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ORIGINAL ARTICLE

Tongue-Strengthening Exercises in Healthy Older Adults: Does Exercise Load Matter? A Randomized Controlled Trial

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Abstract

Tongue-strengthening exercises (TSE) are based on the principles of exercise and motor learning, including intensity. Intensity is manipulated by gradually adjusting the resistive load. This randomized controlled trial (RCT) investigates the effect of three different values resistive load during TSE in healthy older adults. Sixty subjects completed 8 weeks of TSE while exercising with Iowa Oral Performance Instrument (IOPI). They were randomly distributed to 4 different treatment arms: 3 exercise groups (EG1: $n = 15$; EG2: $n = 16$, EG3: $n = 16$) and 1 control group performing lip-strengthening exercises (CG: $n = 13$). Values of resistive load for EG1, EG2, and EG3 were 100, 80, and 60% 1RM, respectively. Anterior and posterior maximal isometric pressures (MIP_A, MIP_P) were measured at baseline, after 4 and 8 weeks of training and 4 weeks post-training. MIP_A and MIP_P in the EG were significantly higher than in the CG at all time points, except baseline. No significant differences between EG were found, but some trends were observable. Anteriorly, the higher the resistive load, the higher the increase in MIP. Posteriorly, 100% 1RM caused the highest values, followed by 60% and 80% 1RM. No detraining effects were measured. The degree of exercise load had a significant negative effect on the registered success rate. This RCT confirms the efficacy of TSE in healthy older adults. For MIP_A and MIP_P, TSE at a resistive load of 100% 1RM are the most efficient choice in this population, while lowering the resistive load will lead to an increased success rate. No detraining effects were registered.

Keywords Dysphagia · Tongue-strengthening exercises · Resistive load · Lip-strengthening exercises

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Introduction

Regardless of etiology, the medical consequences of dysphagia are life-threatening and immensely demanding on health care resources [1, 2]. Dysphagia also has a huge impact on quality of life [3–5]. Therefore, identifying effective methods of dysphagia treatment is a top priority in rehabilitation research [2, 6].

Tongue-strengthening exercises (TSE) are a well-documented form of isolated non-swallowing exercises, and interestingly leading not only to increased tongue strength (TS) but also to improved swallowing function [7–18]. Oh et al. [12] explain this carryover from tongue strength by the direct impact from tongue strength on the oral phase of swallowing, including bolus formation, mastication, and increasing intra-oral pressure. Sufficient intra-oral pressure is needed to push the bolus quickly and safely through the pharynx, preventing and/or clearing previous pharyngeal residue, thereby contributing to the avoidance of aspiration [7, 17, 19]. It is generally accepted that TSE, like other swallowing rehabilitation methods, should be based on principles of cortical plasticity, motor learning, and muscle strength training [9, 20, 21]. Part of these principles is intensity, encompassing the amount of load, volume, and duration of the exercise stimulus. Intensity can be manipulated by adjusting the mechanical or resistive load placed on the system over time [21]. Specified percentages of a person's maximal strength, referred to as single repetition maximum (1RM), are used to define the resistive load and thus the intensity of resistance training [21, 22]. Lower loads result in less training effect, while high loads maximize effect [23]. Efficiently increasing the resistive load as part of dysphagia rehabilitation is an elusive challenge [6].

General strength training guidelines, based upon skeletal muscle rehabilitation, are unambiguous and recommend a load of 60% 1RM in untrained individuals, while 80–85% 1RM elicit maximal gains for those who are trained [24, 25]. Training at even higher loads is considered a risk for muscle fatigue, reduced total load, or acute overuse injuries, both with associated pain and function loss of the muscles involved [26, 27]. However, training with an insufficient load will fail to achieve the desired strength improvement [25]. Historically, resistive loads in TSE vary between 20 and 100% 1RM, with a majority of protocols using 80% 1RM [8–13, 15–18, 28, 29] and detraining effects described 4 weeks post-treatment [15]. Noteworthy is that even TSE at maximal load, equally 100% 1RM, does not seem to result in fatigue or overuse symptoms like pain and deterioration in tongue strength [13, 15, 16, 28]. Literature about tongue fatigue is scarce, but Solomon et al. [30, 31] conclude that the tongue, like other facial muscles, is generally fatigue resistant due to its composition out of predominant fatigue-resistant type I and type IIa muscle fibers [32, 33].

To our knowledge, orofacial problems following overuse are only reported in research about professional musicians [21, 26, 34]. Since the tongue, a muscular hydrostat, has different characteristics than skeletal muscles, it may be inappropriate to generalize general strength training guidelines based on skeletal muscles. This specific structure may lead to different responses to training regimens based on the known principles of strength training [6, 28, 35–38]. Although several studies on TSE mention resistive load, research on the most efficient resistive load is still lacking.

The purpose of this study was to investigate the training and detraining effects of three different levels of resistive load in healthy older adults on both anterior and posterior maximum isometric tongue pressure (MIP_A and MIP_P), namely, 60, 80, or 100% 1RM.

Our research hypotheses are that:

(1) Regardless of resistive load, TSE will increase MIP_A and MIP_P.
(2) Detraining effects will be observed.
(3) Lower resistive loads will improve the success rate (i.e., the number of successful repetitions) during training.

Methods

Participants

Sixty-three healthy older adults with a minimum age of 70 years were recruited in nursing homes by convenience sampling. All participants were required to meet the following inclusion criteria: no cognitive deficit, as measured by the Mini-Mental State Examination (score > 24) [39]; of Belgian origin and native speakers of Dutch allowing comparison with the Belgian normative data [40]; MIP_A and MIP_P within the 95%-prediction range of the patients' age and sex [40]; able to complete the Yale Swallowing Protocol [41]; thereby, ruling out silent aspiration and possible as yet undocumented dysphagia. Subjects with a history of neurogenic disorders [42–44], head and neck cancer [14], and other health conditions with a possible influence on tongue strength were excluded from this study.

