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ORIGINAL ARTICLE

Tongue-Controlled Computer Game: A New Approach for Rehabilitation of Tongue Motor Function

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Abstract

Objective: To investigate the influence of tongue disability, age, and sex on motor performance for a tongue-training paradigm involving playing a computer game using the Tongue Drive System (TDS).

Design: Two controlled observational studies.

Setting: A neurorehabilitation center and a dental school.

Participants: In study 1, tongue-disabled patients with symptoms of dysphagia and dysarthria (n=11) and age- and sex-matched controls (n=11) participated in tongue training. In study 2, healthy elderly persons (n=16) and healthy young persons (n=16) volunteered.

Intervention: In study 1 and study 2, the tongue training lasted 30 and 40 minutes, respectively. Participants were instructed to play a computer game with the tongue using TDS.

Main Outcome Measures: Motor performance was compared between groups in both studies. Correlation analyses were performed between age and relative improvement in performance. Subject-based reports of motivation, fun, pain, and fatigue evaluated on 0-to-10 numeric rating scales were compared between groups.

Results: In study 1, tongue-disabled patients performed poorer than healthy controls ($P=.005$) and with a trend of a sex difference ($P=.046$). In study 2, healthy young participants performed better than healthy elderly participants ($P<.001$), but there was no effect of sex ($P=.140$). There was a significant negative correlation between age and relative improvement in performance ($\delta=-.450$; $P=.009$). There were no significant differences in subject-based reports of motivation, fun, pain, and fatigue between groups in any of the studies ($P>.094$).

Conclusions: The present study provides evidence that tongue disability and age can influence behavioral measures of tongue motor performance. TDS may be a new adjunctive neurorehabilitation regimen in treating tongue-disabled patients.

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Dysphagia and dysarthria often occur after acquired brain injury and may have a serious negative impact on health and quality of life.[1-4] Approximately 50% of patients with stroke, 61% of patients with traumatic brain injury, and more than 80% of patients with Parkinson's disease have dysphagia, which may cause fatal pneumonia because of aspiration of, for example, food.[5-9] For the tongue, an immediate and precise coordination of sensory and motor function is crucial for normal oral functions such as swallowing, mastication, and speech.[10-12]

The current clinical oral rehabilitation regimens for dysphagia, dysarthria, or for both encompass several stimulation paradigms such as Facio-Oral Tract Therapy or oral motor exercises or conventional therapy, which are all mainly based on experience

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and lack scientific validation.[13-16] Currently, most of the conventional dysphagia therapies comprise an amalgamation of diet modification, position adjustment, and effortful swallowing, which augments airway protection during swallowing.[16] The main objective of various motor rehabilitation regimens is to promote plasticity at the subcortical and cortical levels, such that a long-term and beneficial alteration in motor control strategies can be attained.[17] Various tongue-training studies[18-21] have shown training-induced plasticity in human corticomotor control of the tongue by demonstrating an increase in motor-evoked potentials produced by transcranial magnetic stimulation (TMS).

The specific type of a tongue-training paradigm could possibly be important for the level of involvement and motor performance, and we speculate that frequent repetition of a simple task may prove less advantageous than a more complex 3-dimensional task, since it has been shown that limb skill training induces more cortical plasticity than simple strength training.[22]

Age-related physiological changes are not only interesting but also significant with respect to pathophysiology. A number of neurologic diseases occurring primarily in the later decades (5th−8th) of life trigger motor deficits.[23] In order to evaluate pathophysiologic processes in the elderly population, it is important to first evaluate normal age-related physiological changes in motor function.[23] Results from studies on motor cortical activation in an aging population are inconsistent and have been reported to be increased,[24] decreased,[25,26] or not different[27] compared with younger participants. Interestingly, the aging brain has been shown to involve a more widespread network of cortical regions in order to achieve the same goal compared with younger participants.[23]

