that this difference is a result of increases in gravity-assisted bolus flow during chin-up swallowing (phase 2), in which swallow onset is triggered faster to maintain adequate swallowing safety. It is possible that repeated swallowing in the chin-up position involved attempts to slow down and control the bolus as it entered the pharynx. Therefore, if participants were able to keep the bolus flow constant throughout the study, it could explain why no differences in hyoid burst measures were found between head neutral swallows in phase 1 and chin-up swallows in phase 2. Instead, a significant difference was found between the first 5 chin-up swallows (P1) and the first 5 head neutral swallows upon returning to the neutral position (N2), in which hyoid burst occurred later in N2 compared to P1. When returning to the head neutral position in phase 3, bolus flow was no longer gravity-assisted (and perhaps perceived to feel slower than usual) and may lead to active effort to push the bolus into the pharynx causing later swallow onset. This after-effect might represent the system's need to recalibrate to its previous sequence of events.

Upper esophageal sphincter events

Even though upper esophageal sphincter-related events were not different when comparing phase 1 to phase 3, upper esophageal sphincter open, bolus head in the upper esophageal sphincter, and bolus tail past the upper esophageal sphincter happened significantly later in phase 3 compared to phase 2 (see Figure 2). We propose that these changes in the upper esophageal sphincter and bolus flow kinematics might be driven by the delays in swallow onset (later hyoid burst onset) in phase 3, meaning that the cascade of subsequent swallowing events all occurred later as a response to the delayed trigger. This is consistent with the findings of Castell et al¹⁵ who described that upper esophageal sphincter relaxation is affected during chin-up swallows, and the time between pharyngeal contraction and upper esophageal sphincter relaxation increases as the angle of chin-up increases.

Clinical relevance and future studies

Chin-up swallows are often performed in normal daily living when drinking from a bottle (across the age span), and chin-up swallows are taught as a safe method to improve pill swallowing in children and adults.^{43,44} Nonetheless, our findings show that the chin-up posture presents a challenge to healthy swallowing, altering the normal sequence of swallowing events. In this study, the healthy participants may have had faster LVC onset to protect the airway. In people treated for head and neck cancer, the effects of chemotherapy and/or radiotherapy can impact epiglottic inversion^{2,7,8} and cause delayed LVC,² reduced laryngeal elevation and closure,^{7,9,45} and reduced hyolaryngeal mechanics.⁴⁶ Our study indicates that swallowing in the chin-up posture challenges the onset of hyoid burst and peak hyoid elevation, but hastens the onset of LVC. Thus, future studies are warranted to study the possibility of using the chin-up posture as a rehabilitative strategy that challenges

hyolaryngeal function. Studies might also investigate whether some patients should not be prescribed the chin-up posture if they are put at risk of aspiration that is too great.

This is important to understand because the chin-up posture is frequently taught as a swallowing compensatory strategy in people with head and neck cancer, and it is also spontaneously performed by patients while swallowing.⁵ Moreover, as the sequence of events in populations with swallowing disorders differs from healthy individuals,³¹ it is necessary to further investigate how the chin-up posture affects the sequence of events of impaired swallows.

The clinical interpretation of this study is limited because base of tongue movements, that are frequently impaired in head and neck cancer populations and play a role in holding the bolus during chin-up posture, were not examined. Moreover, although the sensory aspects of swallowing were beyond the scope of this article, people treated for head and neck cancer often experience changes in taste and altered sensation⁹ that can alter the motor responses and mechanics of swallowing. Participants in this study performed 30 chin-up swallows while continuously maintaining the chin-up posture, and were cued to swallow a bolus administered through a syringe; however, this clinical situation does not reflect a typical daily living eating circumstance. Our bolus volume was controlled and may have been smaller than spontaneously sipped bolus volumes; therefore, findings of this study might not generalize in natural eating situations because bolus size is known to affect swallowing kinematics.³²

CONCLUSIONS

Our data indicate that chin-up swallowing directly impacts the peak hyoid elevation and LVC events with immediate changes occurring during posture performances. Moreover, differences were found for other events (hyoid burst, upper esophageal sphincter open, and the bolus head in the upper esophageal sphincter) upon returning to a head neutral swallowing position after chin-up posture swallowing. Our findings show how chin-up posture impacts the pharyngeal phase of swallowing, adding to previous studies that described its effect on the oral phase. Furthermore, our findings provide initial evidence for the potential rehabilitative use of the chin-up posture to challenge select events of the pharyngeal swallow.