Study Design and Interventions

Participants were randomly assigned to 4 different treatment groups. Three exercise groups (EG) completed TSE at three different values of resistive load and one control group (CG) performed lip-strengthening exercises (LSE). LSE was chosen as standardized sham therapy for the control group, because the instrumentation and training regime are identical to the TSE [45], no training at all has no effect on TS [13], and pharyngeal exercises may influence TS [46]. EG1 trained at a resistive load of 100% 1RM, EG2 at 80% 1RM, and EG3 at 60% 1RM. LSE were performed at a resistive load of 80% 1RM. A new MIP and correspondent levels of resistance were recalculated every 2 weeks according to the principle of progressive overload [21]. All subjects completed three sessions per week on non-consecutive days for a total of 8 weeks [47, 48]. Every training session was conducted at the patients' nursing home and supervised by one of the researchers. Each session involved 120 efforts (60 anterior and 60 posterior) divided into 24 sets of 5 repetitions with 30 s rest following each set. A successful repetition was defined as reaching the target level for 3 s, using the biofeedback on the LED by the IOPI. Figure 1 illustrates the inclusion and attrition

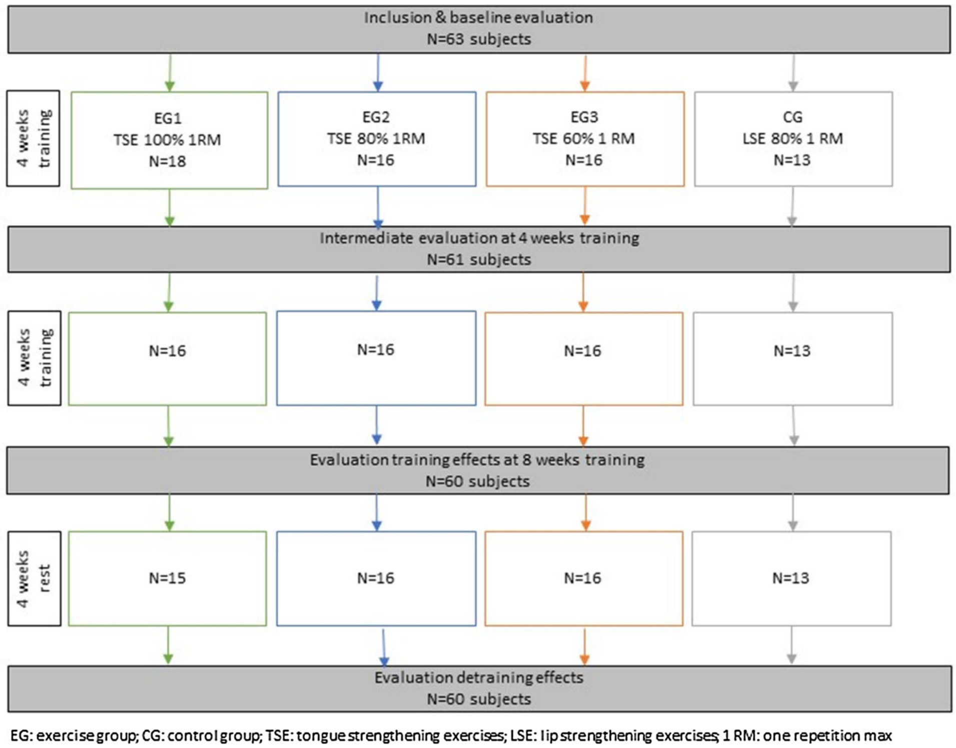

Fig. 1 Inclusion and attrition of patients

of the patients during the study protocol. Two people in EG1 ended training, at their own initiative, before the intermediate evaluation and 1 person from EG1 discontinued before the post-training evaluation. Finally, 15 subjects in EG1 (mean age 79 year (70–90), 7 males and 8 females), 16 subjects in EG2 (mean age 81 year (71–90), 7 males and 9 females), 16 subjects in EG3 (mean age 77 year (71–84), 3 males and 10 females) finished the entire protocol.

Instrumentation

The Iowa Oral Performance Instrument version 2.3 (IOPI Medical LCC, Redmond, WA USA) was used for MIP-measurements and for monitoring tongue-palate pressures during training in the EG and for monitoring lip closing pressures during training in the CG. The location for MIP_A was determined by placing the part of the bulb closest to the connecting tube in contact with the posterior face of the upper incisors, thereby positioning the bulb against the hard palate just posterior to the alveolar ridge. The location for MIP_P was determined by placing the main part of the bulb at the level of the transition of the hard to soft palate. A permanent mark on the connecting tube just anterior to the incisors assures accurate placement for each MIP_P repetition and measurement, providing visual feedback for the researcher and tactile feedback for the participant. This marked bulb is used during training sessions to maintain the accurate posterior location. MIP-measurements were performed as described in previous research [28, 40, 49, 50]. For lip strength training, the patient was asked to squeeze the bulb between the lips, as described by Perry et al. [51]. For tongue strength as well as lip strength, the LCD-screen on the IOPI displays the exerted pressure in kPa and the LED lights display the exercise target as visual feedback during training.

Outcome Measures

Anterior as well as posterior MIP were measured in every group. The highest MIP value obtained over three repetitions was recorded as described by Lazarus et al. [13]. MIP_A and MIP_P were performed at baseline, after 4 and 8 weeks training and 4 weeks after the last training session to document possible detraining effects [15, 28]. A margin of 48 h was tolerated for all evaluation moments to accommodate for rescheduling.