We have introduced playing a computer game with the tongue using the Tongue Drive System (TDS) as a training method, with emphasis on skill training.[28] So far we have shown that force level, task complexity, and different motivational conditions influence tongue motor learning in healthy young participants.[28,29] In addition, we have recently shown that playing this tongue computer game (TDS) induces cortical plasticity in human corticomotor control of the tongue.[30] The TDS can wirelessly distinguish the tongue position inside the oral cavity and translate its motion into a set of specific user-defined computer commands.[31,32] The tongue thereby can act as a computer mouse and aids in playing tongue-controlled computer games.[31,33,34] Playing a computer game may possibly increase a subject's level of motivation during training in comparison with simple repeated tasks. However, the age of the person involved in a rehabilitation strategy involving computer games should be considered. Computer game performance may be influenced by age for various reasons. For example, there may be factors related to the difference in familiarity with the use of a computer or playing a computer game between age groups. This may influence the results when investigating the difference in computer game performance between age groups. Also, a large amount of evidence suggests that healthy older adults have more trouble learning new information, exhibit less efficient reasoning skills, are slower to respond on all types of cognitive tasks, and are more susceptible to disruption from interfering information than younger adults.[35-37]

List of abbreviations:

ANOVA	**analysis of variance**
RM	**repeated measurement**
TDS	**Tongue Drive System**
TMS	**transcranial magnetic stimulation**

For any new tongue rehabilitation strategy to be clinically implemented, it must at least have the same level of benefit as the current standard of care for dysphagia, dysarthria, or both.

This is the first study to apply tongue training with TDS in patients with tongue motor disability. We aimed to investigate the influence of tongue disability, age, and sex on performance and relative improvement of performance (%). In addition, we aimed to compare subject-based reports of motivation, fun, pain, and fatigue after training between tongue-disabled patients and an age- and sex-matched healthy control group, as well as between healthy elderly and healthy young participants.

Methods

Participants

Study 1: influence of tongue disability

Twelve tongue-disabled patients with dysphagia, dysarthria, or both (6 men, 6 women; age range, 18−73y; mean age ± SEM, 46.5±6.0y) were recruited at Hammel Neurorehabilitation and Research Center, Denmark (for specific diagnosis and onset of lesion, see table 1). Eleven age- and sex-matched healthy controls (5 men, 6 women; age range, 18−73y; mean age ± SEM, 46.7±5.5y) were recruited at the Department of Dentistry, Aarhus University. One male patient was later excluded from the study because he was not able to complete the tongue training as a result of extreme fatigue (see table 1).

Study 2: influence of age

Sixteen healthy elderly participants (7 men, 9 women; age range, 52−72y; mean age ± SEM, 61.9±1.4y) and 16 healthy young participants (7 men, 9 women; age range, 21−35y; mean age ± SEM, 26.7±1.2y) were recruited at the Department of Dentistry, Aarhus University.

In both studies, the healthy participants were without any serious medical, physical, or psychological disorders. Inclusion criteria were the ability to perform the entire tongue training with TDS, and the ability to read and understand the project information. All participants gave informed consent and received financial compensation for their participation. The study was approved by the local ethics committee and performed in accordance with the Helsinki Declaration II. Ten control participants overlapped between the 2 studies. Every session lasted approximately 60 minutes including calibration. Those overlapping healthy participants volunteered only once in the 40-minute session, and their data were used as control data in both study 1 (only 30 of 40min) and study 2.

Procedure

Tongue-disabled patients and healthy participants volunteered in a tongue training session involving playing a computer game using TDS for 30 minutes in study 1. Many of the tongue-disabled patients could perform no longer than 30 minutes, which was why this training duration was chosen. In study 2, healthy elderly and young participants participated for 40 minutes, which was in accordance with our previous study.[28] After each session, all groups were asked to report motivation, fun, pain, and fatigue on 4 separate 0-to-10 numeric rating scales. On the scale, 0 indicated no motivation/fun/pain/fatigue at all, and 10 indicated the highest level of motivation/fun/pain/fatigue imaginable. Before and during training, all participants in both studies were encouraged to

Table 1 Patient description

Subject No.	Time Since Injury (d)	Diagnosis	Signs and Symptoms
1	49	Stroke	Left facial nerve palsy and light problems in moving the tongue to the left with hypertonicity in the posterior region of the tongue
2	48	Stroke	Coordination problems in the tongue with reduced sensitivity of the tongue and mouth
3	184	Traumatic brain injury	Left facial nerve palsy with hypertonicity in the posterior region of the tongue and slurred speech
4	150	Polyneuropathy	Reduced activation of tongue and swallowing muscles
5	128	Stroke	Reduced coordination of swallowing movements
6	20	Stroke	Reduced sensation of right side of the mouth
7	140	Polyneuropathy	Reduced activation of tongue and swallowing muscle and continuing facial paralysis
8	60	Stroke	Left side paralysis and facial palsy
9	53	Stroke	Left side facial paralysis with reduced attention toward left
10	165	Traumatic brain injury	Diffuse axonal damage with dysphagia and dysarthria
11	40	Stroke	Dysphagia and dysarthria
12*	115	Stroke	Left facial palsy with dysphagia and dysarthria

