Research Article

The Recline and Head Lift Exercises: A Randomized Clinical Trial Comparing Biomechanical Swallowing Outcomes and Perceived Effort in Healthy Older Adults

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Purpose: The aim of this study was to compare biomechanical swallowing outcomes and perceived effort as well as detraining effects of the established Head Lift Exercise (HLE) and the novel Recline Exercise (RE) in healthy older adults.

Method: Twenty-two healthy older adults were randomized to perform either the RE or the HLE for a period of 6 weeks. Subjects underwent videofluoroscopic swallowing studies at 3 time points (baseline, postexercise, and following a 6-week detraining period). Primary outcome measures included biomechanical measures of superior and anterior hyoid excursion and upper esophageal sphincter opening, obtained using kinematic analyses on the recorded swallows. Perceived exertion ratings during exercise, as measured by the Borg scale, were included as a secondary outcome measure. Linear mixed-effects models were utilized to compare exercise groups and evaluation time points.

Results: The 2 exercise groups did not differ significantly in age, body mass index, or body fat percentage at baseline. Significant postexercise increases were seen in superior hyoid excursion, $F(2, 36.7) = 24.01, p \leq .0001$, and anterior hyoid excursion, $F(2, 36.7) = 5.40, p = .0088$, for both exercise

groups. Upper esophageal sphincter opening did not increase significantly following the exercise regimens, $F(2, 36.5) = 2.14, p = .1322$. Both groups displayed a significant decrease in perceived exertion levels over the course of the exercises, $F(5, 98) = 23.73, p \leq .0001$. On average, Borg ratings were 20% lower for the RE group than the HLE group at all time points, $F(5, 20) = 7.94, p = .0106$, indicating that this exercise was perceived as easier to perform. Eighteen participants were followed after detraining, and no differences in detraining effects were seen between groups. In general, gains in biomechanical measures were better maintained on larger bolus types.

Conclusions: In healthy older adults, the HLE and the RE produced similar gains and detraining effects in biomechanical swallow outcomes. The RE exercise, however, required significantly less effort. These findings suggest that the RE is easier to perform for healthy older adults and thus may be a valuable treatment option for individuals who have difficulty performing the HLE. Further investigation in patients with dysphagia is warranted.

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Functional deglutition is essential in order to satisfy basic nutritional needs. To be completed successfully, deglutition requires the coordination of multiple sensorimotor events in order to ensure adequate transfer

of foods and liquids into the stomach and airway protection during swallowing. Hyolaryngeal excursion is one such event that occurs when the suprahyoid muscles contract and displace the hyolaryngeal complex superiorly and anteriorly during the pharyngeal stage of swallowing (Pearson, Langmore, Yu, & Zumwalt, 2012; Steele et al., 2011). In addition, this displacement acts in conjunction with the relaxation of the cricopharyngeus muscle to facilitate opening of the upper esophageal sphincter (UES; Cook et al., 1989). Incomplete UES opening may result in increased aspiration risk

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due to poor pharyngeal clearance and/or residue (Hellemans, Pelemans, & Vantrappen, 1981; Shaker et al., 2002).

Sarcopenia and other age-related processes can decrease suprahyoid muscle strength and thereby compromise hyoid excursion and UES opening in older individuals (Kim & McCullough, 2008; Shaker & Lang, 1994). In addition, the UES itself undergoes age-related changes including decreased resting pressure and decreased capacity for food passage (Easterling, Grande, Kern, Sears, & Shaker, 2005; Yarasheski, 2002). In order to increase suprahyoid muscle strength and thereby improve hyolaryngeal excursion and UES function, clinicians often prescribe the Head Lift Exercise (HLE)—commonly called the Shaker exercise. Surface electromyography (sEMG) data suggest that many muscles are potentially active during the HLE, including the mylohyoid, geniohyoid, and digastric muscles, as well as infrahyoid muscles such as the stylohyoid and sternohyoid (Ferdjallah, Wertsch, & Shaker, 2000; Mishra, Rajappa, Tipton, & Malandraki, 2015).

Small-scale clinical trials have examined the effects of the HLE on swallowing in both healthy individuals and those with dysphagia. In a randomized clinical trial with 19 healthy adults, Shaker and colleagues observed that the HLE effectively increased anterior hyoid excursion (AHE) and increased the anteroposterior diameter of the UES during swallows of 5-ml thin liquid boluses (Shaker et al., 1997). This finding was later replicated in 11 tube-fed patients, where improved AHE and anteroposterior diameter of the UES were again observed during 5-ml liquid swallows (Shaker et al., 2002). In addition, Logemann and colleagues found that, in 14 patients with dysphagia, those who performed the HLE ($n = 5$) experienced fewer aspiration events when compared with those who performed other exercises ($n = 9$), including tongue strengthening exercises and the supraglottic swallow (Logemann et al., 2009). In a clinical trial of 26 healthy older adults, Easterling and colleagues further found that anteroposterior UES opening and AHE improved following the HLE (Easterling et al., 2005). In another smaller study, the HLE was also observed to augment thyrohyoid muscle shortening in 11 patients with dysphagia (Mepani et al., 2009). Although these studies have featured relatively small sample sizes and have examined limited bolus types, they provide preliminary evidence that the HLE is effective for improving hyoid excursion, increasing UES opening, and potentially reducing aspiration risk.

