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Perception of Muscle Strength With and Without Biofeedback During Swallowing and Fist-Clenching Tasks

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Biofeedback is described as "the use of instrumentation to make a covert physiologic process obvious to the user by providing timely and specific visual and/or auditory representations of that process" (Wolf, 1994, p. 563). Biofeedback may be used with either the neurologically or nonneurologically impaired

ABSTRACT: The purpose of this study was to investigate the accuracy of the proprioceptive system in swallowing as compared to fist clenching. The role of surface electromyography (SEMG) biofeedback in replicating motor strength was also evaluated. It was hypothesized that (a) strength of muscle contraction during swallowing would be less accurately replicated than in a fist-clenching task, (b) there would be greater variability in motor tasks attempted without the use of biofeedback, and (c) there would be greater variability in contractions of graded strength than maximal strength. The study was completed in three phases. Phase 1 participants (*N* = 50) were aged 20–30 years, Phase 2 participants (*N* = 50) were greater than 50 years, and Phase 3 participants (*N* = 12) were greater than 50 years and had been diagnosed with pharyngeal phase dysphagia. It was anticipated that variation in amplitude of responses would increase with age and in patients with dysphagia.

SEMG activity was measured during performance of maximal- and graded-strength swallowing and fist-clenching tasks. Subjects performed each task eight consecutive times, under three conditions: with biofeedback; without biofeedback; and without feedback, following a delay. An SEMG biofeedback device recorded the strength and timing of muscular activity and represented the information in analog waveform on a computer screen. Under biofeedback conditions, participants were instructed to observe the SEMG waveform to determine their maximal peak SEMG amplitudes. Data were collected from the final five of eight consecutive attempts of each task and a measure of variance was calculated. Results provided partial confirmation of the hypotheses. Research participants from Phase 1 demonstrated greater variation in strength of muscle contraction for swallowing attempts than for fist-clenching tasks; however, this effect was only statistically significant for full-strength conditions regardless of feedback. No conclusive feedback effect was identified, and performance on half-strength fist-clenching tasks evidenced more variation than performance on full-strength fist-clenching tasks. Within the Phase 2 data, no task effect was identified; variation was higher in the "with feedback" condition and, within the fist-clenching tasks, variation was higher when performed at graded than at maximal strength. Results obtained from the Phase 3 data indicated greater variation in strength of muscle contraction for fist-clenching responses than swallowing responses; no conclusive feedback effect was found, and maximal-strength responses produced greater variation of amplitude over all tasks and conditions than graded-strength responses. Implications of results and suggestions for future research are discussed.

KEY WORDS: biofeedback, dysphagia, sensory perception

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population. Scientists have used biofeedback to help them teach, understand, and control animal and human behavior that originates not only in the central nervous system (CNS), but also in the autonomic nervous system (ANS).

The purpose of using biofeedback in rehabilitative therapy is to teach a patient to consciously manipulate physiologic events that may otherwise go undetected because of neurological impairment (Basmajian, 1989; Olson, 1987). Additionally, biofeedback may be used to help individuals increase their awareness of a motor act that is not easily perceived due to the nature of the event, such as swallowing. Depending on the disorder being treated and its severity, clinicians may use biofeedback to assist rehabilitation in different ways. Biofeedback signals are generally used in a continuous manner in the early stages of rehabilitation (Basmajian, 1989). That is, patients attend to the biofeedback signal(s) and attempt to adjust their movements accordingly. Over time, the signal may be gradually withdrawn as patients begin to relearn awareness of their own proprioceptive cues. At this stage, tasks may be altered so that therapeutic exercises emphasize an increased reliance on the patients' own proprioceptive system. For example, the clinician might ask patients to produce a movement while biofeedback signals are present and then withdraw the biofeedback, thus requiring the patient to replicate the movement using internal cues. In such a task, patients are able to compare their response without the biofeedback signal to the original response made with the use of biofeedback. In doing so, it is thought that patients are increasing their awareness of their own proprioceptive cueing system (Wolf, 1994).

Biofeedback is considered an effective tool for providing the patient with specific information regarding performance in the area of motor rehabilitation. The introduction of biofeedback modality therapy has provided both the patient and clinician with immediate, accurate, and ongoing information regarding performance of specific physiological movements. By incorporating biofeedback into the rehabilitative process, the speed of recovery may be increased and functional therapeutic gains may be maximized (LeCraw, 1989). Wolf (1994) theorized that when surface electromyography (SEMG) biofeedback is integrated into a patient's rehabilitation program, despite long-standing limitations, patients are offered an increased possibility of success due to the speed and precision of the information provided. With biofeedback, patients are able to alter their responses in accordance with each trial in order to improve on their personal attempts.

SEMG biofeedback generally employs surface electrodes that are fixed to the skin surface in the overlying area of the muscles requiring treatment. Electrodes are subsequently connected to a biofeedback device that records and displays the myoelectric movement of the muscles. SEMG biofeedback measures the strength and timing of myoelectric signals from the muscles and translates this information into visual and/or acoustic signals that the patient and clinician are able to understand. The signals therefore provide reinforcement with almost instantaneous and ongoing indication of muscle function. The goal of therapy using SEMG biofeedback is for individuals to learn to manipulate or control internal physiologic events, such as muscle activity, in order to improve movement (Mulder & Hulstyn, 1984).

Therapy that employs EMG or SEMG biofeedback has provided positive results for patients in many areas of medicine, including physiotherapy, occupational therapy, general medicine, and speech-language therapy. The current article will focus on the view that use of SEMG biofeedback is becoming a popular tool in dysphagia rehabilitation (Bryant, 1991; Crary, 1995; Huckabee, 1996; Huckabee & Cannito, 1999).