* Subject 12 was later excluded from the study because he was not able to complete the tongue training for 30 minutes owing to extreme fatigue.

perform as well as possible. In study 2, we also asked participant to fill out a "computer experience questionnaire." The following questions were asked:

1. Have you ever had experience with computers? If yes, for which of the following reasons do you use a computer? E-mails, computer games, browsing and surfing, or all of them?
2. Have you ever played computer games? If yes, go to questions 3 and 4.
3. How many kinds of computer games have you played? 1 to 3, 4 to 6, 7 to 10, or more than 10?
4. In the past month, how much time did you spend playing computer games? 0 hours, 1 to 5 hours, 5 to 10 hours, or more than 10 hours?

Tongue Drive System

TDS is an assistive technology initially developed for patients with quadriplegia. The device allows them to have control over a computer, a powered wheelchair, or the user's environment by using the tongue as a manipulator (eg, computer mouse).[31,32,38,39] To implement TDS, a small disk-shaped rare earth permanent magnet[a] with the size of 5×1.3mm (10,800G strength), secured with interdental floss[b] and embedded inside putty soft impression material,[c] was attached on the tongue as a magnetic tracer by the use of a tissue adhesive.[d] A magnetic field was produced inside and around the mouth by this magnet. These magnetic fields were identified by a range of magnetic sensors attached on a headgear, which was worn by the participant/patient on the head while executing the task (fig 1).[28,34,40] The USB receiver attached to the computer and headgear had a built-in wireless connection (2.4MHz) that allowed the tongue to act as a computer mouse. After the placement of the TDS headgear, a setup procedure was followed, where participants were required to define specific positions in their mouth with the magnet attached to the tip of their tongue, and associate them to each "tongue command"; that is, the participants were trained to steadily place their tongue at 3 recommended positions (tooth 14 [upper right first premolar] for the "up" command, tooth 24 [upper left first premolar] for the "down" command, and tongue resting position) 10 times in a row, such that enough data could be gathered by the TDS to be able to recognize those specific commands based on the recorded data (see fig 1).[28] Later on, when participants placed their tongue at those specific positions, the TDS could properly associate the positions to the commands trained during the setup session (see fig 1).[28,31,39] The TDS was developed by a research group of engineers at Georgia Tech University. The TDS developers had originally defined the command positions keeping in mind that they should be away from the midline in order for the sensors on the headgear to detect and define them. Therefore, "up" cannot be in the midline at the roof of the mouth, for example, since that would be in the midline. To be consistent among all participants, the commands were divided by having up/down commands on the right and left upper premolar and left/right commands on the lower premolar. For the purpose of the present study, only the up and down commands were used. One of the key advantages of the TDS is its flexibility, allowing its users to define any commands (up to a total of 6) at any position in their mouth as long as they are sufficiently distinct from the other commands.

Fig 1 Participant wearing headgear of the TDS with control of the computer cursor through the magnet attached to the tongue. (Illustration courtesy of Ole Hein Pedersen.)

After the setup procedure, the patients/participants were instructed to play the computer game *Scuba Diver* (http://www.

icq.com/greetings/cards/142/) using the tongue as the computer mouse for 30 minutes of continuous training in study 1, and 40 minutes of continuous training in study 2. The patients/participants were given 3 lives in *Scuba Diver* and were instructed to collect as many coins (number of game points achieved) as possible while swimming. In addition, they had to escape from obstacles such as fish, bottles, and rocks coming their way. Every time they lost their 3 lives, the performance (number of game points) was noted manually. They were instructed to play the game several times, until the total *Scuba Diver* game time reached to 30 minutes in study 1 and 40 minutes in study 2.[28]

Statistics

All data are presented as mean ± SEM. Age and sex distributions were compared between groups with *t* tests and chi-square tests. Before analysis, normal quantile plots were used to evaluate the assumption of normal distribution. All data were normally distributed after log conversion. In all groups, training performance was averaged in blocks of 5 minutes. Analysis of performance over time was done by repeated measurement (RM) 3-way analysis of variance (ANOVA), with group (tongue-disabled group and control group in study 1, and healthy elderly and young participants in study 2) and sex as an independent factor and time as the RM factor. In addition, a 2-way ANOVA was performed, with subgroup (acute cases [n=6] vs chronic cases [n=5] irrespective of diagnosis) as an independent factor and time as the RM factors. When appropriate, Tukey honestly significant difference tests with correction for multiple comparisons were performed. Relative improvement in performance (%) over time was calculated for each participant, and unpaired *t* tests were performed to compare between the groups in both studies. Relative increase in performance (%) was calculated as follows: (Last time block value−First time block value)/First time block value×100%. A Spearman correlation analysis was performed between age and relative improvement in performance (%).