Despite these promising results, patients in the literature have reported back and neck pain as well as dizziness and fatigue following the exercise (Antunes & Lunet, 2012; Easterling et al., 2005). Also, individuals with medical complications such as stroke, head and neck cancer, or pharyngeal radiation have experienced significant neck pain or difficulty performing the HLE (Rudberg et al., 2015; Shaker et al., 2002). Hence, it is not surprising that Easterling and colleagues (2005) found that dropout rates during the HLE were high even in healthy subjects. Clinically, we have observed that back and neck problems, tracheostomy, and age-related postural changes often render this exercise

impractical for aging and medically fragile patients. Due to these challenges, alternatives to the HLE have been developed (Hughes & Watts, 2016; Mishra et al., 2015; Sze, Yoon, Escoffier, & Liow, 2016; Yoon, Khoo, & Liow, 2014; Yoshida, Groher, Crary, Mann, & Akagawa, 2007) and are often sought after by clinicians. However, strong evidence of the efficacy and effectiveness of these alternative procedures is sparse.

The Recline Exercise (RE; Mishra et al., 2015) is one of these alternatives. The RE protocol targets the same musculature as the HLE and follows the same frequency and intensity paradigm but has two distinct differences: It (a) is performed sitting at a 45° angle and (b) uses gravity for isometric resistance. sEMG data show that the RE activates the same muscle groups utilized in the HLE (Easterling, 2008; Ferdjallah et al., 2000; Shaker et al., 1997) as well as other muscles including the trapezius, the scalenes, and the levator scapulae (Mishra et al., 2015). Mishra et al. (2015) compared the effects of this exercise and the HLE on sEMG and tongue strength measures in healthy young adults. Not surprisingly, suprahyoid muscle activity (amplitude and duration) did not significantly change following either exercise as both groups included healthy young individuals. However, improvements were observed in lingual strength in both groups, although these improvements only reached significance in the RE group (Mishra et al., 2015). Although these preliminary results suggest that the RE and the HLE may have similar neuromuscular effects in healthy young adults, it is important to understand how these exercise regimens compare when used by older individuals, more typical of patient groups. Furthermore, investigating the biomechanical effects of these regimens on swallowing is critical in order to fully understand the underlying physiological mechanisms that are impacted by these exercises. It is also important to understand how perceived exertion levels may differ between the two regimens, as this may have implications for exercise adherence.

Hence, this clinical trial aimed to determine the individual and comparative effects of the RE and the HLE on swallowing physiology and perceived exertion in healthy older adults. Our first aim was to determine whether the aforementioned exercises would produce changes in hyoid and UES biomechanical (kinematic) measures during swallowing, as these measures are directly associated with suprahyoid muscle strengthening. Therefore, our primary outcome measures consisted of superior hyoid excursion (SHE), anterior hyoid excursion (AHE), and anterior–posterior UES opening. We also sought to compare these biomechanical outcomes between groups in order to determine if one exercise would produce greater changes than the other. Based on prior literature (Mishra et al., 2015; Shaker et al., 1997), we hypothesized that both groups would experience similar gains in hyoid displacement and UES opening. Perceived exertion as measured by the Borg scale (Borg, 1998) was included as a secondary (functional) outcome measure. Based on previous work (Easterling et al., 2005; Mishra et al., 2015), we hypothesized that the exercise regimens would get easier with time and that the RE would

be easier to perform than the HLE. Our second aim was to determine whether any changes observed following exercise in biomechanical outcomes or perceived exertion would be maintained after a 6-week detraining period. We also sought to compare any differences in detraining effects between exercise groups. Again, we hypothesized that maintenance patterns would be similar between groups.

Method

Design

This study was conducted as a Phase II randomized clinical trial with two arms: Participants were randomly assigned to the RE group or the HLE group. Subjects were evaluated at three time points: at baseline, postexercise, and at a follow-up 6 weeks after exercise completion (see Figure 1). Participants completed the baseline evaluation 1 day prior to commencing the exercise protocol. Posttreatment and follow-up evaluations were performed within 5 days of exercise completion or the 6-week postexercise mark. Our university institutional review board approved this protocol.

Participants

Participants were recruited from the greater Lafayette, IN, area using fliers, newspaper ads, and e-mails during the November 2016 to March 2017 period. Inclusion criteria consisted of age (between 60 and 85 years), normal cognition as evaluated using the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, Psychological Corporation, & Pearson Education, 2001), and the ability to perform daily exercise. Exclusion criteria consisted of previous diagnoses or history of swallowing or voice disorders, history of smoking, head/neck or back injuries, cervical spine surgery, neurological disorders, or surgery/radiation to the head/neck. Eligible subjects participated in a detailed cranial nerve and clinical swallowing assessment to ensure functional cranial nerve and clinical swallowing function. All eligible participants gave written consent prior to participation.