When SEMG biofeedback is used for the rehabilitation of dysphagia, surface electrodes are fixed to the skin surface and SEMG activity is typically measured from the submental musculature and displayed in analog form on a computer monitor (Bryant, 1991; Crary, 1995; Huckabee, 1996; Huckabee & Cannito, 1999). Consequently, the patient and clinician are able to observe and monitor a representation of one aspect of swallowing. Visualization of an abstract partially reflexive neuromotor activity such as swallowing may allow for rehabilitative exercises to be taught more effectively and may provide a measurement of comparative progress.

Research in the area of biofeedback and swallowing remains limited. In recent years, researchers have begun to investigate the effects of SEMG biofeedback on dysphagia rehabilitation. Clinical reports have outlined the results of therapy employing SEMG biofeedback on psychogenic dysphagia (Haynes, 1976), the treatment of dysphagia and dysarthria (Draizar, 1984), and the treatment of a patient with oral dysphagia secondary to pharyngeal carcinoma (Bryant, 1991). Additionally, clinical programs have been set up and outcomes of SEMG biofeedback have been noted in patients with brainstem lesions (Crary, 1995; Huckabee & Cannito, 1999). Crary and Groher (2000) provided a summary of the use of SEMG biofeedback procedures that may be used in the rehabilitation of dysphagia.

Despite the success of the above studies in using SEMG biofeedback-assisted therapy, it is clear that in order to provide unquestionable verification of its value, scientific studies using controls and a larger sample size are necessary. To date, there are no published research studies that control for other contributing factors and provide sufficient data to provide empirical results that support the use of SEMG biofeedback-assisted dysphagia therapy. However, following the initial reports of successful dysphagia rehabilitation with SEMG biofeedback-assisted therapy, some researchers developed clinical programs to further investigate the potential for swallowing therapy (Crary, 1995; Huckabee & Cannito, 1999). Crary (1995) described a therapeutic program for 6 patients who presented with chronic neurogenic dysphagia secondary to a brainstem stroke who were between 5 and 54 months post onset. All subjects were receiving complete nutritional and hydration requirements through gastrostomy feeding tubes before beginning treatment. Additionally, each subject had received traditional dysphagia therapy before commencing the program. Involvement in this program resulted in positive outcomes for all subjects. Five of the six subjects eventually returned to total oral nutrition and had their gastrostomy tubes removed.

Despite its obvious success, it is important to note some procedural weaknesses in Crary's (1995) program. Each patient was assessed objectively using videofluoroscopy before initiating treatment. However, because videofluoroscopy was not used to assess the participant's swallow post treatment, it is unclear whether improvement was a result of altered physiology or additional compensatory strategies developed over the treatment period. Crary attempted to overcome this limitation by using SEMG tracings as an objective assessment of swallowing physiology. Nevertheless, insufficient information exists regarding SEMG tracings in relation to physiologic characteristics to validate them as objective measurements of swallowing physiology.

Huckabee and Cannito (1999) responded to some of these limitations when they reported on a similar program for 10 patients with chronic dysphagia resulting from a single brainstem stroke. Unlike the previous study, frequency and duration of treatment was controlled. The duration of time post treatment until each of the patients had their enteral feeding tubes removed was also measured. Changes in swallowing physiology were objectively examined via pre- and posttreatment videofluoroscopies. Improvement in swallowing function was supported by each patient's diet tolerance level before and after receiving treatment. Symptoms of pulmonary difficulties were measured through the occurrence of aspiration before and after treatment. Six of the ten participants studied showed signs of pretreatment pulmonary illness compared to none of the patients indicating pulmonary symptoms after treatment.

As with Crary's (1995) study, SEMG biofeedback was used to assist implementation of the rehabilitation exercises. In order to provide stronger support for biofeedback-assisted therapy, inclusion criteria dictated that each participant be a minimum of 8 months post onset without having achieved significant gains. Results of this study were similar to those found in the earlier study by Crary. Following the completion of 10 treatment sessions, 9 out of 10 of the participants showed some improvement in diet level toleration; by completion of the long-term follow-up, 6 participants were receiving full oral nutrition. Additionally, none of the patients reported symptoms of pulmonary compromise at the long-term follow-up.

The results of the Huckabee and Cannito (1999) study provide further support for swallowing rehabilitation and the use of SEMG biofeedback-assisted therapy. Nevertheless, it should be noted that the small sample size used in this program does not provide sufficient support for evidence-based practice. Additionally, time post onset of dysphagia varied between subjects from 8 to 84 months. The 2 participants who did not achieve long-term removal of their feeding tubes were seen after the longest amount of time post cerebral vascular accident (CVA) (60 and 84 months). However, those who were seen after the shortest time post CVA did not recover faster than other participants.

The studies outlined above have provided a valuable introduction to the use of SEMG biofeedback in dysphagia rehabilitation. Additional research using controlled trials is necessary to address some of the queries developed by these clinical programs. Additionally, in order to completely appreciate the effects of SEMG biofeedback in increasing an individual's awareness of proprioceptive movements, it is necessary to acknowledge what is currently understood about proprioceptive ability.

Proprioception is a term used to describe an individual's ability to perceive his or her own body and its movement and orientation in space (Schmidt, 1988). In other words, our proprioceptive abilities allow us to know what movements our limbs and body are making in relation to each other and to our environment. According to Schmidt, the proprioceptive signal results from a combination of information from several receptors that is integrated by the CNS. The signal then proceeds through what Schmidt refers to as the stimulus-identification phase, response-selection phase, and, finally, the response-programming phase. Human motor control is reliant on each part of this process to work efficiently so that crucial information is provided to motor and sensory receptors in order to carry out a given task. A discussion regarding the individual receptors and their role in the execution and completion of movements is beyond the scope of the current manuscript. However, it is important to note that it is necessary for receptors to work simultaneously in order to prove effective. It is when one or more of these receptors fails to provide the support necessary to supply an individual with adequate information to accurately complete a movement that motoric difficulties develop (Schmidt, 1988).