Data Analysis

Statistical analysis was performed by means of SPSSv21. Descriptive statistics, tests for normality (Kolmogorov–Smirnov), Mixed Models Effects, post hoc analysis with Holm–Bonferroni correction, and effect sizes (Cohen's *d*) were calculated. For analysis of success rate, One Way ANOVA was used for all data. During analysis, there was one outlier in EG2 who was excluded from statistical analysis based on an extreme increase of MIP_P during and post TSE, i.e., 2 SD higher than normative values. This compromises the reliability of baseline measurements in this subject. Statistical analysis was therefore performed on a total of 62 subjects ($n = 18$ for EG1, $n = 15$ for EG2, N = 16 for EG3, and $N = 13$ for CG).

Results

Training and Detraining Effects on MIP_A

There are no significant differences in tongue strength among the four different groups at baseline (Table 1). Significant effects on MIP_A were found for the interaction of treatment by time ($F(9,164) = 6.037$, $p < 0.001$) and time ($F(3,164) = 124.551$, $p < 0.001$), but there is no significant effect of treatment arm ($F(3,58) = 2.652$, $p = 0.057$). At 4 weeks, 8 weeks, and detraining, MIP values are significantly higher for all EGs in comparison with the CG, but no other significant effects were found (Table 1). Every level of resistance results in significant increases in MIP_A with at 8 weeks training, a minimum increase of 50% from baseline (Table 2, Fig. 2). Although there is no significant difference between the EGs, Fig. 2 illustrates the largest gain from baseline in MIP_A in EG1 (+ 64%), followed by EG2 (+ 60%), and EG3 (+ 52%). LSE result in a significant, but smaller increase of MIP_A (+ 14%) in comparison with the increases of MIP_A following TSE. No significant detraining effects on MIP_A were found at 4 weeks post TSE (detraining) in comparison with MIP_A values at 8 weeks for any treatment arm. All three exercise groups demonstrated large effect size from 4 weeks until 8 weeks (> 0.8 [52]), with no effects measured between 8 weeks and detraining (Cohen's $d < 0.2$ [52]).

Training and Detraining Effects on MIP_P

There are no significant differences in tongue strength between EGs and CG at baseline (Table 3). For MIP_P, significant effects were found for the interaction of treatment arm and time ($F(9,164) = 5.762$, $p < 0.001$), treatment arm ($F(3,57) = 3.051$, $p = 0.036$), and time ($F(3,163) = 88.034$, $p < 0.001$). At 4 weeks, 8 weeks, and detraining, MIP values are significantly higher for all EGs in comparison with the CG (Table 3). Only TSE lead towards significant increases in MIP_P with a minimum gain of 50% between baseline and 8 weeks post (Table 3, Fig. 3). No significant increases in MIP_P were measured in the CG. Table 3 does not demonstrate any significant difference between the EGs, whereas Fig. 3 shows the largest increase in MIP_P in EG1 (+ 75%), followed by EG3 (+ 53%), and EG2 (+ 50%). LSE lead towards non-significant increases of MIP_P (+ 12%). No significant detraining effects on MIP_P were found at 4 weeks post TSE in comparison with MIP_P values at 8 weeks for any treatment arm. Furthermore, three exercise groups demonstrated large effect size from 4 weeks until 8 weeks (Cohen's $d > 0.8$ [52]), while no effect size is measured between 8 weeks and detraining (Cohen's $d < 0.2$ [52]) (Table 4).

Success Rate During Training

Figure 4 demonstrates the number of successful trials per session, with a maximum of 120 attempts, over the 24 training sessions. There is a significant difference in the ability to reach the goal between the three different exercise groups ($F(2,1109) = 689.860$, $p < 0.001$), with the highest number of successful attempts per session in EG3 (mean 109, range 59–120), less successful trials in EG2 (mean 85, range 15–118), and the lowest number of successful trials in EG1 (mean 52, range 0–120).

Discussion

TSE are frequently used in dysphagia rehabilitation, but research on the relation between dose of training and training-efficacy is very limited. The main purpose of this study was to compare different levels of the resistive load in order to determine the most efficient level in healthy older adults.

Table 1 Differences in MIP_A between the different treatment arms expressed as p values

	Baseline			4 weeks			8 weeks			4 weeks post		
	EG1	EG2	EG3	EG1	EG2	EG3	EG1	EG2	EG3	EG1	EG2	EG3
CG	0.527	0.169	0.285	0.007	0.031	0.158	0.000	0.006	0.012	0.002	0.067	0.008
EG1		0.403	0.621		0.598	0.171		0.121	0.051		0.209	0.647
EG2			0.732			0.411			0.719			0.418

TSE tongue-strengthening exercises

Table 2 Summary of effect sizes by group and time point for MIP_A

	Baseline	4 weeks	8 weeks	4 weeks post
EG1 TSE				
100% 1RM				
Mean ± SD (kPa)	36.9 ± 9.1	52.5 ± 10.5	59.4 ± 12.6	56.8 ± 14.4
p		< 0.001[a]	< 0.001	0.197[b]
Cohen's *d*		**1.64**	**2.12**	− 0.20
EG2 TSE				
80% 1RM				
Mean ± SD (kPa)	34.1 ± 8.0	51.5 ± 8.0	54.7 ± 7.7	53.1 ± 8.1
p		< 0.001[a]	< 0.001[a]	0.451[b]
Cohen's *d*		**2.72**	**3.26**	− 0.21
EG3 TSE				
60% 1RM				
Mean ± SD (kPa)	35.3 ± 6.8	48.6 ± 7.6	53.6 ± 731	56.1 ± 8.8
p		< 0.001[a]	< 0.001[a]	0.200[b]
Cohen's *d*		**1.90**	**2.72**	0.32
CG LSE				
Mean ± SD (kPa)	39.2 ± 9.9	43.5 ± 10.2	44.5 ± 11.7	46.5 ± 12.6
p		0.044[a]	0.015[a]	0.355[b]
Cohen's *d*		0.45	0.51	0.017