Randomization

Participants who met the eligibility criteria were randomized to perform either the RE or the HLE using a random number generator. Participants had to further demonstrate the ability to perform their assigned exercise. Because evidence suggests that swallow gains can be achieved

with the HLE even if the regimen is gradually progressed (Easterling et al., 2005), participants were not excluded if they could not perform the entire regimen on their initial visit. Participants were, however, required to attain the isokinetic and isometric goals of the exercise by the end of Week 2 of the regimen. Participants who were lost to follow-up before the completion of their full 6-week protocol were not included in the final analysis, as it was not possible to reliably impute missing data for these subjects. Body mass index and body fat percentage (as an indirect measure of muscle mass) were collected from all participants to allow for comparisons of exercise groups at baseline.

Exercise Protocols

Previous literature has described the HLE protocol in detail (Shaker et al., 1997, 2002). Participants randomized into this exercise group performed both the isometric and isokinetic portions of the HLE. The isometric portion of the exercise consisted of three 1-min head lifts, each followed by a 1-min rest period. The isokinetic portion of the exercise consisted of lifting the head 30 times in a continuous motion with no holding. Both the isometric and isokinetic portions of the exercise were performed in a supine position with shoulders touching the floor (see Figure 2). Participants performed the exercise protocol three times a day over a period of 6 weeks at their homes.

The RE protocol was similar to the HLE in frequency and duration; however, the RE was performed while seated at a 45° angle with the head unsupported. The isometric portion of the exercise required participants to hold their head straight at this 45° angle, resisting gravity, for 1 min (see Figure 3). Each 1-min hold was followed by a 1-min rest period. The isokinetic portion of the exercise consisted of bringing the head to a 45° angle and then returning the chin to the chest 30 times. Participants performed the exercise in a chair (with a 90° angle between the seat and the backrest) with no headrest and were supplied with 45° pillows in order to ensure accuracy and consistency among participants. This regimen was also completed three times a day over a period of 6 weeks at home.

Participants in both exercise groups were trained using instructional videos (see Supplemental Material S1). In addition, written and pictorial instructions and an exercise log were distributed to all participants for home use. Participants were required to exhibit mastery of the exercise during the baseline evaluation. Throughout the 6-week

Figure 1. Study design. RE = Recline Exercise; HLE = Head Lift Exercise.

Figure 2. Participant performing the isometric portion of the Head Lift Exercise, with rest position above and exercise position below.

intervention period, they were contacted via e-mail and/or phone on a weekly basis in order to ensure adherence to the exercise regimen (Easterling, 2008; Mishra et al., 2015). They were also asked to record their exercise set completions in the log. Each time the exercise set was performed, participants rated and recorded their level of exertion during the isokinetic and isometric portions of the exercise using the Borg scale (Borg, 1998). The Borg scale ranged from 0 = *no effort* to 11 = *maximum effort*. The scale was explained to each participant in detail, who made his or her first Borg scale ratings with a researcher present in order to ensure comprehension of the rating scale. The exercise log was collected from all participants at the close of the 6-week exercise regimen. Subjects randomized into the RE group were also given a wedge pillow to place on their chair while performing the exercise. Leaning against the pillow ensured that subjects performed the exercise at a 45° angle.

Between postexercise and 6-week follow-up appointments, subjects were instructed to completely abstain from

performing their assigned exercise. They were not monitored weekly during this time but were given the date of their final evaluation.

Data Collection

All data collected at the three time points (baseline, postexercise, and follow-up) followed identical data collection procedures described below.

Videofluoroscopic Swallow Studies

Swallow studies were performed at the videofluoroscopy suite of the Purdue I-EaT Swallowing Research laboratory using a videofluoroscopic C-arm system (OEC 9800 Plus Digital Mobile 12" GE). Images were acquired at full resolution (30 pulses/s) and recorded at 30 frames/s. Participants were seated in an upright position in lateral view, to allow visualization of the lips, oral and nasal cavities, cervical vertebrae, and the upper esophagus.

Figure 3. Participant performing the isometric portion of the Recline Exercise, with rest position on the left and exercise position on the right.

Participants were presented with two of each of the following bolus trials: 5-ml Varibar thin liquid barium (Cat. no. 105, E-Z-EM Canada Inc.), 10-ml Varibar thin liquid, self-administered cup Varibar thin liquid (30 ounces), 5-cc Varibar barium pudding (Cat. no. 125, E-Z-EM Canada Inc.), and half of a Lorna Doone cookie dipped in Varibar barium pudding. All participants self-fed all boluses.

Postintervention Satisfaction, Eating, and Health Surveys

At both postexercise and 6-week postdetraining evaluations, subjects also completed a short postintervention satisfaction, eating, and health survey, which included 12 open-ended short-answer questions regarding their satisfaction/experience with the exercise program, their perceived effort while eating, and their general health status between visits. These surveys were identical across participants but did not come from a validated assessment tool. No baseline data were collected for postexercise survey questions. Participants were asked to record their responses on the survey form, which they then discussed with a researcher who made additional notes if necessary. Subjects were asked to be completely honest during the survey completion, were reminded that their honest responses could help improve this experience for patients in the future, and were given no information regarding the currently established level of evidence supporting their assigned exercise.