Patients with neurological impairment often present with proprioceptive difficulties as a result of damage to the receptors and the sensory system as a result of their impairment. The natural deterioration of sensation with aging increases the possibility of patients with neurological impairment experiencing a reduction in proprioceptive abilities (Birren & Fisher, 1995). This natural decline must also be considered when treating patients with dysphagia because the majority of such patients tend to be elderly. In addition, swallowing may present a particularly challenging area for rehabilitation because it involves adaptation of a behavior that has previously been under highly automatic and, under certain conditions, reflexive, control. Thus, when compared to a more voluntary motor task, proprioceptive awareness may be further minimized.

The literature in the area of general motor control suggests the necessity for biofeedback during the learning of a motor skill (Mulder & Hulstyn, 1984; Wolf, 1994). It may be argued that motor relearning following neuromuscular injury is different from initial acquisition of a behavior, and therefore cannot be considered in the same light. Mulder and Hulstyn opposed this view by maintaining that such an individual must develop a strategy that allows conscious control over impaired muscles that were not previously damaged. These researchers believe this to be new learning, as a different program must be acquired in order to gain the necessary control to move voluntarily despite the impairment.

Some theorists suggest that biofeedback may compensate for damaged components of the proprioceptive system in general (Kasman, 1996; Wolf, 1994; Wolf & Binder-MacLeod, 1989). Previous studies in the area of dysphagia have provided an indication that this hypothesis may be true (Bryant, 1991; Crary, 1995; Huckabee, 1996; Huckabee & Cannito, 1999). However, little scientific proof exists to support this theory. The present study aimed to further evaluate the role of proprioception in the execution of two motor behaviors (swallowing and fist clenching) and to investigate the contribution of SEMG biofeedback in augmenting this system in three groups (younger, elder, and dysphagic individuals).

RESEARCH AIMS AND HYPOTHESES

The objectives of this study were designed to evaluate a single component of the motor relearning theories referred to in the review. Information was sought as to the accuracy of the proprioceptive system in regard to swallowing, as compared to another more visible, frequently manipulated motor task (i.e., fist clenching) in participants with and without dysphagia. Additionally, the study aimed to evaluate the potential facilitatory role of SEMG biofeedback in enhancing sensory perception of muscle contraction.

This project sought responses to the following research questions:

- Is strength of muscle contraction from submental musculature during swallowing less accurately replicated than muscle contraction during a fist-clenching task? In other words, will there be greater variability in strength of muscle contraction for swallowing responses than for fist-clenching responses?
- Is there greater variability in strength of muscle contraction for responses made without visual biofeedback than for those made with feedback, across motor tasks (fist clenching and swallowing)?
- Is there greater variability in contractions of graded strength in comparison to maximal strength across motor tasks (fist clenching and swallowing).

METHODS

Participants

The study was completed in three phases to evaluate the priori hypotheses in three different groups distinguished by age and presence or absence of dysphagia.

Phase 1. Fifty participants (25 female, 25 male), aged between 20 and 30 years, were recruited for Phase 1. Recruitment notices were distributed on department notice boards around the University of Canterbury campus. The inclusion criteria dictated that no subjects would be accepted who had a reported history of neurologic, neuromuscular, neurosensory, or dysphagic disorders. Therefore, the first 25 males and 25 females registering their interest who satisfied requirements regarding the inclusion criteria were recruited.

Phase 2. Fifty participants (25 male, 25 female) aged 50 years and over were included in Phase 2. Recruitment notices were placed in University of Canterbury departments, Christchurch newspapers, and the newsletters of senior citizens' organizations. The first 25 volunteers of each gender who satisfied requirements regarding the inclusion criteria were recruited.

Phase 3. Participants in Phase 3 included patients admitted to The Princess Margaret Hospital (TPMH), previous inpatients, and outpatients status post CVA with clinically identified pharyngeal phase dysphagia identified via speech-language therapist evaluation. Detailed information regarding lesion sites, time post onset of CVA, or the degree and nature of individual impairment were not included because the intent of the current study was to evaluate any differences between participants who had experienced dysphagia post CVA compared to those who had not. Study aims were not intended to evaluate patient behavior within the stroke population. Participants were aged 50 years and over and the mean age was 74 years (range 62–91 years). All had adequate cognitive functioning, allowing them to understand and follow basic instructions, as determined by the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975) and informal discussion with each participant. The Mini-Mental State Exam was administered at least 3 weeks before completion of the research tasks by each volunteer. The average Mini-Mental State Exam score was 81.5%, and scores ranged from 61% to 96%. The ability to follow directions was necessary, as participants were asked to follow specific instructions in relation to swallowing and fist-clenching tasks.

Each patient was initially approached by the principal investigator, who explained the study and provided a comprehensive information sheet. A minimum of 3 days following initial contact, the principal investigator discussed the study with each referred patient and gained written or verbal consent, in the presence of a witness, to include each patient in the study. Because of time restrictions combined with stricter inclusion criteria for the third phase, only 12 subjects were recruited for Phase 3.