MIP_A anterior maximal isometric pressure, *TSE* tongue-strengthening exercises, *LSE* lip-strengthening exercises, *EG* exercise group, *CG* control group

[a]Difference versus baseline

[b]Difference versus 8 weeks; large effect sizes (> 0.8) reflecting training effects are denoted in bold

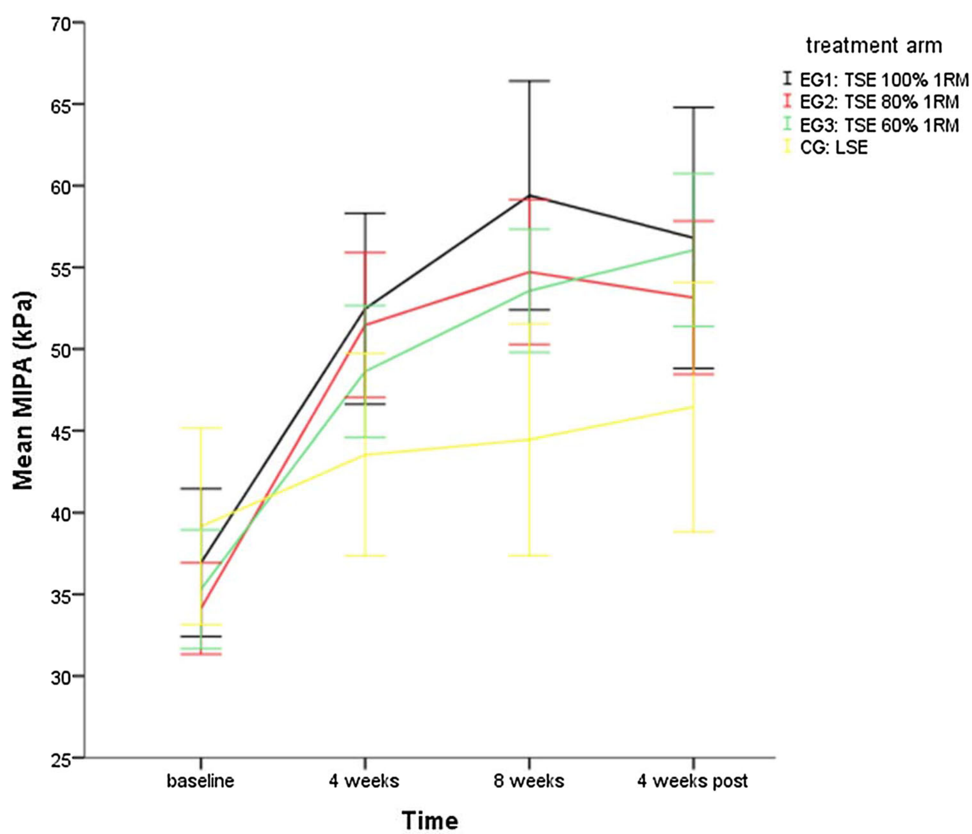

Fig. 2 Training effects on MIPA for all treatment arms; error bars: 95% CI

Table 3 Differences in MIP_P between the different treatment arms expressed as p-values

	Baseline			4 weeks			8 weeks			4 weeks post		
	EG1	EG2	EG3	EG1	EG2	EG3	EG1	EG2	EG3	EG1	EG2	EG3
CG	0.228	0.872	0.633	0.001	0.002	0.004	0.001	0.002	0.003	0.001	0.05	0.009
EG1		0.279	0.446		0.883	0.608		0.811	0.623		0.129	0.379
EG2			0.743			0.721			0.810			0.507