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FIGURE 1.

Study design showing (A) number of swallows, swallow type (by position), and categorization in phases and stages. (B) Comparisons made between phases and stages for each research question.

Event	Phase 1	Phase 2	Phase 3	N1	P1	P2	N2
Bolus head enter pharynx							
Bolus tail enter pharynx							
Hyoid burst							
Hyoid maximum peak							
LVC							
LVO							
UES open							
Bolus head into UES							
Bolus tail past UES							

FIGURE 2.

Significant differences in occurrences of events across phase 1 = 5 head neutral swallows; phase 2 = 30 chin-up swallows; phase 3 = 10 swallows upon returning to neutral position; N1 (first 5 head neutral swallows), P1 (first 5 chin-up swallows), P2 (last 5 chin-up swallows), and N2 (first 5 head neutral swallows upon returning the head to the neutral position). Arrows are pointing the direction of the occurrence → later and ← earlier. Arrows in bold show significant effect size.

TABLE 1

Means and SDs for ordinal data (swallow events 1–9) for the 3 phases.

Event	No. of swallows	Mean	SE mean	SD	Minimum	Maximum
Hyoid burst						
Phase 1	54	1.09	0.04	0.29	1.00	2.00
Phase 2	345	1.08	0.01	0.27	1.00	2.00
Phase 3	107	1.21	0.04	0.41	1.00	2.00
Bolus head enters the pharynx						
Phase 1	54	1.65	0.08	0.55	1.00	3.00
Phase 2	345	1.67	0.03	0.47	1.00	2.00
Phase 3	107	1.63	0.05	0.49	1.00	2.00
Upper esophageal sphincter open						
Phase 1	54	3.11	0.10	0.72	2.00	5.00
Phase 2	345	2.88	0.03	0.55	2.00	6.00
Phase 3	107	3.19	0.05	0.52	2.00	4.00
Peak hyoid elevation						
Phase 1	54	3.06	0.12	0.86	2.00	5.00
Phase 2	345	3.52	0.04	0.75	2.00	6.00
Phase 3	106	3.34	0.09	0.89	2.00	6.00
Bolus head into the upper esophageal sphincter						
Phase 1	54	3.09	0.09	0.68	2.00	4.00
Phase 2	345	2.88	0.03	0.53	2.00	4.00
Phase 3	107	3.19	0.05	0.52	2.00	4.00
Bolus tail enters the pharynx						
Phase 1	54	4.67	0.12	0.85	3.00	6.00
Phase 2	344	4.72	0.05	0.85	3.00	6.00
Phase 3	107	4.62	0.06	0.65	3.00	6.00
LVC						
Phase 1	54	5.07	0.11	0.77	3.00	7.00
Phase 2	345	4.75	0.04	0.83	3.00	6.00
Phase 3	107	5.11	0.07	0.77	3.00	6.00

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Event	No. of swallows	Mean	SE mean	SD	Minimum	Maximum
LVO						
Phase 1	54	6.31	0.10	0.72	5.00	8.00
Phase 2	345	6.11	0.04	0.81	4.00	7.00
Phase 3	107	6.26	0.07	0.73	4.00	7.00
Bolus tail exits the upper esophageal sphincter						
Phase 1	54	7.28	0.10	0.76	5.00	9.00
Phase 2	334	7.07	0.04	0.81	5.00	8.00
Phase 3	107	7.23	0.07	0.76	5.00	8.00

Abbreviations: Phase 1, 5 head neutral swallows; phase 2, 30 chin-up swallows; phase 3, 10 head neutral swallows upon returning to the head neutral position; LVC, laryngeal vestibule closure; LVO, laryngeal vestibule open.

TABLE 2

Means and SDs for ordinal data (swallow events 1–9) for the 4 stages.