Equipment

Surface triode patch electrodes secured with an adhesive patch under the chin and over the inner forearm measured the amount of SEMG activity that was produced by muscles while participants performed maximal- and graded- (half) strength swallowing and fist-clenching motor tasks. In the first phase, muscle function was evaluated using the Myo III portable SEMG biofeedback device (Verimed Limited, Florida). Due to technical difficulties, this was replaced by a Myotrac2 #9501-02 portable SEMG biofeedback device (Thought Technology Limited, Montreal) in the second phase and by the EMG biofeedback unit of the Kay Digital Swallowing Workstation (Kay Elemetrics Corp., New Jersey) in the third phase. These devices analyze the strength and timing of myoelectric events (SEMG activity) and represent the information in analog form on a computer screen. Strength of the contraction is measured in microvolts and is represented on the vertical axis (y axis) of the computer monitor. Timing of contraction is measured in seconds and is represented on the horizontal axis (*x* axis). The use of different SEMG devices was not considered to impact on final results because a coefficient of variation was used as the dependent variable in the statistical analysis. This meant that the results described the amount of variance in the responses rather than the absolute amplitude.

Procedure

Strength of muscle contraction was measured during the performance of two motor tasks (fist clenching and swallowing) under varying conditions related to strength and feedback (see Table 1). Subjects were randomly assigned to A and B groups, which determined the order of presentation of tasks. Specifically, participants in Group A performed swallowing tasks first followed by fist-clenching tasks. For Group B participants, tasks were completed in reverse order in order to avoid biasing results with learning or practice effects. Therefore, performance of fist-clenching tasks preceded swallowing tasks in Group B. The tasks were sequenced to be completed with feedback and without feedback. As a result of patient fatigue and discomfort with swallowing tasks, the condition of "without feedback following a delay" was deleted with participants in the older impaired group.

For presentation of both swallowing and fist-clenching tasks, ambulatory participants were seated on a swivel chair and participants in wheelchairs remained seated in their wheelchairs. All subjects were positioned in front of a computer screen. The skin surface was prepared by cleansing with an alcohol swab. Adhesive patches containing electrodes were subsequently placed on the area to be measured. For the swallowing task, myoelectric activity was monitored from a surface triode electrode placed under the chin at midline between the spine of the mandible and the superior palpable edge of the thyroid cartilage. The ground was placed equidistant and lateral from the two recording electrodes. For the fist-clenching task, myoelectric activity was measured from a surface triode electrode positioned over the region of the brachioradialis muscle in the forearm. The ground was placed equidistant and lateral from the two recording electrodes. This site was chosen because it is clinically used for SEMG electrode placement in clinical practice (Huckabee & Cannito, 1999). During initial practice trials, the investigator adjusted the scale of sensitivity that was to be represented on the *y* axis of the computer monitor so that the waveform filled approximately 75% of the screen, in order to provide the participant with optimal visual feedback. For example, participants demonstrating a low relative strength on either task benefited from a more sensitive scale, whereas participants with greater relative strength required a less sensitive scale.

Participants performed both tasks under two strength conditions (maximal and graded strength) and under two feedback conditions (with feedback and without feedback). Participants in each group were provided with specific verbal instructions before each trial. For elicitation of a maximal-strength swallow, participants were instructed to "swallow as hard as possible." For elicitation of a graded-strength swallow, participants were instructed to adapt the strength of their motor response and provide a response of half the strength of the maximal-strength swallow. For trials of maximal strength, fist-clenching participants were instructed to squeeze a soft ball as hard as possible and then quickly release it. A motor response of graded strength was elicited by requesting participants to squeeze the soft ball at half the strength of their full-strength squeezes. For each trial, participants were asked to produce a response

Table 1. Sequence of presentation of tasks and conditions for subjects in Group A.

	Conditions	
Task	*Strength*	*Feedback*
Swallowing	Maximal	With feedback Without feedback Without feedback following a delay period[a]
	Graded (half)	With feedback Without feedback Without feedback following a delay period[a]
Fist clenching	Maximal	With feedback Without feedback Without feedback following a delay period[a]
	Graded (half)	With feedback Without feedback Without feedback following a delay period[a]

Note. Sequence of presentation of fist-clenching and swallowing tasks was inverted for subjects in Group B.
[a]The without feedback following a delay period condition was completed by Phase 1 and 2 participants only.

eight consecutive times, at a rate of approximately one to two responses per 30 s.

Under biofeedback conditions for both swallowing and fist-clenching tasks, participants were instructed to observe the SEMG waveform to monitor their maximal peak SEMG amplitudes during performance of the task. In the absence of biofeedback, participants were asked to replicate the strength of their responses based on their internal perception of strength. Therefore, the earlier viewing of the waveform provided visual information that participants could match with the sensory information of the strength of muscle contraction required to perform full- and half-strength tasks during the trials where feedback was not available. In the initial two phases of the study involving unimpaired participants, a period of distraction was introduced between trials without biofeedback in order to determine a possible change in motor memory following a delay. To facilitate a delay period, researchers asked participants to alternately shuffle a deck of cards and play a card game. These activities were selected to divert the participants' attention from the swallowing and fist-clenching motor tasks. Because of the difficulty that most of the participants from the impaired group had producing multiple swallows, it was decided to eliminate this condition from the third phase because it required participants to complete a further 16 swallows.

In the first phase of the study, participants were simply asked to produce a response at either maximal or graded strength, eight times for each set of responses. These instructions were modified for the second phase to ensure that participants understood that their goal was not to exceed the strength of each previous response, but to replicate it. In Phase 2, which involved the older age group, participants were instructed to first produce one response under biofeedback conditions, and then to accurately *replicate* the strength of this response seven times. They were then asked to provide a further set of eight responses without biofeedback, at the *same* strength as those previously produced using biofeedback. After the delay period, they were once again asked to produce responses of the same strength as those previously produced.