TSE tongue-strengthening exercises

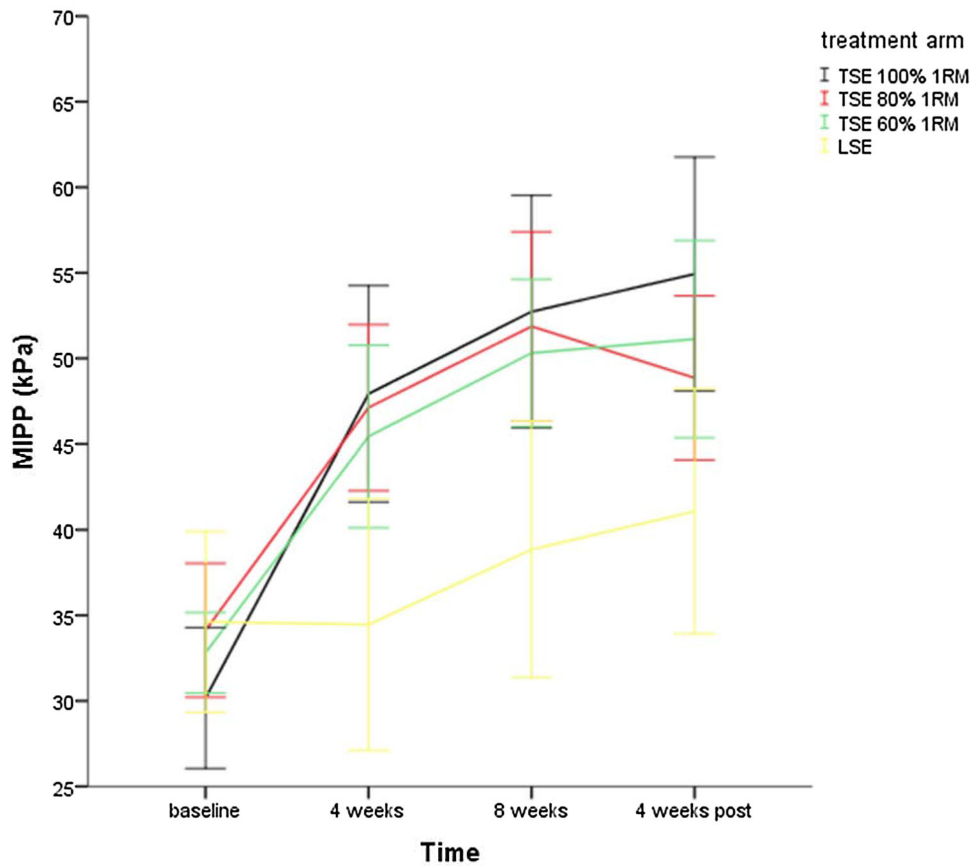

Fig. 3 Training effects on MIPP for all treatment arms; error bars: 95% CI

Similar to previous research about TSE (and disregarding the level of resistive load used in each study), the used protocol for TSE results in statistically significant and clinical relevant increases in TS [7, 11, 13, 29, 53], implying that the observed gains in TS do not appear to be attributable solely to learning effects or overall energizing effects [15]. The improvements documented in this study are more pronounced in comparison with available research about the results of TSE. This increase can presumably be explained by the high amount of repetitions and exercise load.

Overall, there are no significant differences in gain of MIP_A and MIP_P between the three EGs after 4 and 8 weeks training, but looking at the percentages of increased TS, some trends are observable. For MIP_A, lower loads result in less training effect, while high loads maximize effect, at 8 weeks post-training, with increases of 64, 60, and 52% for training at resp. 100, 80, and 60% 1RM. Furthermore for MIP_P, 100% 1RM resistive load leads to a marked gain in TS (+ 75%) in comparison with training at 80% 1RM (+ 50%) and 60% 1RM (+ 53%). It is remarkable that, unlike suggested by general strength training guidelines [26, 27], no overuse symptoms like diminished function (decrease in TS) or reported pain are registered when training at 100% 1RM. Three drop-outs occurred at 100% 1RM, but without reporting specific reasons. These findings are in line with conclusions from Solomon et al. [30, 31] describing the tongue as a fatigue-resistant muscle. Future research targeting measurement of specific overuse symptoms, especially in patients, is necessary.

No significant detraining effects are measured for any treatment group after 4 weeks rest. Moreover, a maximum loss of MIP_A and MIP_P is 5%, which can be considered as clinical irrelevant [53].

Table 4 Summary of effect sizes by group and time point for MIP_P

	Baseline	4 weeks	8 weeks	4 weeks post
EG1 TSE				
100% 1RM				
Mean ± SD (kPa)	30.2 ± 8.3	47.9 ± 11.4	52.7 ± 12.3	54.9 ± 12.3
p		< 0.001[a]	< 0.001[a]	0.316[b]
Cohen's *d*		**1.84**	**2.22**	0.19
EG2 TSE				
80% 1RM				
Mean ± SD (kPa)	34.0 ± 7.6	46.7 ± 9.3	51.1 ± 9.9	48.6 ± 8.9
p		< 0.001[a]	< 0.001[a]	0.271[b]
Cohen's *d*		**1.54**	**2.00**	− 0.27
EG3 TSE				
60% 1RM				
Mean ± SD (kPa)	32.8 ± 4.4	45.4 ± 10.0	50.3 ± 8.1	51.1 ± 10.8
p		< 0.001[a]	< 0.001[a]	0.702[b]
Cohen's *d*		**1.85**	**2.77**	0.09
CG LSE				
Mean ± SD (kPa)	34.6 ± 8.7	34.5 ± 12.2	38.9 ± 12.3	41.1 ± 11.8
p		0.948[a]	0.073[a]	0.344[b]
Cohen's *d*		− 0.01	0.42	0.019

MIP_P posterior maximal isometric pressure, *TSE* tongue-strengthening exercises, *LSE* lip-strengthening exercises, *EG* exercise group, *CG* control group

[a]Difference versus baseline

[b]Difference versus 8 weeks; large effect sizes (> 0.8) reflecting training effects are denoted in bold

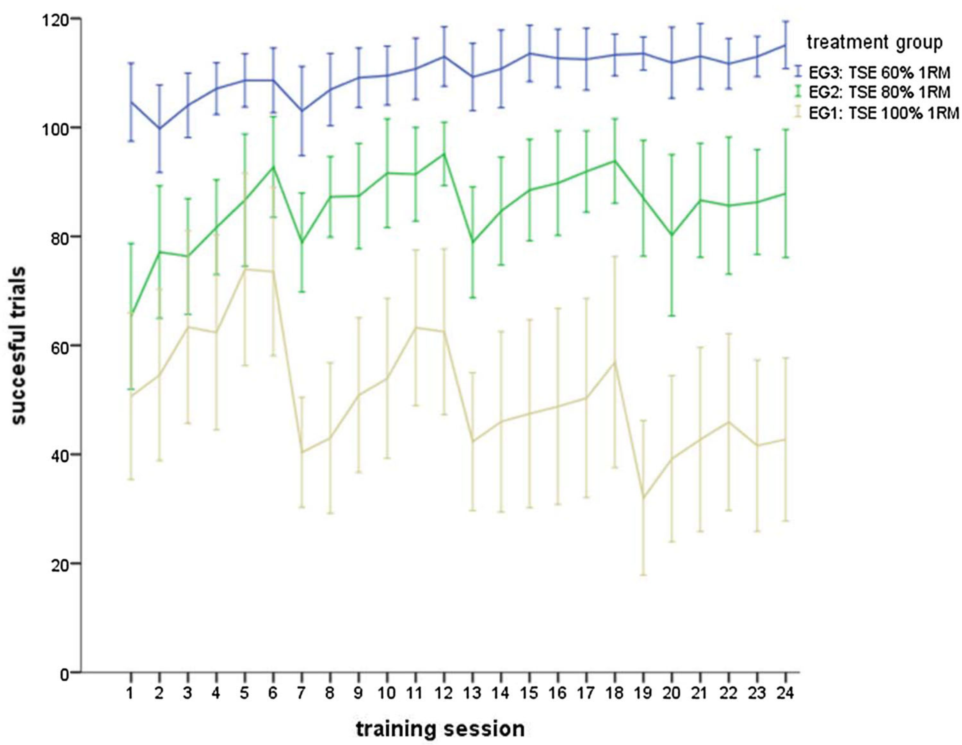

Fig. 4 Mean n of successful trials (max 120) per session for all exercise groups; error bars: 95% CI