Primary Outcome Measures and Analysis

Primary outcomes included kinematic measures of hyoid excursion and UES opening and were analyzed using the videofluoroscopic data. Kinematic data were analyzed by two graduate research assistants. Both had been trained

by the principal investigator (PI) and had reached > 90% agreement with the PI and > 95% intrarater agreement in kinematic analysis before this research study was initiated. In addition, 20% of all data were reanalyzed by the same rater and a different rater to establish interrater and intrarater reliability measures. Data for reanalysis were chosen using a random number generator. Analyzers were blinded to exercise group and evaluation time point.

Hyoid Excursion

Superior (SHE) and anterior hyoid excursion (AHE) was analyzed using Image J (<https://imagej.nih.gov/ij/index.html>; Rasband, 1997–2018), utilizing a protocol and algorithm developed by Molfenter and Steele (2014). This algorithm calculates hyoid position in relation to an anatomical scalar (i.e., C2 and C4 vertebrae). Hyoid displacement analysis was chosen over hyoid peak position analysis in order to understand the magnitude of hyoid displacement observed in subjects across time points, as opposed to inferring this information from hyoid peak position. The hyoid rest frame was located postswallow and was defined as the lowest postswallow position of the hyoid with concurrent pharyngeal relaxation and return of the epiglottis to vertical position (Molfenter & Steele, 2013). Specifically, rest frame was identified as the frame containing the lowest position of the hyoid within 10 frames of return of the epiglottis to vertical position and relaxation of the pharynx postswallow. If the hyoid was still clearly descending at the end of this 10-frame period, the analyzer went an additional 10 frames forward and chose the lowest hyoid position within this range. When this occurred, a note was made and a second analyzer confirmed that this was appropriate. Once this frame was identified, the most

anterior–inferior points of C2 and C4 and the most anterior–inferior point of the hyoid bone were marked. Next, the frame at which the hyoid was maximally displaced was identified for each swallow. The most anterior–inferior points of C2 and C4, as well as the most anterior–inferior point of the hyoid bone, were again marked. If the frame at which maximal superior and anterior excursion occurred were not the same, then one point was recorded for superior excursion and another was recorded for anterior excursion. These points were then entered into an Excel data sheet where the algorithm calculated hyoid displacement percentages in relation to C2 and C4 vertebrae. SHE and AHE were measured on 5- and 10-ml thin liquid and pudding boluses. These measures were not completed for the cookie and self-administered thin liquid boluses, because the rest frame could not be identified reliably for these swallows.

UES Opening

UES opening was measured using a protocol developed by Leonard, Kendall, McKenzie, Gonçalves, and Walker (2000). Image J (<https://imagej.nih.gov/ij/index.html>) and Universal Ruler 3.7 (AVPSOft.com; Popov, 2002–2010) were used in order to make the measurements. A 1.5-in. spherical ball was taped under the chin during the video-fluoroscopic swallowing study evaluations and was used in order to calibrate all measurements. UES opening was calculated by measuring the narrowest point of the UES between C4 and C6 vertebrae at maximal distention (Leonard & Kendall, 2013; Leonard et al., 2000). UES opening was measured on 5- and 10-ml thin liquid, pudding, and cookie boluses.

Secondary Outcome Measure and Analysis

Perceived exertion level as measured via the Borg scale (Borg, 1998) was examined as a secondary functional outcome measure.

Exertion Level Analysis

Borg scale ratings were gathered from participant exercise logs following the 6-week exercise regimen. Because each participant had three ratings per day, these three ratings were averaged to produce one rating for each day. Then, an average rating for the entire week was calculated in the same manner.

Statistical Analysis

Statistical analysis was performed using SPSS (Version 23, 2016) and SAS (Version 9.4, 2013). Treatment groups were first compared for baseline characteristics such as age, body mass index, body fat percent, and CLQT scores using independent-sample *t* tests. In addition, adherence and dropout rates for both exercise groups were compared using Fisher's exact test. Normality for all tests was assessed using the Shapiro–Wilk test of normality, and data were transformed if assumptions of normality were not met.

Intraclass correlation coefficients (ICCs) were calculated in order to measure interrater and intrarater reliability. Reliability was calculated on all primary outcome measures. Reliability was not calculated on perceived exertion, as these values were reported directly by participants and were not calculated by analyzers; however, all data entry was double-checked for accuracy by a second investigator.

In order to examine changes in outcome measures (i.e., SHE and AHE, UES opening, and perceived exertion ratings) across time points and groups, linear mixed-effects models were performed. Time (baseline, postexercise, and 6-week follow-up), exercise group (HLE or RE), and bolus (5- and 10-ml thin, pudding, and cookie) were included as fixed factors in the statistical model. Subject was included as a random factor in order to account for variation among individuals. In addition, all appropriate interactions were included as well. If interactions were not significant, main effects were reported. A Tukey adjustment was made on all post hoc *t* tests in order to account for multiple comparisons. In addition, Cohen's *d* for repeated measures was calculated on all significant post hoc analyses. Cohen's *d* calculations were performed using a repeated-measures Cohen's *d* calculator developed by Psychometrica.de (https://www.psychometrica.de/effect_size.html; Lenhard & Lenhard, 2016).