Data Analysis

SEMG amplitudes were recorded using the SEMG biofeedback devices described under the Equipment section above. The principal investigator measured each response produced by participants by entering a saved file and placing the cursor on the peak amplitude of each response. In doing so, the computer-generated measurement of amplitude was provided and recorded. The final five of each set of eight consecutive swallows or fist clenches were used to derive a measure of the coefficient of variation (*SD*/*M*). This was the dependent variable. The three independent variables were feedback conditions (with feedback or without feedback,), task (swallowing or fist clenching), and strength (maximal or graded). These measures were submitted to a three-way analysis of variance (ANOVA) to test for relationships between the variables. The significance level was set at 0.05.

RESULTS

Table 2 displays the results of the three-way ANOVAs, which were performed on the data from the younger unimpaired group (Phase 1), the older unimpaired group (Phase 2) and the older impaired group (Phase 3).

Table 2. Analysis of variance for the effects of feedback conditions (condition), task, and strength on the measure of variation in strength for Phase 1 (*N* = 50), Phase 2 (*N* = 50), and Phase 3 (*N* = 12).

	Phase 1				*Phase 2*				*Phase 3*			
	Sum of squares	df	F	p	*Sum of squares*	df	F	p	*Sum of squares*	df	F	p
Main effects												
Condition	0.0870	2	1.968	.141	0.13200	2	7.162	<.001*	8.9230	1	0.07560	0.784
Task	0.2250	1	10.200	.001*	0.00952	1	1.034	.310	733.2290	1	6.21100	0.015*
Strength	0.5910	1	26.721	<.001*	0.33600	1	36.453	<.001*	799.2320	1	6.77000	0.011*
2-way interactions												
Condition × task	0.0547	2	1.237	.291	0.00965	2	0.524	.592	0.1640	1	.001390	0.970
Condition × strength	0.0939	2	2.123	.121	0.03020	2	1.641	.195	0.0432	1	0.000366	0.985
Task × strength	0.2110	1	9.554	.002*	0.16200	1	17.565	<.001*	413.3510	1	3.501000	0.065
3-way interaction												
Condition × task × strength	0.0293	2	0.663	.516	0.04030	2	2.190	.113	0.4160		0.003520	0.953
Error	12.9980	588			5.41300	588			10389.4830	88		

*Significant at 0.05 level.

Phase 1

This analysis demonstrated that in Phase 1, the independent variable of task had a significant effect on the dependent variable, $F(1, 588) = 10.2$, $p = 0.01$. Further analysis indicated that swallowing responses were more variable than fist-clenching responses for Phase 1 participants.

A significant strength effect, $F(1, 588) = 26.721$, $p = 0.01$, and a task-by-strength interaction, $F(1, 588) = 9.554$, $p = 0.02$, were also revealed by the three-way ANOVA. Phase 1 participants produced a greater variation in amplitude of responses produced at graded strength as compared to those produced at maximal strength. A task-by-strength interaction was revealed by the three-way ANOVA. Therefore, a series of multiple comparisons using Mann-Whitney Rank Sum Tests was performed to investigate this interaction. The significance level was set at $p < 0.01$. A significant difference was found between the graded- and maximal-strength conditions for the fist-clenching task ($T = 27764$, $n = 150$, $p < .001$), but not for the swallowing task ($T = 24164$, $n = 150$, $p = 0.034$). In other words, graded-strength fist-clenching responses were significantly more variable than full-strength fist-clenching responses, but no significant difference was found between graded- and full-strength swallowing responses. A significant difference was also found between the two tasks under maximal-strength conditions ($T = 26878$, $n = 150$, $p <.001$), but not for graded strength ($T = 23530$, $n = 150$, $p = 0.204$) for Phase 1 participants. This meant that maximal-strength swallowing responses were more variable than maximal-strength fist-clenching responses in Phase 1. However, no significant variation between fist-clenching and swallowing responses was found under graded-strength conditions.

No statistically significant feedback effect or interaction effect was found within the Phase 1 data.

Phase 2

The results of the three-way ANOVA that was performed on the data from Phase 2 revealed no statistically significant task effect. However, a significant strength effect, $F(1, 588) = 36.453$, $p = 0.01$, and a task-by-strength interaction, $F(1, 588) = 17.565$, $p = 0.01$, were revealed within the Phase 2 data. Two two-way repeated measures ANOVAs were performed to investigate the swallowing and fist-clenching data separately. The results for the swallowing and fist-clenching tasks are displayed in Tables 3 and 4, respectively.

It was revealed that whereas a significant difference existed between the "maximal-strength" and "graded-strength" conditions within the fist-clenching task ($p = .001$), no such difference existed within the swallowing task ($p = .045$). Thus, within the fist-clenching task data for Phase 2, variation was higher when responses were performed at graded strength. Within the swallowing task data for Phase 2, no significant variation existed between maximum- and graded-strength responses.

Table 4 also shows that feedback conditions had a significant effect on the measure of variation in amplitude of strength within the fist-clenching task ($p = .001$) in Phase 2. Post hoc testing using the Tukey procedure demonstrated that although there was no difference between the conditions "without feedback" and "without feedback after delay," there were significant differences between both of these levels and the "with feedback" condition ($p < 0.05$). Specifically, variation was higher with feedback than without, and variation was higher for responses produced at graded strength than for those produced at maximal strength.

Within the Phase 2 data, feedback conditions produced a significant effect on the measure of variation in strength, $F(1, 588) = 7.162$, $p = 0.01$. Post hoc testing using a Tukey procedure was carried out to identify significant differences between various combinations of feedback conditions within the Phase 2 data. The results of this analysis indicated that there was no significant difference between the "without feedback" and "without feedback after delay" data sets. However, the "with feedback" condition produced responses that were significantly more variable ($p < 0.05$) than responses from both of the conditions without feedback.

Table 3. Analysis of variance for the effects of feedback conditions (condition) and strength on the measure of variation in strength of swallowing responses in Phase 2 ($N = 50$).