As previously described, there are no significant differences between the EGs in the outcome, but there is a significant difference in feasibility to reach the exercise goal: the highest number of successful attempts are measured in the EG with the lowest exercise load and vice versa. Noticeable are recurring relapses in the number of successful trials every 2 weeks (session 3, 12, and 18). These relapses correspond to the different time points when the resistive load is adjusted depending on the subject's achieved MIP (i.e., progressive overload). As illustrated in Fig. 4, relapses are most pronounced in EG3, training at 100% 1RM, with less than 50% of the subject's trials able to reach training goals between 4 and 8 weeks training.

Thus, to determine a specific subject-dependent training goal, it seems preferable to train at 100% 1RM for maximal immediate gain in anterior as well as posterior tongue strength. In people who need more positive, extrinsic feedback, however, it is recommendable to adjust the resistive load to 80 or even 60%, since there is no significant difference in outcome between training at different values of resistive load, and the perception of succeeding will be remarkably higher.

This randomized controlled study describes long-term effects, uses isolated TSE instead of a combination of various swallowing exercises, and includes a control group of subjects performing different exercises than the study group. Therefore, it can be concluded that TSE have well-supported evidence for their efficacy and use [6, 21]. Although our study has three important limitations. First, it relies upon healthy subjects, so it is important to repeat this research in populations with dysphagia [50]. Secondly, our conclusions are restricted to the development of tongue strength, since we did not measure the evolution of the swallowing function. Although increase in tongue strength seems correlated with a gain in swallowing strength [12], future research should also include swallow parameters. In addition, more research is needed to determine the most appropriate dosages for other muscle functions (e.g., endurance, power…), since various muscle functions may have unique optimal dosage [54] and a different contribution to a safe and efficient swallow function. Finally, different parameters, amount of repetitions, and exercise load, contribute to an effective training intensity [21]. Current research compares different values of resistive load, but dose-dependent research concerning the amount of repetitions is lacking. Therefore, replication of this study protocol should not change the number of repetitions. Future research is required to determine the impact of the volume of repetitions per session and the interaction with resistive load.

As speech-language pathologists are urged to use the theoretical principles of strength training [6, 21, 55], it is of major importance that the training principles based on skeletal muscles are tested on the unique physiology of the tongue [15]. Like earlier research concerning specificity in TSE [28], actual results demonstrate some differences between the tongue hydrostat and other skeletal muscles.

In conclusion, this randomized controlled study confirms the increase of TS following TSE in healthy older adults. Furthermore, these results suggest that for MIP_A as well as MIP_P, TSE at a resistive load of 100% 1RM are the most efficient choice in highly motivated subjects, while lowering the resistive load to 80 or 60% 1RM will be more suitable for participants with a lower frustration threshold.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Committee This study was approved by the Ethical Committee of the University Hospital of Antwerp (B300201421549). All subjects agreed voluntarily to participate in this study and signed an informed consent.

References

1. Murphy BA. Clinical and economic consequences of mucositis induced by chemotherapy and/or radiotherapy. J Support Oncol. 2007;5(9):13–21.
2. Robbins J, Langmore S, Hind JA, Erlichman M. Dysphagia research in the 21st century and beyond: proceedings from Dysphagia Experts Meeting, August 21. J Rehabil Res Dev. 2001;39(4):543–8.
3. Pontes ÉS, Amaral AK, Rêgo FL, Azevedo EH, Silva PO. Quality of life in swallowing of the elderly patients affected by stroke. Arquivos de gastroenterological. 2017;54(1):27–32. https://doi.org/10.1590/S0004-2803.2017v54n1-05.
4. Bressan V, Bagnasco A, Aleo G, Catania G, Zanini MP, Timmins F, Sasso L. The life experience of nutrition impact symptoms during treatment for head and neck cancer patients: a systematic review and meta-synthesis. Support Care Cancer. 2017;25(5): 1699–712. https://doi.org/10.1007/s00520-017-3618-7.
5. Ayres A, Jotz GP, Rieder CR, Schuh AF, Olchik MR. The impact of dysphagia therapy on quality of life in patients with Parkinson's disease as measured by the swallowing quality of life questionnaire (SwalQol). Int Arch Otorhinolaryngol. 2016;20(3):202–6.
6. Langmore SE, Pisegna JM. Efficacy of exercises to rehabilitate dysphagia: a critique of the literature. Int J Speech Lang Pathol. 2015;17(3):222–9.
7. Kim HD, Choi JB, Yoo SJ, Chang MY, Lee SW, Park JS. Tongue-to-palate resistance training improves tongue strength and oropharyngeal swallowing function in subacute stroke survivors