The subject-based reports of motivation, fun, pain, and fatigue were compared between groups and sexes with *t* tests. Finally, Spearman correlation analyses were performed between relative increase in performance (%) and subject-based reports of motivation, fun, pain, and fatigue. The level of significance was set at $P<.025$ because of the preliminary nature of the study.

Results

Study 1

There was no statistically significant difference in sex or age between groups ($P>.983$). There was a main effect of group ($P=.005$) and time ($P<.001$), and a tendency toward a significant effect of sex ($P=.046$) on performance. A post hoc test revealed that there was a higher performance in the control group compared with the tongue-disabled group ($P=.005$) (fig 2). Another post hoc test revealed that there was a tendency toward a higher performance in men compared with women ($P=.046$). Performance in all time-blocks was significantly higher than at baseline ($P<.001$), and highest in the last time-block (see fig 2). There were no significant interactions between factors ($P>.264$). There was no significant difference between acute and chronic cases ($P=.300$). Relative improvement in performance showed no significant difference between groups (tongue-disabled, 218.7%±21.4%; healthy controls, 221.9%±69.0%; $P=.971$). There was no significant correlation between age and relative improvement in performance (%) ($\delta=-.327$; $P=.137$).

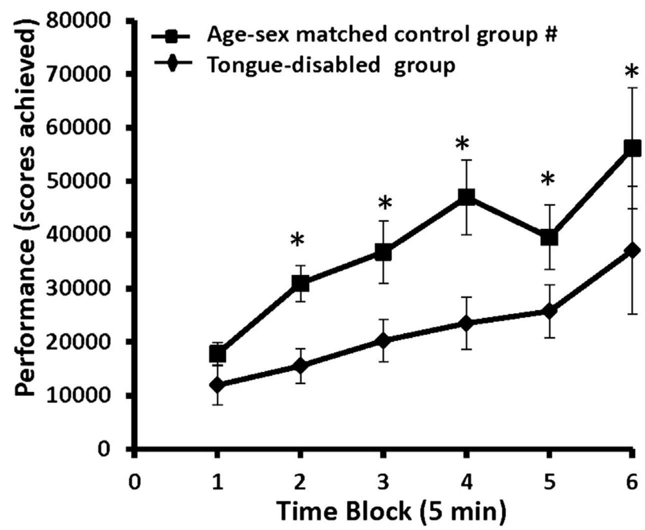

Fig 2 Mean ± SEM performance (number of game points) during 30 minutes (averaged 6 blocks of 5min) of playing computer game with the tongue using TDS. *Indicates significant difference from baseline in both groups ($P<.001$). #Indicates significant difference between tongue-disabled patient group (n=11) and age- and sex-matched control group (n=11) ($P=.005$).

There were no significant differences between groups regarding subject-based reports of motivation ($P=.800$), fun ($P=.633$), pain ($P=.694$), or fatigue ($P=.694$) (fig 3). There were no significant correlations between relative improvement in performance (%) and subject-based reports of motivation, fun, pain, and fatigue ($\delta<.282$; $P>.204$).

Study 2

In study 2, there were also main effects of group ($P<.001$) and time ($P<.001$) on performance, but there was no significant effect of sex ($P=.140$). The post hoc test revealed that there was a higher performance in the young participants' group compared with the elderly group ($P<.001$) (fig 4). Performance in all time-blocks was significantly higher than at baseline ($P<.001$), and highest in the last time-block (see fig 4). There was no significant difference in relative improvement in performance in the young group (238.1%±26.2%) compared with the elderly group (164.6%±26.3%) ($P=.091$). Spearman correlation analysis showed a significant negative correlation between age and relative improvement in performance (%) ($\delta=-450$; $P=.009$).