Source of variation	*Sum of squares*	df	F	p
Main effects				
Condition	0.0455	2	3.208	.045*
Strength	0.0157	1	1.058	.309
2-way interaction				
Condition × strength	0.0289	2	2.617	.078
Error	0.5410	98		

*Significant at $p < 0.05$.

Table 4. Analysis of variance for the effects of feedback conditions (condition) and strength on the measure of variation in strength of fist-clenching responses in Phase 2 ($N = 50$).

Source of variation	*Sum of squares*	df	F	p
Main effects				
Condition	0.0961	2	9.434	<.001*
Strength	0.4820	1	57.020	<.001*
2-way interaction				
Condition × strength	0.0416	2	2.782	.067
Error	2.6500	299		

*Significant at $p < 0.05$.

Phase 3

Finally, in the third phase of the study, analyses indicated that the independent variable of task had a significant effect on the dependent variable, $F(1, 88) = 6.211$, $p = 0.015$. Further analysis indicated that fist-clenching responses were more variable than swallowing responses in Phase 3 participants. Figure 1 represents the means of the measure of variation in amplitude of fist-clenching versus swallowing responses in each phase.

The three-way ANOVA also indicated that the independent variable of strength had a significant effect on the dependent variable, $F(1, 88) = 6.77$, $p = 0.011$. Further analysis using a two-way ANOVA (Table 5) revealed that maximal-strength responses were more variable than graded-strength responses within the Phase 3 data. Hence, participants produced greater variability of amplitude in attempting to replicate responses at maximal strength than when producing responses at graded strength. Figure 2 represents the means of the measure of variation in amplitude of maximal-strength responses versus graded-strength responses.

Statistical analysis of the Phase 3 data indicated that no significant feedback effect existed within the participants tested. Figure 3 represents the means of the measure of variation in amplitude of responses produced with biofeedback, without biofeedback, and without biofeedback following a delay for each phase of the study.

Table 5. Analysis of variance for the effects of feedback conditions (condition), task, and strength on the measure of variation in strength for all participants in Phase 3 (*N* = 12).

Source of variation	*Sum of squares*	df	F	p
Main effects				
Condition	8.9230	1	0.075600	0.784
Task	733.2290	1	6.211000	0.015*
Strength	799.2320	1	6.770000	0.011*
2-way interactions				
Condition × task	0.1640	1	.001390	0.970
Condition × strength	0.0432	1	0.000366	0.985
Task × strength	413.3510	1	3.501000	0.065
3-way interaction				
Condition × task × strength	0.4160	1	0.003520	0.953
Error	10389.4830	88		
Total	12344.8420	95		

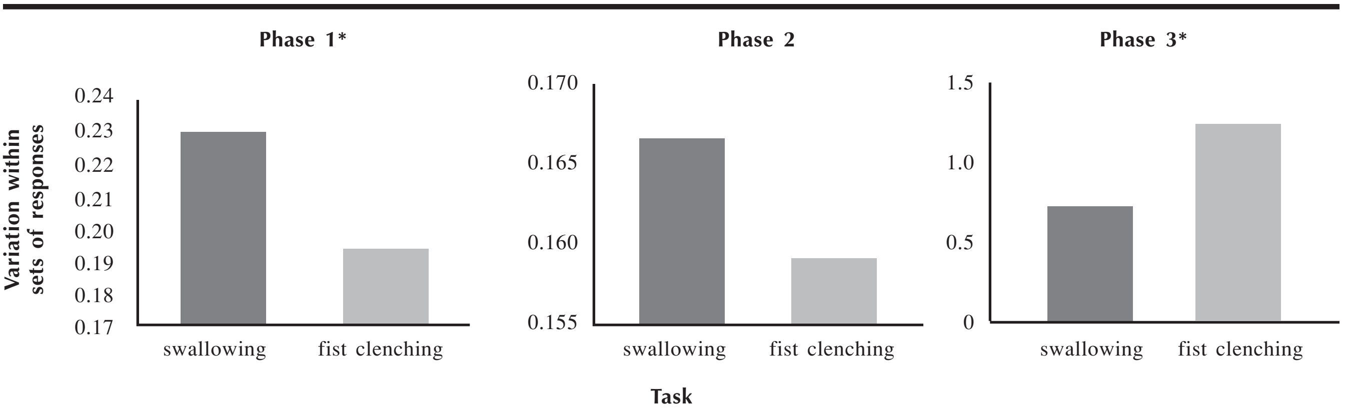
*Significant at $p < 0.05$.

DISCUSSION

The purpose of this project was to evaluate the replicability of strength of muscle contraction, with and without biofeedback, during two motor tasks as a means of commenting on motor memory. It was hypothesized that monitoring of myoelectric activity would identify comparative differences in sensory perceptual systems associated with swallowing relative to those controlling fist clenching. This hypothesis was based on the premise that swallowing is a more automatic and less consciously monitored motor behavior than outer extremity movement such as fist clenching. Thus, it was speculated that individuals have less experience in consciously interpreting the sensory feedback produced by the act of swallowing.