Results

Demographic and Baseline Data Comparisons

The consort flow diagram is shown in Figure 4. Of 93 screened subjects, 27 (17 women and 10 men) were eligible for participation in this study. One participant withdrew from the RE group, and one from the HLE group, both due to work-related schedule conflicts. In addition, three participants failed to complete the HLE due to difficulty with the exercise. After dropouts, both the RE (male = 4, female = 7, $M_{\text{age}} = 69$) and HLE (male = 6, female = 5, $M_{\text{age}} = 64$) groups included 11 participants each. Detailed subject demographics are presented in Table 1. Three participants in the HLE group could not complete the full exercise regimen at their initial evaluation but were able to do so before the end of the second week of the regimen. All participants in the RE group were able to complete the exercise regimen at their initial evaluation. No significant differences in age, body mass index, body fat percentage, or CLQT scores at baseline were observed between exercise groups (see Table 1).

Four subjects (two in each group) who completed both preexercise and postexercise evaluations did not return for the follow-up postdetaining evaluation. The reasons for these follow-up dropouts included vacation for two subjects and strong dislike for barium for two subjects. Therefore, 18 subjects were considered for analysis of detraining effects.

Intrarater and Interrater Reliability

For superior hyoid excursion (SHE) data, both intrarater and interrater reliability were excellent as indicated by ICCs of .94 ($p = .000$, 95% CI [.91, .96]) and .91 ($p = .000$,

Figure 4. Consort flow diagram. RE = Recline Exercise; HLE = Head Lift Exercise.

Table 1. Subject demographics and baseline comparison of exercise groups.

Subject	Gender	Age	Body fat %	BMI
1	Female	74	47.4	34.7
2	Female	66	37.4	27.0
3	Female	82	39.0	22.5
4	Female	67	46.7	35.2
5	Female	60	32.0	21.6
6	Female	60	41.7	27.8
7	Female	60	40.0	42.0
8	Female	76	45.7	27.8
9	Female	60	40.1	28.3
10	Female	70	48.5	36.8
11	Female	83	46.3	31.9
12	Female	65	29.7	19.5
13	Male	66	44.3	38.8
14	Male	68	31.2	29.1
15	Male	65	24.1	25.8
16	Male	73	33.3	31.6
17	Male	61	29.2	28.6
18	Male	65	25.1	22.5
19	Male	62	26.1	24.2
20	Male	66	27.6	27.0
21	Male	67	30.7	30.3
22	Male	63	31.6	32.1

Characteristics	RE	HLE	p
Age, <i>M</i> (<i>SD</i>)	69 (7.4)	64 (4.4)	.089
BMI, <i>M</i> (<i>SD</i>)	32 (7.2)	27.7 (6.14)	.601
Gender (male/female)	4/7	6/5	.416
Dropout rate (%)	8.3	26.7	.342
Exercise adherence, <i>M</i> (<i>SD</i>)	90% (0.09)	88% (0.17)	.102

Note. BMI = body mass index; RE = Recline Exercise; HLE = Head Lift Exercise.

95% CI [.85, .95]), respectively. For AHE, intrarater reliability was in good range with an ICC of .86 ($p = .000$, 95% CI [.81, .91]) and interrater reliability had an ICC of .85 ($p = .000$, 95% CI [.75, .91]). Intrarater and interrater reliability for rest frame identification for hyoid excursion analyses were also excellent with ICCs of .96 ($p = .000$, 95% CI [.95, .97]) and .95 ($p = .000$, 95% CI [.91, .96]), respectively. Intrarater and interrater reliability for UES opening were both excellent with ICCs of .95 ($p = .000$, 95% CI [.90, .97]) and .95 ($p = .000$, 95% CI [.86, .98]), respectively.

Adherence Results

The RE group performed the exercise with 90% adherence, and the HLE group performed the exercise with 88% adherence. Adherence rates were not significantly different between exercise groups, $F(1, 20) = 2.939$, $p = .102$. Participants in the RE group missed an average of 9.7 exercise repetitions, and participants in the HLE group missed an average of 15.7 exercise repetitions.

Primary Outcomes Results: Effects of Time and Group

Means, standard errors, and confidence limits for all primary outcome measures across bolus types can be found in Table 2.

Superior Hyoid Excursion (SHE)

Means and standard errors for SHE data across all evaluation time points and swallows are plotted in Figure 5. No significant interactions between bolus, time, or group were observed. However, a significant main effect of time

Table 2. Means and standard errors for biomechanical data, divided by exercise group.