The subject-based reports revealed that there was no significant difference between age groups regarding the level of motivation ($P=.940$), fun ($P=.390$), pain ($P=.140$), or fatigue ($P=.094$) (see fig 3B). There were no significant correlations observed between relative improvement in performance (%) and subject-based reports for motivation, fun, pain, and fatigue ($\delta<.328$; $P>.067$).

The "computer experience questionnaire" revealed that 8 of 16 healthy elderly participants never played any computer games throughout their life, and of the 8 who had played computer games, 3 had not played games in the last month. The other 5 had

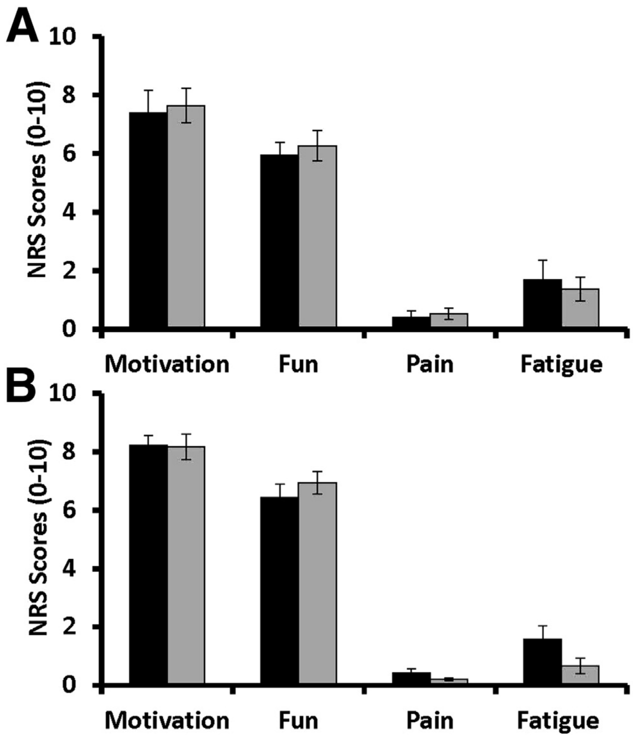

Fig 3 Mean ± SEM subject-based report of motivation, fun, pain, and fatigue on 0-to-10 numeric rating scales in different groups. (A) Tongue-disabled patient group (n=11), age- and sex-matched control group (n=11). No significant difference between groups was found for fun, pain, fatigue, or level of motivation (*P*>.633). (B) Healthy elderly group (n=16), healthy young participants (n=16). No significant differences between groups were found for level of motivation, fun, pain, and fatigue (*P*>.094). NRS, numerical rating scale.

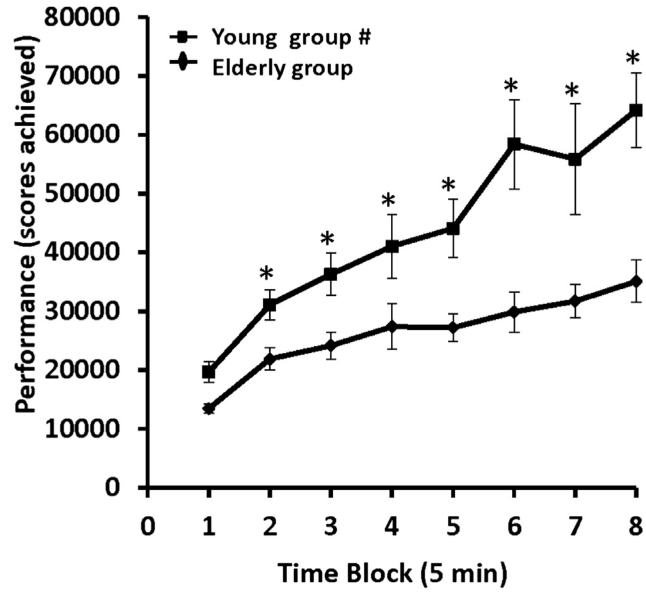

Fig 4 Mean ± SEM performance (number of game points) during 40 minutes (averaged 8 blocks of 5min) of tongue training with TDS. *Indicates significant increase compared with baseline in both groups (*P*<.001). #Indicates significant difference between healthy elderly group (n=16) and healthy young group (n=16) (*P*<.001).

at least devoted 1 hour to computer games during the last month. All 16 healthy elderly participants had experience with computers (e-mails, browsing, surfing). In contrast, all 16 young participants had experience with computers and computer games. Six of 16 young participants had not played computer games in the last month, 5 participants had at least devoted 1 hour to computer games, and another 5 participants spent more than 10 hours playing computer games in the last month.