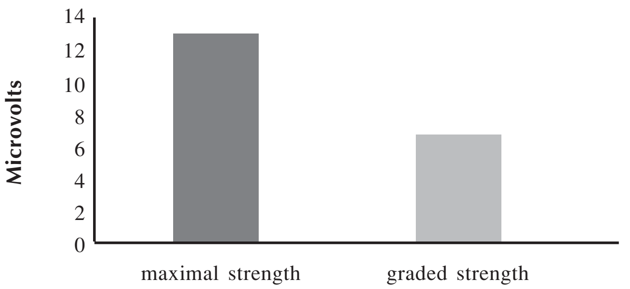
Data collected from the younger, unimpaired participant group was consistent with this prediction, as variation in strength of contraction was higher for swallowing than for fist-clenching responses. This result provides some support for the use of biofeedback to increase proprioceptive awareness of swallowing. On the other hand, no difference between performances on the two tasks was found in the older, unimpaired age group, and fist-clenching responses were more variable than swallowing responses in the older, swallowing-impaired group. These were unexpected outcomes, as previous research has shown that sensory perceptual ability as it relates to swallowing declines with

Figure 1. Variation of amplitude for task effect for Phase 1 (*N* = 50), Phase 2 (*N* = 50) and Phase 3 (*N* = 12).



*Significant at $p < 0.05$.

Figure 2. Variation of overall strength effect for participants in Phase 3 (N = 12) .



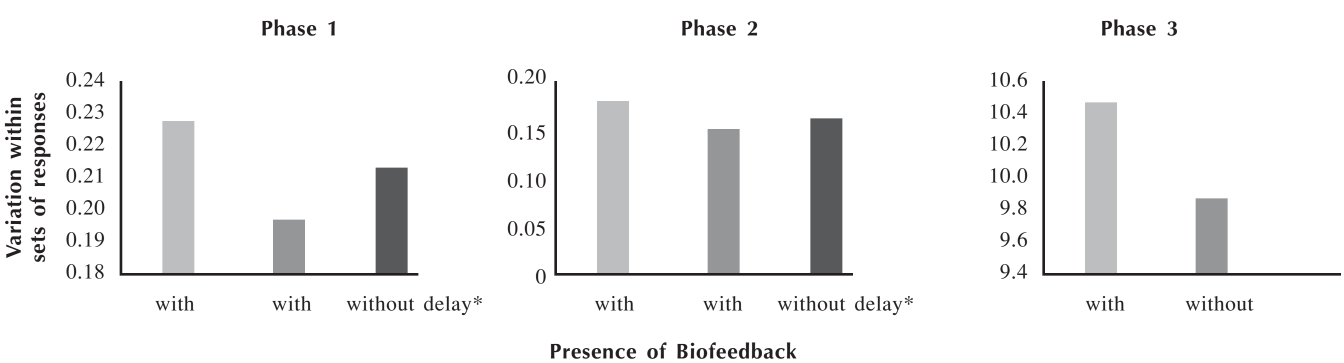
*Significant at $p < 0.05$.

age (Robbins, 1996). In her review of the literature regarding the effects of aging on the deglutitive system, Robbins concluded that the normal aging process affects the neural, muscular, and sensory systems. Each of these systems in turn affects the swallowing process. It is also clear that these systems are often affected in patients following a CVA. However, it is noteworthy that sensory perception and proprioception may refer to different types of sensation; therefore, conclusions drawn by Robbins regarding sensation can only be used as a guide for swallowing proprioception. It is also conceivable that the elderly impaired participants had begun to focus their attention on swallowing from the onset of their illness but had put little to no attention on the conscious effort to clench a fist or squeeze a ball. Swallowing is a function of living, and perhaps for patients experiencing dysphagia, the will to relearn the coordinated muscle movements of swallowing is naturally motivating. Therefore, it is possible that the conscious act of swallowing had already been practiced before their participation in the study.

It was further hypothesized that the presence of biofeedback would facilitate greater consistency in performance across responses. Conversely, results showed that variation was in fact higher under the biofeedback condition, in each age group and in the combined data set of the first two phases. Two possible explanations for this finding must be considered. The first explanation applies to Phase 1 and the instructions given to participants within Phase 1. As was explained in the Method section, participants in that group were not explicitly instructed to replicate the strength of successive responses. They were merely asked to produce a response at either maximal or graded strength throughout each set of responses. Thus, participants may have been attempting to exceed the strength of each previous response. The presence of biofeedback could have exacerbated this by providing a specific target to exceed. Another possible explanation could be extrapolated from Wolf and Binder-MacLeod's (1989) suggestion that biofeedback may compensate for damaged components of the proprioceptive system in patients with dysphagia. It was proposed that in healthy participants, the proprioceptive system is normally able to perceive and control the strength of responses. Therefore, when feedback is introduced into the loop via another (visual) modality, a new learning process must take place as participants attempt to integrate the new information. However, in the third phase of the study, no biofeedback effect was found to support the second hypothesis. This again is an unexpected result and appears contrary to what has been reported from clinical programs using SEMG biofeedback (Crary, 1995; Huckabee & Cannito, 1999). However, perhaps elderly impaired subjects were already using proprioceptive cues as a result of the natural aging process combined with swallowing difficulty before participating in the study. If this is so, it may have been easier for this group of participants to adjust their swallows as per the investigators' instructions. Conversely, younger participants who may not have had the necessity to develop proprioceptive awareness of swallowing may require greater time and training in order to use the equipment. Additionally, perhaps the methodology of the current study does not adequately assess the proprioceptive system that we use for swallowing.

The final hypothesis predicted that responses of graded strength would be replicated with greater variability than

Figure 3. Variation of feedback effect for Phase 1 (N = 50), Phase 2 (N = 50), and Phase 3 (N = 12).