Event	No. of swallows	Mean	SE mean	SD	Minimum	Maximum
Hyoid burst						
Stage N1	54	1.09	0.04	0.29	1.00	2.00
Stage P1	57	1.05	0.03	0.23	1.00	2.00
Stage P2	56	1.09	0.04	0.29	1.00	2.00
Stage N2	52	1.23	0.06	0.43	1.00	2.00
Bolus head enters the pharynx						
Stage N1	54	1.65	0.08	0.55	1.00	3.00
Stage P1	57	1.72	0.06	0.45	1.00	2.00
Stage P2	56	1.70	0.06	0.46	1.00	2.00
Stage N2	52	1.60	0.07	0.50	1.00	2.00
Peak hyoid elevation						
Stage N1	54	3.06	0.12	0.86	2.00	5.00
Stage P1	57	3.67	0.10	0.79	2.00	5.00
Stage P2	56	3.46	0.09	0.69	2.00	5.00
Stage N2	51	3.33	0.12	0.89	2.00	6.00
Bolus head into the upper esophageal sphincter						
Stage N1	54	3.09	0.09	0.68	2.00	4.00
Stage P1	57	2.95	0.08	0.58	2.00	4.00
Stage P2	56	2.91	0.07	0.51	2.00	4.00
Stage N2	52	3.21	0.08	0.57	2.00	4.00
Upper esophageal sphincter open						
Stage N1	54	3.11	0.10	0.72	2.00	5.00
Stage P1	57	2.95	0.08	0.58	2.00	4.00
Stage P2	56	2.91	0.07	0.51	2.00	4.00
Stage N2	52	3.23	0.09	0.61	2.00	5.00
Bolus tail enters the pharynx						
Stage N1	54	4.67	0.12	0.85	3.00	6.00
Stage P1	56	4.68	0.12	0.92	3.00	6.00

Event	No. of swallows	Mean	SE mean	SD	Minimum	Maximum
Stage P2	56	4.71	0.11	0.85	3.00	6.00
Stage N2	52	4.63	0.09	0.66	3.00	6.00
LVC						
Stage N1	54	5.07	0.11	0.77	3.00	7.00
Stage P1	57	4.88	0.11	0.80	3.00	6.00
Stage P2	56	4.86	0.12	0.90	3.00	6.00
Stage N2	52	5.04	0.12	0.86	3.00	6.00
LVO						
Stage N1	54	6.31	0.10	0.72	5.00	8.00
Stage P1	57	6.21	0.11	0.82	4.00	7.00
Stage P2	56	6.21	0.12	0.87	4.00	7.00
Stage N2	52	6.21	0.11	0.80	4.00	7.00
Bolus tail exits the upper esophageal sphincter						
Stage N1	54	7.28	0.10	0.76	5.00	9.00
Stage P1	54	7.13	0.11	0.83	5.00	8.00
Stage P2	55	7.15	0.12	0.87	5.00	8.00
Stage N2	52	7.17	0.12	0.83	5.00	8.00

Abbreviations: Stage N1, first 5 head neutral swallows; Stage P1, first 5 chin-up swallows; Stage P2, last 5 chin-up swallows; Stage N2, first 5 head neutral swallows upon returning to the neutral position; LVC, laryngeal vestibule closure; LVO, laryngeal vestibule open.

TABLE 3

Pairwise comparison for events in the 3 phases.

Research question	Event	Phase	No. of swallows	Mean	Facilitated or inhibited?	SE mean	SD	Minimum	Maximum	p value	Cohen's d
1	Peak hyoid elevation	1	54	3.06	Inhibited	0.12	0.86	2.00	5.00	.001	−0.570
		2	345	3.52		0.04	0.75	2.00	6.00		
1	LVC	1	54	5.07	Facilitated	0.11	0.77	3.00	7.00	.041	0.399
		2	345	4.75		0.04	0.83	3.00	6.00		
3	Hyoid burst	1	54	1.09	Inhibited	0.04	0.29	1.00	2.00	.025	−0.374
		3	107	1.21		0.04	0.41	1.00	2.00		

Abbreviations: Phase 1, first 10 head neutral swallows; phase 2, 30 chin-up swallows; LVC, laryngeal vestibule closure; phase 3, 10 swallows upon returning to the neutral position.