with dysphagia. J Oral Rehabil. 2017;44(1):59–64. https://doi.org/10.1111/joor.12461.
8. Rogus-Pulia N, Rusche N, Hind JA, Zielinski J, Gangnon R, Safdar N, Robbins J. Effects of device-facilitated isometric progressive resistane oropharyngeal therapy on swallowing and health-related outcomes in older adults with dysphagia. J Am Geriatr Soc. 2016;64:417–24. https://doi.org/10.1111/jgs.13933.
9. Steele CM, Bailey GL, Polacco RE, Hori SF, Molfenter SM, Oshalla M, Yeates EM. Outcomes of tongue-pressure strength and accuracy training for dysphagia following acquired brain injury. Int J Speech Lang Pathol. 2013;15:492–502. https://doi.org/10.3109/17549507.2012.752864.
10. Steele CM, Bayley MT, Peladeau-Pigeon M, Nagy A, Namasivayam AM, Stokely SL, Wolkin T. A randomized trial comparing two tongue pressure resistance training protocols for post-stroke dysphagia. Dysphagia. 2016;31:452–61. https://doi.org/10.1007/s00455-016-9699-5.
11. Park JS, Kim HJ, Oh DH. Effect of tongue strength training using the Iowa Oral Performance Instrument in stroke patients with dysphagia. J Phys Ther Sci. 2015;27:3631. https://doi.org/10.1589/jpts.27.3631.
12. Oh JC. Effects of tongue strength training and detraining on tongue pressures in healthy adults. Dysphagia. 2015;30:315–20. https://doi.org/10.1007/s00455-015-9601-x.
13. Lazarus CL, Logemann JA, Huang CF, Rademaker W. Effects of two types of tongue strengthening exercises in young normals. Folia Phoniatr Logop. 2003;55:199–205.
14. Lazarus CL, Husaini H, Hu K, Culliney B, Li Z, Urken M, Jacobson A, Persky M, Tran T, Concert C, Palacios D, Metcalfe-Klax R, Kumar M, Bennett B, Harrison L. Functional outcomes and quality of life after chemoradiotherapy: baseline and 3 and 6 months post-treatment. Dysphagia. 2014;29(3):365–75. https://doi.org/10.1007/s00455-014-9519-8.
15. Clark HM, O'Brien K, Calleja A, Corrie SN. Effects of directional exercise on lingual strength. J Speech Lang Hear Res. 2009;52:1034–47. https://doi.org/10.1044/1092-4388(2009/08-0062).
16. Yeates EM, Molfenter SM, Steele CM. Improvements in tongue strength and pressure-generation precision following a tongue-pressure training protocol in older individuals with dysphagia: three case reports. Clin Interv Aging. 2008;3:735–47.
17. Robbins J, Gangnon RE, Theis SM, Kays SA, Hewitt AL, Hind JA. The effects of lingual exercise on swallowing in older adults. J Am Geriatr Soc. 2005;53:1483–9. https://doi.org/10.1111/j.1532-5415.2005.53467.x.
18. Robbins J, Kays SA, Gangnon RE, Hind JA, Hewitt AL, Gentry LR, Taylor AJ. The effects of lingual exercise in stroke patients with dysphagia. Arch Phys Med Rehabil. 2007;88:150–8. https://doi.org/10.1016/j.apmr.2006.11.002.
19. Steele CM, Cichero JA. Physiological factors related to aspiration risk: a systematic review. Dysphagia. 2014;29(3):295–304. https://doi.org/10.1007/s00455-014-9516-y.
20. Humbert IA, German RZ. New directions for understanding neural control in swallowing: the potential and promise of motor learning. Dysphagia. 2013;28(1):1–10. https://doi.org/10.1007/s00455-012-9432-y.
21. Burkhead LM, Sapienza CM, Rosenbek JC. Strength-training exercise in dysphagia rehabilitation: principles, procedures, and directions for future research. Dysphagia. 2007;22:251–65. https://doi.org/10.1007/s00455-006-9074-z.
22. Pekünlü E, Agalağ O. Relationship between fatigue index and number of repetitions maxima with submaximal loads in biceps curl. J Hum Kinetics. 2013;38:169–81. https://doi.org/10.2478/hukin-2013-0057.
23. Pollock M, Gaesser G, Butcher J, Despres J, Dishman R, Franklin B, et al. ACSM position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc. 1998;30(6):975–91.
24. Sheppard JM, Triplett NT. Program design for resistance training. In: Haff GG, Triplett NT, editors. Essentials of strength training and conditioning. 4th ed. Champaign: Human Kinetics; 2016. p. 439–69.
25. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. Med Sci Sports Exerc. 2003;35(3):456–64. https://doi.org/10.1249/01.MSS.0000053727.63505.D.
26. Cowley JC, Gates DH. Proximal and distal muscle fatigue differentially affect movement coordination. PLoS ONE. 2017;12(2):e0172835. https://doi.org/10.1371/journal.pone.0172835.
27. Silver JK, Rozmaryn LM. Overuse tendinitis of the intrinsic muscles. Orthopedics. 1998;21(8):891–4.
28. Van den Steen L, Schellen Van den C, Verstraelen K, Beeckman A, Vanderwegen J, De Bodt M, Van Nuffelen G. Tongue strengthening exercises in healthy older adults: specificity of bulb position and detraining effects; 2017. Submitted to dysphagia; accepted October 2017.
29. Lazarus CL, Husaini H, Falciglia D, DeLacure M, Branski RC, Kraus D, Lee N, Ho M, Ganz C, Smith B, Sanfilippo N. Effects of exercise on swallowing and tongue strength in patients with oral and oropharyngeal cancer treated with primary radiotherapy with or without chemotherapy. Int J Oral Maxillofac Surg. 2014;43:523–30. https://doi.org/10.1016/j.ijom.2013.10.023.
30. Solomon NP, Drager KD, Luschei ES. Sustaining a constant effort by tongue and hand: effects of acute fatigue. J Speech Lang Hear Res. 2002;45(4):613–24.
31. Solomon NP. What is orofacial fatigue and how does it affect function for swallowing and speech? Semin Speech Lang. 2006;27(4):268–82.
32. Saigusa H, Nijmi S, Yamashita K, Gotoh T, Kumada M. Morphological and histochemical studies of the genioglossus muscle. Ann Otol Rhinol Laryngol. 2001;110(8):779–84.
33. Stål P, Marklund S, Thornell LE, De Paul R, Eriksson PO. Fibre composition of human intrinsic tongue muscles. Cells, Tissues, Organs. 2003;173(3):147–61.
34. Rodríguez-Lozano FJ, Sáez-Yuguero MR, Bermejo-Fenoll A. Orofacial problems in musicians: a review of the literature. Med Probl Perform Artist. 2011;26(3):150–6.
35. Sanders I, Mu L. A 3-dimensional atlas of the human tongue muscles. Anat Rec. 2013;296:1102–14. https://doi.org/10.1002/ar.22711.
36. Gilbert RJ, Napadow VJ, Gaige TA, Wedeen VJ. Anatomical basis of lingual hydrostatic deformation. J Exp Biol. 2007;210:4069–82.
37. Kier WM, Smith KK. Tongues, tentacles and trunks: the biomechanics of movement in muscular-hydrostats. Zool J Linn Soc. 1985;83:307–24.
38. Felton SM, Gaige TA, Reese TG, Wedeen VJ, Gilbert RJ. Mechanical basis for lingual deformation during the propulsive phase of swallowing as determined by phase contrast magnetic resonance imaging. J Appl Physiol. 2007;103:255–65.
39. Folstein MF, Folstein SE, McHugh PR. "Mini mental state": a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12:189–98.
40. Vanderwegen J, Guns C, Van Nuffelen G, Elen R, De Bodt M. The influence of age, sex, bulb position, visual feedback, and the order of testing on maximum anterior and posterior tongue strength and endurance in healthy Belgian adults. Dysphagia. 2013;28:159–66. https://doi.org/10.1007/s00455-012-9425-x.
41. Suiter DM, Sloggy J, Leder SB. Validation of the Yale Swallow Protocol: a prospective double-blinded videofluoroscopic study.