*Significant at $p < 0.05$.

responses of maximal strength. This was postulated for two reasons. First, the peak muscle contraction in a maximal-strength response is governed by a physical limit, whereas a muscle contraction of graded strength must be controlled by a conscious effort to reach an arbitrarily defined target. Second, maximal-strength responses may result in more intense sensations than those of graded strength. Results from the first two phases confirmed that responses of graded strength are more variable than responses of maximal strength for the fist-clenching task, but not for swallowing. This discrepancy between the swallowing and fist-clenching data was an unexpected outcome. One possible explanation for this finding is that the values of the dependent variable were so much higher overall for swallowing responses than for fist-clenching responses. As a result of this anomaly, the data points for swallowing responses had a much higher spread than those produced by fist-clenching responses. Thus, any difference between the measure of variation in strength for graded and maximal strength within the swallowing task would be proportionately small. In the third phase of the study, results were contrary to the hypothesis and it was found that maximal-strength responses were more variable than graded-strength responses across tasks. It is conceivable that this result is indicative of the fact that participants with dysphagia had difficulty producing any swallow. It is proposed that asking them to adapt the strength of their voluntary swallows was asking too much of them as they appeared to struggle during the production of all swallows. It is possible that when patients with dysphagia are asked to produce voluntary swallows and the task is effortful for them, it is easier to produce a maximal swallow than to produce a graded swallow. In addition, the removal of an external stimulus in the swallowing tasks such as the smell, taste, texture, and temperature of a bolus may have increased the variability seen in swallowing tasks as compared to the variability seen in fist-clenching tasks. However, further research in this area is required in order to provide conclusive evidence.

DIRECTIONS FOR FURTHER RESEARCH

Although this study did not produce the expected results regarding the effect of SEMG biofeedback on the proprioceptive systems of unimpaired and impaired subjects, opportunities for future investigations in this area remain. Further research could benefit from using stricter inclusion criteria for a similar study. It may be beneficial to study participants with specific lesion sites and provide comparisons between populations with similar sites of lesion. Further research could compare swallowing with a more closely related motor task, such as lip protrusion, which is also a fine motor task but is often consciously controlled. It is possible that comparing an innate pattern behavior that is produced from the brainstem (swallowing) to a volitionally controlled behavior (fist clenching) introduced another confounding factor to the current study. Changes with ageing should also be reexamined, possibly using narrower and more distant age groups, as methodological differences between the present studies affected comparisons between the two age groups.

Another interesting area for further examination is the possibility that visual biofeedback produces a short-term detrimental effect on the accuracy of motor control in individuals with intact proprioceptive systems. An investigation into the prospect that elderly individuals and elderly individuals with dysphagia involuntarily use proprioceptive cues when swallowing is also of interest to this topic area. In addition, it should be noted that the present study did not distinguish between the effects of motor memory and those of proprioception. This issue warrants further investigation. Finally, a further study that compares the variation in amplitude of responses produced by elderly participants and by elderly participants with dysphagia is needed. Due to the lack of data supporting the hypotheses for the elderly dysphagic participants in this study, a comparison analysis was not completed. However, it was noted that variation in amplitude of responses was more variable for the patients who presented with dysphagia as compared to those who did not. This may provide important information regarding sensory perception and proprioceptive ability in patients with dysphagia.

REFERENCES

Basmajian, J. E. (1989). *Biofeedback principles and practice for clinicians* (3rd ed.). Baltimore: Williams & Wilkins.

Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior. *Annual Revue of Psychology, 46,* 329–353.

Bryant, M. (1991). Biofeedback in the treatment of a selected dysphagic patient. *Dysphagia, 6,* 140–144.

Crary, M. A. (1995). A direct intervention program for chronic neurogenic dysphagia secondary to brainstem stroke. *Dysphagia, 10,* 6–18.

Crary, M. A., & Groher, M. E. (2000). Basic concepts of surface electromyographic biofeedback in the treatment of dysphagia. *American Journal of Speech-Language Pathology, 9,* 116–125.

Draizar, A. (1984). Clinical EMG feedback in motor speech disorders. *Archives of Physical Medicine and Rehabilitation, 65,* 691–696.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Haynes, S. N. (1976). Electromyographic biofeedback treatment of a woman with chronic dysphagia. *Biofeedback and Self-Regulation, 1*(1), 121–126.

Huckabee, M. L . (1996). SEMG biofeedback: An adjunct to swallowing therapy. *Biofeedback, 24*(3), 220–223.

Huckabee, M. L., & Cannito, M. (1999). Outcomes of swallowing rehabilitation in chronic brainstem dysphagia: A retrospective evaluation. *Dysphagia, 14,* 93–109.

Kasman, G. (1996). Motor learning with EMG biofeedback: An information processing perspective for rehabilitation. *Biofeedback, 24*(3), 4–7.

LeCraw, D. E. (1989). Biofeedback in stroke rehabilitation. In J. V. Basmajian (Ed.), *Biofeedback principles and practice for* *clinicians* (3rd ed., pp. 105–117). Baltimore: Williams & Wilkins.

Mulder, T., & Hulstyn, W. (1984). Sensory feedback therapy and theoretical knowledge of motor control and learning. *American Journal of Physical Medicine, 63*(5), 226–244.

Olson, R. P. (1987). Definitions of biofeedback. In M. S. Schwartz (Ed.), *Biofeedback: A practitioner's guide* (pp. 33–38). New York: The Guilford Press.

Robbins, J. (1996). Normal swallowing and aging. *Seminars in Neurology, 16*(4), 309–317.

Schmidt, R. (1988). *Motor control and learning: A behavioral emphasis* (2nd ed.). Champaign, IL: Human Kinetics.

Wolf, S. L. (1994). Biofeedback. In J. A. Downey, S. J. Myers, E. G. Gonzales, & J. S. Lieberman (Eds.), *The physiological basis of rehabilitation medicine* (pp. 563–572). New York: Butterworth & Heinemann.

Wolf, S. L., & Binder-MacLeod, S. A. (1989). Electromyographic biofeedback in the physical therapy clinic. In J. Basmajian (Ed.), *Biofeedback: Principles and practice for clinicians* (3rd ed., pp. 91–103). Baltimore: Williams & Wilkins.

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