TABLE 4

Ordinal data for 3 phases showing percent occurrence of each swallowing measure as events 1 through 9.

Swallowing measure	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Hyoid burst									
Phase 1	91	9							
Phase 2	92	8							
Phase 3	79	21							
Bolus head enters the pharynx									
Phase 1	39	57	4						
Phase 2	33	67							
Phase 3	37	63							
Upper esophageal sphincter open									
Phase 1		18	54	26	2				
Phase 2		20.7	71	8		0.3			
Phase 3		6	70	24					
Bolus head into the upper esophageal sphincter									
Phase 1		18	54	28					
Phase 2		21	71	8					
Phase 3		6	70	24					
Peak hyoid elevation									
Phase 1		28	44	22	6				
Phase 2		9	36	49	6				
Phase 3		17	42	31	9	1			
LVC									
Phase 1			2	18	52	26	2		
Phase 2			6	32	43	19			
Phase 3			3	16	48	33			
Bolus tail enters the pharynx									
Phase 1			7	35	41	17			
Phase 2			8	32	42	18			
Phase 3			3	39	51	7			

Swallowing measure	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
LVO									
Phase 1					13	44	41	2	
Phase 2				3	20	41	36		
Phase 3				3	8	49	40		
Bolus tail exits the upper esophageal sphincter									
Phase 1					2	11	46	39	2
Phase 2					3	21	42	34	
Phase 3					4	8	49	39	

Abbreviations: Phase 1, 5 head neutral swallows; phase 2, 30 chin-up swallows; phase 3, 10 head neutral swallows upon returning to the head neutral position; LVC, laryngeal vestibule closure; LVO, laryngeal vestibule open.

TABLE 5

Pairwise comparison of the 4 stages.

Research question	Event	Stage	No. of swallows	Mean	Facilitated or inhibited?	SE mean	SD	Minimum	Maximum	p value	Cohen's d
1	Peak hyoid elevation	N1	54	3.06	Inhibited	0.12	0.86	2.00	5.00	.001	-0.738
		P1	57	3.67		0.10	0.79	2.00	5.00		
1	LVC	N1	54	5.07	Facilitated	0.11	0.77	3.00	7.00	.041	0.241
		P1	57	4.88		0.11	0.80	3.00	6.00		
3	Hyoid burst	N1	54	1.09	Inhibited	0.04	0.29	1.00	2.00	.025	-0.381
		N2	52	1.23		0.06	0.43	1.00	2.00		

Abbreviations: N1, first 5 head neutral swallows; P1, first 5 chin-up swallows; LVC, laryngeal vestibule closure; N2, first 5 neutral swallows upon returning the head to the neutral position.

TABLE 6

Ordinal data for the 4 stages showing the percentage of occurrence of each swallowing measure as events 1 through 9.

Swallowing measure	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Hyoid burst									
Stage N1	91	9							
Stage P1	95	5							
Stage P2	93	7							
Stage N2	77	23							
Bolus head enters the pharynx									
Stage N1	39	57	4						
Stage P1	28	72							
Stage P2	26	74							
Stage N2	40	60							
Upper esophageal sphincter open									
Stage N1	18	54	26	2					
Stage P1	19	67	14						
Stage P2	16	63	21						
Stage N2	8	63	27	2					
Bolus head into the upper esophageal sphincter									
Stage N1	18	54	28						
Stage P1	19	67	14						
Stage P2	16	63	21						
Stage N2	8	63	29						
Peak hyoid elevation									
Stage N1	28	44	22	6					
Stage P1	7	32	49	12					
Stage P2	7	53	37	3					
Stage N2	16	45	31	6	2				
LVC									
Stage N1		2	18	52	26	2			
Stage P1		5	23	51	21				