Head Lift Exercise group			
Measure	Baseline	Postexercise	Postdetraining
SHE	39.1 (2.2) CL [34, 43]	45.9 (2.1) CL [41, 50]	43.3 (2.1) CL [37, 47]
AHE	20.8 (1.3) CL [18, 23]	23.0 (1.2) CL [19, 25]	20.7 (1.1) CL [18, 24]
UES	0.63 (0.02) CL [0.58, 0.68]	0.67 (0.02) CL [0.63, 0.71]	0.65 (0.02) CL [0.61, 0.69]
Recline Exercise group			
Measure	Baseline	Postexercise	Postdetraining
SHE	33.1 (1.8) CL [29, 36]	37.6 (1.9) CL [33, 41]	39.1 (1.7) CL [35, 43]
AHE	24.4 (1.1) CL [21, 26]	27.5 (0.9) CL [25, 29]	27.2 (1.3) CL [24, 30]
UES	0.65 (0.02) CL [0.60, 0.70]	0.67 (0.03) CL [0.62, 0.72]	0.69 (0.03) CL [0.62, 0.75]

Note. Means for SHE and AHE are in %C2–C4, and means for UES opening are in millimeters. SHE = superior hyolaryngeal excursion; CL = 95% confidence limit for means; AHE = anterior hyolaryngeal excursion; UES = upper esophageal sphincter opening.

was observed for SHE, $F(2, 36.7) = 24.01, p \leq .0001$. Specifically, SHE significantly increased from baseline to postexercise, $t(2, 36.6) = -6.62, p \leq .0001$, Cohen's $d = 0.77$. In addition, a significant main effect of bolus was observed, $F(2, 37.9) = 6.27, p = .0044$. Specifically, SHE was observed

to be significantly greater on the pudding bolus than on the liquid boluses, $t(2, 38) = -3.50, p = .0012$, Cohen's $d = 0.52$. The effect of group was not significant, indicating no differences between exercise groups across time points, $F(2, 20.1) = 2.6, p = .1226$.

To examine detraining effects, analysis was completed on the 18 subjects who returned for a third evaluation. Of those 18 individuals, 14 made gains in SHE following the exercise regimens. These gains were maintained 100% for pudding, 63% for 10 ml, and 11% for 5-ml thin liquid. Overall, postdetraining data remained significantly above baseline, $t(2, 36.9) = -4.89, p \leq .0001$, Cohen's $d = 0.66$.

Anterior Hyoid Excursion (AHE)

Means and standard errors for AHE data across the three evaluation time points and boluses are plotted in Figure 6. Similarly, no significant interactions between time, bolus, or group were observed. A significant main effect of time was noted for AHE, $F(2, 36.6) = 4.87, p = .0133$. Specifically, AHE significantly increased from baseline to postexercise, $t(2, 36.8) = -2.83, p = .0074$, Cohen's $d = 0.48$. The effect of group was not significant, indicating no differences between exercise groups across time points, $F(1, 20.2) = 3.20, p = .0887$. In addition, no significant effect of bolus was observed.

Postexercise, of the 18 participants who returned for the follow-up assessment, 11 experienced increased AHE on the 10-ml thin liquid bolus. These individuals maintained an average of 75% of these gains after detraining. Thirteen participants experienced increased AHE on the pudding bolus and maintained an average of 80% of these gains

Figure 5. Means and standard errors for superior hyoid excursion across boluses and evaluation time points. RE = Recline Exercise; HLE = Head Lift Exercise.

Figure 6. Means and standard errors for anterior hyoid excursion across boluses and evaluation time points. RE = Recline Exercise; HLE = Head Lift Exercise.

after detraining. Overall, AHE data remained significantly above baseline postdetraining, $t(2, 36.8) = -2.47$, $p = .0183$, Cohen's $d = 0.22$.

UES Opening

Means and standard errors for UES opening data across all evaluation time points and boluses are plotted in Figure 7. No significant interactions between time, exercise, or group were observed. UES opening increased from baseline to postexercise; however, this increase did not reach statistical significance, $F(2, 36.5) = 2.14$, $p = .1322$. A significant effect of bolus was observed, $F(2, 59.3) = 9.99$, $p \leq .0001$. Specifically, UES opening was observed to be smaller for the 5-ml bolus than the other bolus types, $t(2, 59) = -4.80$, $p \leq .0001$, $d = 1.1$. No significant main effect of exercise group was observed for UES opening, $F(1, 19.7) = 0.15$, $p = .6994$.

Although there was no significant main effect of time for UES opening, detraining effects were calculated for the cookie bolus, because this was the bolus upon which subjects demonstrated the most improvement. Of the 18 individuals who returned for the follow-up assessment, 10 experienced gains in UES opening on the cookie bolus postexercise. These individuals maintained 100% of these gains after detraining; however, it should be remembered that there was no significant main effect of time for the group as a whole.

Secondary Outcome Results: Effects of Time and Group

Effort Ratings

Perceived exertion ratings are plotted in Figure 8. Perceived exertion significantly decreased over the course of the 6-week exercise regimen for both exercise groups, $F(5, 98) = 23.73$, $p \leq .0001$. Importantly, a significant effect of exercise group was observed, $F(5, 20) = 7.94$, $p = .0106$.

Figure 7. Means and standard errors for upper esophageal sphincter opening across boluses and evaluation time points. RE = Recline Exercise; HLE = Head Lift Exercise.

On average, perceived exertion was 20% higher for the HLE group across all time points, indicating increased perceived effort for this group.

Postintervention Satisfaction, Eating, and Health Survey Results

In the postintervention surveys, six members of the HLE group reported experiencing neck pain while performing the exercise. Of these, five subjects reported that this pain resolved around 2 weeks into the 6-week exercise regimen. The final subject reported experiencing neck pain throughout the exercise regimen. In addition, two subjects reported mild neck stiffness, which resolved before the 2-week marker of the exercise regimen. In the RE group, two participants reported experiencing neck pain and six participants reported experiencing mild stiffness through the neck and shoulders, both of which resolved before the end of the second week of the exercise.