Discussion

Influence of tongue disability

The main findings of study 1 were that computer gaming with the tongue as a training paradigm was feasible in tongue-disabled patients with dysphagia and dysarthria, and that performance improved over time in accordance with our previous findings in healthy participants.[28] However, the performance level in the tongue-disabled group was significantly lower than in the healthy controls, as could be expected. This outcome may be important because increasing the complexity of a novel motor skill task over the duration of the rehabilitation period has been suggested to promote cognitive effort and thereby enhance cortical plasticity.[41] The socioeconomic and health consequences of dysphagia and dysarthria are huge and demand more research into rehabilitation strategies.[42-44] Computer game training may prove beneficial and keep the participant more actively involved in contrast with more simple and less fun training paradigms.[28] Virtual reality and interactive video gaming have arisen as a new treatment methodology in stroke rehabilitation,[45] and provide an opportunity for patients to devote more time in therapy. Therefore, the activity may be more motivating and engaging for patients.[45] Computerized training platforms could be more flexible and personalized approaches, compared with traditional cognitive training programs.[46] In addition, computerized programs present real-time performance feedback and can adjust to the user's ability level, keeping the activity engaging and fun.[46]

Another finding of study 1 was that sex tended toward having a slight influence on the outcome in terms of performance and learning. Men tended to perform better than women. We did find sex difference in our earlier study.[29] The possibility of a higher performance in men may be due to a confounding factor that women generally do not play computer games to the same degree as men.[29,47,48] The clinical implication of possible sex differences in performance could be that different approaches to this kind of training (eg, different level of computer games) between sexes could be beneficial in patients undergoing neurorehabilitation programs involving tongue disability.

Influence of age

The main finding of study 2 was that age played an important role in the performance: Young, healthy participants performed better than elderly participants. Age is therefore an important factor to consider in future studies involving the need for a healthy control group. The age difference may be due to a decline in motor speed and fine motor skills in the elderly group,[49] but is probably also due in part to a difference in familiarity with computer games between age groups.[50] This was revealed in the computer experience questionnaire. During normal aging, psychomotor skills such as reaction speed and manual dexterity begin to show some deterioration around the third decade, with decrements in spatial ability beginning a decade later.[49,51] According to the results of previous electrophysiological and imaging studies of skilled movements,[52] it can be suggested that, at least for some tasks, the aging brain needs to mobilize more resources in order to produce the same output as younger control participants.[53]

Finally, the analyses of the subject-based reports showed that both groups in both studies experienced similar levels of motivation, fun, pain, and fatigue while playing the tongue-controlled computer game, which may suggest that these factors have not had a major influence on the differences in performance between groups in this study. Motor learning is negatively influenced by fatigue and pain, which are therefore important factors to consider.[53]

Study limitations

In the present study, the tongue-disabled patient group was diverse and heterogenic, with moderate to severe tongue disabilities. We suggest that future studies with TDS should aim to include a more homogenous patient sample (subacute to chronic cases, ie, at least 3mo poststroke onset) with mild levels of tongue dysfunction. We did not include functional measures or evaluation tools to measure the effect of TDS on, for example, swallowing or speech improvement. This should also be done in future studies. Another limitation was that the computer experience questionnaire was not administered to the tongue-disabled patients, and therefore we were not able to compare this factor between patients and healthy controls. The effect of computer gaming with the tongue in comparison with other tongue-training paradigms (eg, Facio-Oral Tract Therapy and the tongue protrusion task) on the degree of training-induced cortical plasticity should be investigated in future studies using, for example, TMS. This may help to guide the development of optimal tongue-training strategies.

Conclusions

The present study provides the evidence that tongue disability and age can influence performance in a tongue-controlled computer game, and that there is a negative correlation between age and relative improvement in performance. Tongue training with TDS may, after further studies, be considered as a new adjunctive neurorehabilitation regimen for tongue-disabled patients.

Suppliers

a. K&J Magnetics. Available at: kjmagnetics.com.
b. Colgate-Palmolive, Guildford GU2 8JZ, Dublin 24, Ireland.
c. Coltené/Whaledent AG, Feldwiesenstrasse 20, 9450 Altstätten, Switzerland.
d. GluStitch Inc, #307-7188 Progress Way, Delta, BC V4G 1M6, Canada.

Keywords

Aging; Performance; Rehabilitation; Tongue disability; Tongue Drive System; Tongue training

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