Swallowing measure	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Stage P2			7	18	40	35			
Stage N2			4	23	38	35			
Bolus tail enters the pharynx									
Stage N1			7	35	41	17			
Stage P1			11	30	39	20			
Stage P2			5	35	48	12			
Stage N2			3	35	56	6			
LVO									
Stage N1					13	44	41	2	
Stage P1				5	9	46	40		
Stage P2				4	14	33	49		
Stage N2				4	12	44	40		
Bolus tail exit upper esophageal sphincter									
Stage N1					2	11	46	39	2
Stage P1					6	11	48	35	
Stage P2					4	16	34	46	
Stage N2					6	10	46	38	

Abbreviations: Stage N1, first 5 head neutral swallows; Stage P1, first 5 chin-up swallows; Stage P2, last 5 chin-up swallows; Stage N2, first 5 neutral swallows upon returning the head to the neutral position; LVC, laryngeal vestibule closure; LVO, laryngeal vestibule open.

TABLE 7

Additional findings for pairwise comparison for events in the 3 phases (statistically significant results only).

Event	No. of swallows	Mean	Facilitated or inhibited?	SE mean	SD	Minimum	Maximum	p value	Cohen's d
Hyoid burst									
Phase 2	345	1.08	Inhibited	0.01	0.27	1.00	2.00	.001	−0.337
Phase 3	107	1.21		0.04	0.41	1.00	2.00		
Peak hyoid elevation									
Phase 2	345	3.52	Facilitated	0.04	0.75	2.00	6.00	.017	−0.218
Phase 3	106	3.34		0.09	0.89	2.00	6.00		
Bolus head into the upper esophageal sphincter									
Phase 2	345	2.88	Inhibited	0.03	0.53	2.00	4.00	.000	−0.590
Phase 3	107	3.19		0.05	0.52	2.00	4.00		
Upper esophageal sphincter open									
Phase 2	345	2.89	Inhibited	0.03	0.55	2.00	6.00	.000	−0.560
Phase 3	107	3.19		0.05	0.52	2.00	4.00		
LVC									
Phase 2	345	4.75	Inhibited	0.04	0.83	3.00	6.00	.003	0.449
Phase 3	107	5.11		0.07	0.77	3.00	6.00		

Abbreviations: Phase 2, 30 chin-up swallows; phase 3, 10 head neutral swallows upon returning to the head neutral position; LVC, laryngeal vestibule closure. Significance level $p < 0.5$.

TABLE 8

Additional findings for pairwise comparison for the 4 stages.

Event	Stage	No. of swallows	Mean	Facilitated or inhibited?	SE mean	SD	Minimum	Maximum	p value	Cohen's d
Peak hyoid elevation										
Stage N1		54	3.06	Inhibited	0.12	0.86	2.00	5.00	.014	0.502
Stage P2		56	3.46		0.09	0.69	2.00	5.00		
Stage P1		57	3.67	Facilitated	0.10	0.79	2.00	5.00	.003	-0.404
Stage N2		51	3.33		0.12	0.89	2.00	6.00		
Hyoid burst										
Stage P1		57	1.05	Inhibited	0.03	0.23	1.00	2.00	.013	-0.522
Stage N2		52	1.23		0.06	0.43	1.00	2.00		
Stage P2		56	1.09	Inhibited	0.04	0.29	1.00	2.00	.008	-0.381
Stage N2		52	1.23		0.06	0.43	1.00	2.00		
Bolus head into the upper esophageal sphincter										
Stage P1		57	2.95	Inhibited	0.08	0.58	2.00	4.00	.019	0.452
Stage N2		52	3.21		0.08	0.57	2.00	4.00		
Stage P2		56	2.91	Inhibited	0.07	0.51	2.00	4.00	.033	-0.554
Stage N2		52	3.21		0.08	0.57	2.00	4.00		
Upper esophageal sphincter open										
Stage P1		57	2.95	Inhibited	0.08	0.58	2.00	4.00	.019	0.470
Stage N2		52	3.23		0.09	0.61	2.00	5.00		
Stage P2		56	2.91	Inhibited	0.07	0.51	2.00	4.00	.022	0.569
Stage N2		52	3.23		0.09	0.61	2.00	5.00		

Abbreviations: Stage N1, first 5 head neutral swallows; Stage P2, last 5 chin-up swallows; Stage P1, first 5 neutral swallows upon returning the head to the neutral position.