Fourteen of the 22 subjects in this study reported that incorporating the exercise regimens into their daily schedule was a challenge. In particular, subjects reported that fitting an exercise set in the middle of the day was difficult. Subjects in the HLE also reported that completing the entire exercise regimen was difficult, although most subjects in this study were able to do so. None of the subjects reported any health changes during the exercise protocols.

Discussion

Clinically, the HLE is often utilized with patients experiencing dysphagia resulting from poor hyoid excursion and/or UES opening. Although, in relatively small-scale studies, the HLE has been observed to improve these physiological swallowing outcomes, its difficult nature renders it impractical for many patients. For this reason, it is

Figure 8. Means and standard errors for Borg ratings of perceived exertion across the 6-week exercise regimens.

important to develop and examine the efficacy of alternatives, such as the RE, for those individuals who cannot perform the HLE. This study sought to determine if the RE is an effective alternative to the HLE in healthy older adults. Specifically, our primary aim was to determine the individual and comparative effects of the HLE and the novel RE on physiological biomechanical swallowing outcomes and perceived effort in healthy older adults. We hypothesized that both exercises would produce similar changes on these swallow outcomes, and this hypothesis was largely proven by our findings.

Specifically, both exercise regimens were effective in improving two key biomechanical outcome measures in our sample, and no statistically significant differences were observed between groups. Specifically, SHE increased following both exercise regimens. This increase in SHE is likely tied to an increase in suprahyoid muscle strength, which has been shown to contribute to the hyolaryngeal complex elevation. This may indicate that mylohyoid in particular was strengthened as this muscle has been hypothesized to play a key role in SHE (Pearson, Langmore, & Zumwalt, 2011). Increases in SHE have been observed following the Mendelsohn maneuver, when used as a rehabilitative exercise targeting suprahyoid strength (McCullough & Kim, 2013; Pearson, Hindson, Langmore, & Zumwalt, 2013). Interestingly, this result has not been previously documented following the HLE (Shaker et al., 1997, 2002). This is possibly due to differences in the methodology used to complete

this measure. As previously explained, we used an anatomical scalar to calculate hyoid excursion, per the Molfenter and Steele (2014) protocol. To our knowledge, this method has not been previously utilized to measure the effects of the HLE, but it was employed in this study in order to control for variation in subject gender, size, and height. In addition to controlling for these factors, high levels of interrater and intrarater reliability were achieved using this analysis method. It is also interesting to note that SHE was observed to be greater on the pudding bolus than on the liquid boluses. This is possibly due to the fact that greater hyoid excursion may be necessary on larger, more viscous bolus types (Dodds et al., 1988; R. J. Leonard et al., 2000).

We further observed significant postexercise increases in AHE in both groups. This finding is in agreement with several previous studies examining the HLE, which have also observed increased AHE (Logemann et al., 2009; Shaker et al., 1997, 2002). This gain is likely also similarly related to increased suprahyoid muscle strength, which was the primary target of the assigned exercise regimens. More specifically, this result may indicate that the exercise regimens specifically strengthened the geniohyoid muscle, which has been hypothesized to play a key role in AHE (Pearson et al., 2011). Healthy older adults display decreases in AHE when compared with young adults (Kim & McCullough, 2008) and are therefore particularly well situated to benefit from this type of exercise.

Descriptively, we observed that UES opening increased following both exercises, particularly on the cookie bolus; however, this increase did not reach statistical significance. A possible reason for the lack in significant change to UES opening may be methodological. Specifically, it may be that the anteroposterior view of the UES is more sensitive to small changes in diameter, as previous studies have observed increases in UES opening on smaller bolus types from this view (Shaker et al., 1997). This study examined lateral rather than anteroposterior UES opening, but anteroposterior opening may be a more sensitive measure for future studies. In addition, it should be remembered that these subjects were healthy and did not display deficits in UES opening at baseline.

Critically, the only significant difference between groups in this study was observed on the secondary (functional) outcome of this study, that is, the perceived exertion ratings. Perceived exertion significantly decreased from baseline to postintervention for both groups and was significantly higher among the HLE group at all time points (by approximately 20%). Although it was expected that the exercise regimens would become easier with time (Easterling et al., 2005), it is noteworthy and clinically relevant that the RE was perceived to be easier to complete both at baseline and after 6 weeks. This finding is particularly critical in light of the fact that both exercises produced similar changes in biomechanical swallow outcomes. This could potentially have implications for patient adherence—as patients may be more likely to perform an exercise that they perceive to be less difficult. Adherence rates in this study were similar between exercise groups; however, it should be noted that participants were closely monitored throughout the duration of this study, and adherence was likely higher than it would be in a clinical setting. It should also be acknowledged that it is possible that the RE regimen could have become too easy with time—although data from the current study would suggest the exercise was adequately difficult to produce exercise gains. The RE could potentially be augmented by increasing the angle at which the subject reclines or with the use of weights. However, either possibility would require further feasibility and clinical testing.