Dysphagia. 2014;29:199–203. https://doi.org/10.1007/s00455-013-9488-3.
42. Hiraoka A, Yoshikawa M, Nakamori M, Hosomi N, Nagasaki T, Mori T, Oda M, Maruyama H, Yoshida M, Izumi Y, Matsumoto M, Tsuga K. Maximum tongue pressure is associated with swallowing dysfunction in ALS patients. Dysphagia. 2017. https://doi.org/10.1007/s00455-017-9797-z.
43. O'Day C, Frank E, Montgomery A, Nichols M, McDade H. Repeated tongue and hand strength measurements in normal adults and individuals with Parkinson's disease. Int J Orofac Myol. 2005;31:15–25.
44. Murdoch BE, Spencer TJ, Theodoros DG, Thompson EC. Lip and tongue function in multiple sclerosis: a physiological analysis. Mot Control. 1998;2(2):148–60.
45. Carnaby-Mann G, Crary MA, Schmalfuss I, Amdur R. Pharyngocise: randomized controlled trial of preventative exercises to maintain muscle structure and swallowing function during head-and-neck chemoradiotherapy. Int J Radiat Oncol Biol Phys. 2012;83(1):210–9. https://doi.org/10.1016/j.ijrobp.2011.06.1954.
46. Lazarus C, Logemann JA, Song CW, Rademaker AW, Kahrilas PJ. Effects of voluntary maneuvers on tongue base function for swallowing. Folia Phoniatr Logop. 2002;54(4):171–6.
47. Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, Tiryaki-Sonmez G. Influence of resistance training frequency on muscular adaptations in well-trained men. J Strength Cond Res. 2015; 29(7):1821–9. https://doi.org/10.1519/JSC.0000000000000970.
48. Fernández-Lezaun E, Schumann M, Mäkinen T, Kyröläinen H, Walker S. Effects of resistance training frequency on cardiorespiratory fitness in older men and women during intervention and follow-up. Exp Gerontol. 2017;95:44–53. https://doi.org/10.1016/j.exger.2017.05.012.
49. Van den Steen L, Vanderveken O, Vanderwegen J, Van Gestel D, Daisne JF, Allouche J, Delacroix L, Van Rompaey D, Beauvois S, Cvilic S, Mariën S, Desuter G, Vermorken JB, Van den Weyngaert D, Specenier P, Van Laer C, Peeters M, Van de Heyning P, Chantrain G, Lawson G, Lazarus C, De Bodt M, Van Nuffelen G. Feasibility of tongue strength measurements during (chemo)radiotherapy in head and neck cancer patients. Support Care Cancer. 2017. https://doi.org/10.1007/s00520-017-3761-1.
50. Van Nuffelen G, Van den Steen L, Vanderveken O, Specenier P, Van Laer C, Van Rompaey D, Guns C, Mariën S, Peeters M, Van de Heyning P, Vanderwegen J, De Bodt M. Study protocol for a randomized controlled trial: tongue strengthening exercises in head and neck cancer patients, does exercise load matter? Trials. 2015;16:395. https://doi.org/10.1186/s13063-015-0889-5.
51. Perry BJ, Richburg BD, Pomahad B, Bueno EM, Green JR. The effects of lip-closure exercise on lip strength and function following full facial transplantation: a case report. Am J Speech Lang Pathol. 2017;26(2S):682–6. https://doi.org/10.1044/2017_AJSLP-16-0101.
52. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale: Erlbaum; 1988.
53. Adams V, Mathisen B, Baines S, Lazarus C, Callister R. Reliability of measurements of tongue and hand strength and endurance using the Iowa Oral Performance Instrument with elderly adults. Disabil Rehabil. 2015;37(5):389–95. https://doi.org/10.3109/09638288.2014.921245.
54. Clark HM. Specificity of training in the lingual musculature. J Speech Lang Hear Res. 2012;55:657–76. https://doi.org/10.1044/1092-4388(2011/11-0045).
55. Clark HM. Neuromuscular treatments for speech and swallowing: a tutorial. Am J Speech Lang Pathol. 2003;1:40–50.

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