Our secondary aim was to determine the detraining effects of the HLE and RE. It is important to understand the detraining effects of any exercise prescribed to patients to determine that physiological gains can be maintained. The detraining effects of the HLE, however, are not known, as they have not been previously reported in the literature. We hypothesized that detraining effects would be similar across the two exercise regimens, and our findings support this hypothesis. Postexercise gains in hyoid excursion and UES opening were at least partially maintained after detraining. This is not surprising as older healthy adults may maintain exercise-induced gains in muscle strength (at least in part) even if they do not maintain hypertrophy (Van Roie et al., 2017). On average, detraining effects were better for the larger, more viscous bolus types (i.e., pudding and cookie) where 80%–100% of hyoid excursion and UES gains were maintained. In comparison, these gains were only

11%–75% maintained on the 5- and 10-ml thin liquid boluses. This may be related to the fact that these gains were less necessary on these smaller bolus types. Although it is encouraging that swallow gains were not lost 6 weeks following exercise cessation, it should be noted that participants in this study were healthy at baseline and that these results may not generalize to individuals with dysphagia as it has also been suggested that baseline motor control affects detraining outcomes (Majika & Padilla, 2000). Further research is needed in order to understand what sort of maintenance program would best prevent loss of the swallow gains produced by the HLE and RE.

Although there were no differences in biomechanical swallowing outcomes following the RE and the HLE, perceived exertion levels during the exercise regimens were significantly different. In addition, there were some other potentially clinically important differences observed between exercises. First, it is important to note that three of the 11 subjects randomized into the HLE group could not complete the full regimen at baseline. These subjects attained the isokinetic and isometric goals of the exercise within the first 2 weeks of the regimen; however, this finding supports previous research that suggests that the HLE is fairly difficult to complete (Easterling et al., 2005; Rudberg et al., 2015). It is also interesting to note that the dropout rate of the HLE group was higher than that of the RE group, although this trend did not reach statistical significance. The dropout rate for the HLE was 26.7% (four participants), whereas the dropout rate for the RE was 8.3% (one participant). These dropouts occurred within the first 2 weeks of exercise, supporting the findings of previous studies (Easterling et al., 2005).

It should also be noted that complaints of neck pain were overall slightly more common among participants in the HLE group, whereas participants in the RE group reported mild stiffness in the neck and shoulders. All complaints of this nature resolved during the first 2 weeks of the exercise regimens, with the exception of one participant in the HLE group who reported neck soreness throughout the exercise but was able to continue and complete the regimen. As reported previously, responses regarding neck pain/stiffness were collected in response to an intentionally open-ended question regarding discomfort experienced during the exercise regimens (specifically, “Did you experience any discomfort while performing the exercise?”). This was done to avoid biasing subjects, and it is noteworthy that common patterns emerged despite the open-ended nature of this question. It should be remembered, however, that these data were not collected using a validated measure of neck pain. It should also be noted that, although subjects were screened for back and neck injuries, data regarding neck stiffness and/or pain were not gathered at baseline, and it is therefore unknown if baseline pain level influences exercise side effects. The fact that neck pain was frequently reported by subjects in the HLE group, however, is in keeping with previous literature, which suggests that neck pain is common during the HLE exercise but usually resolves early in the regimen (Easterling et al., 2005).

Overall, the significantly lower perceived exertion ratings of the RE group and the fact that fewer participants in this group complained of neck pain and that all subjects could perform this regimen at baseline all suggest that the RE is easier to complete and may have fewer side effects than the HLE. It should also be noted, however, that this study examined only healthy older adults, and these findings should therefore be interpreted with caution as results may differ for those with dysphagia.

There are several limitations to the current study, which should be taken into consideration when interpreting these results. First, this study sought to determine the comparative effects of the HLE and the RE in healthy older adults and, as such, did not include a control group. This problem is alleviated by the fact that biomechanical swallowing measures are not particularly vulnerable to placebo effects; however, examining the RE with a control group, and with larger sample sizes, will be an important next step. In addition, this may clarify why, although the majority of participants experienced exercise gains, not every participant in the current study displayed improvements following the RE and HLE protocols. In addition, this study did not use an intent-to-treat approach to account for the three individuals who withdrew due to difficulty with their exercise. These individuals were lost to follow-up, and it was not possible to accurately impute the nature of their follow-up data. However, it will be important to use a control group and an intent-to-treat approach in the future in order to fully understand how dropouts affect the outcomes of the HLE and the RE. Furthermore, the effects of the RE on anteroposterior UES opening should be examined in the future.

Finally, we acknowledge that this work is not immediately clinically applicable as it focused on healthy older individuals and on kinematic swallow measures; however, we feel that this study comprises an important and necessary step in starting to establish the efficacy of the RE on the physiological mechanisms of the swallow. This was done to provide a necessary understanding of the physiological reasons the exercises may or may not be useful. Our next step is to examine the RE in clinical patients.

Conclusions

In healthy older adults, the HLE and the RE produced similar gains and detraining effects in biomechanical swallow outcomes. The RE exercise, however, required significantly less effort. These findings suggest that the RE is easier to perform and thus may be a valuable treatment option for individuals who have difficulty performing the HLE. Further investigation in patients with dysphagia is warranted.

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