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A Game-Based Biofeedback System for Enhancing Masticatory Function in Patients with Stroke: A Case Study

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Original Article

Abstract

Introduction: Orofacial functional impairment is a common complication among stroke survivors, often leading to reduced masticatory function and strength, which ultimately results in gastrointestinal (GI) issues. On the other hand, game-based interventions serve as valuable therapeutic tools by integrating principles of motor learning and neuroplasticity into post-stroke rehabilitation of muscle function. The primary objective of this study was to develop a game-based biofeedback system for patients with stroke that utilizes muscle synergy information from the masticatory muscles to provide necessary feedback.

Materials and Methods: Initially, a two-dimensional (2D) game was designed, featuring an avatar that performs mastication of various food items at different speeds. The onset of each chewing cycle was determined using electromyography (EMG) signals from the masseter muscles. Subsequently, using non-negative matrix factorization (NMF), the contribution of each synergy between the masseter and temporal muscles was calculated to generate a score, which was displayed as visual feedback on the monitor. The proposed intervention was evaluated on the affected side of a post-stroke patient with preserved gum-mastication ability.

Results: Throughout the treatment sessions, in addition to an increase in game scores, the contribution rate of the first synergy (primarily associated with masseter muscle activity) showed a statistically significant linear decrease, while the contribution rate of the second synergy (temporal muscle) increased.

Conclusion: The findings demonstrate the effectiveness of game-based biofeedback rehabilitation as a simple, safe, cost-effective, and motivating approach. This method, which eliminates the need for specialized clinical space or constant professional supervision, shows great potential in assisting stroke survivors.

Keywords: Game-based biofeedback; Stroke; Electromyogram; Masticatory muscles; Muscle synergy

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Introduction

Stroke is a cerebrovascular disease characterized by high prevalence and mortality rates and stands as a primary cause of long-term disability in adults (1, 2). Brain injury in stroke survivors is frequently accompanied by motor dysfunction and abnormal muscle activation patterns. Approximately half of these cases present with a hemisensory syndrome involving sensory alterations on one side of the body, coupled with facial paralysis that often impairs orofacial function. Furthermore, malnutrition has been reported in 20% of acute stroke patients, often associated with dysphagia and masticatory difficulties (1). Consequently, eating disorders represent a critical issue significantly impacting the quality of life of stroke patients. The biting force of masticatory

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muscles on both the affected and unaffected sides in stroke patients is reduced by approximately 20-30% compared to healthy individuals (3). Efficient mastication requires not only adequate dentition and masticatory muscle activity but also the movement, strength, and coordination of the tongue, cheek, and lip muscles to form a bolus ready for swallowing and to reposition it between dental surfaces. Therefore, any lesion disrupting the interaction between central and peripheral mechanisms can impair the complex control of mastication (3). For instance, paralysis or damage to the facial or trigeminal nerves may contribute to masticatory dysfunction. Following a brainstem stroke, masticatory muscle activity, biting force, tongue flexibility, lip strength, and overall chewing performance can be severely compromised (4).

For stroke patients, it is critical to undergo a rehabilitation program designed to restore masticatory function to the greatest extent possible. However, masticatory system dysfunctions in stroke patients exhibit significant heterogeneity in terms of functional deficit severity, muscle involvement patterns, and the degree of muscular asymmetry; therefore, the efficacy of rehabilitation training necessitates the design of optimized interventions tailored to the individual characteristics of each patient (4). Conventional rehabilitation methods for post-stroke masticatory disorders rely primarily on in-person exercises under the direct supervision of a therapist. While effective, these methods are often limited by the need for frequent sessions, high treatment costs, restricted access to specialists, and a gradual decline in patient motivation and adherence over time. These constraints highlight the urgent need for alternative or complementary approaches (5). In recent years, game-based therapies and biofeedback have emerged as promising frameworks to enhance patient engagement and provide repetitive, targeted training; however, evidence regarding the application of these approaches specifically for masticatory function rehabilitation remains scarce. Consequently, game-based therapy represents a valuable clinical tool for integrating various motor learning principles into rehabilitation (5). Such interventions can improve key therapeutic factors, including training intensity, patient interest, motivation, adherence, safety, and cost-effectiveness [5]. The interactive and entertaining nature of games encourages users to overcome challenges and strive for functional improvement [5]. Ultimately, game-based biofeedback, by leveraging the principles of motor learning and neuronal plasticity, can significantly enhance the efficacy of rehabilitation exercises (5, 6).

Although electromyography (EMG) is recognized as a potent tool for quantifying muscle activity patterns, and numerous studies have evaluated masticatory function in stroke patients (4, 7, 8), direct research into the rehabilitation of the masticatory system using EMG signals or interactive game-based frameworks remains limited. Song et al. (2) demonstrated that the masticatory performance of the healthy side in stroke patients is significantly superior to that of the impaired side, observing a significant negative correlation between masseter muscle stiffness and chewing performance. Furthermore, study (9) reported a reduction in masticatory muscle activity on the impaired side relative to the healthy side. Subsequent EMG findings have indicated that stroke patients often lose the ability to maintain coordinated bilateral control of the masticatory muscles (3, 4). Prior research has established that post-stroke masticatory dysfunction is characterized by reduced bite force, asymmetrical muscle activity, and an increased duration of the oral phase, all of which directly impair nutritional intake and the overall quality of life (3, 4). Specifically, EMG-based analyses have reported diminished activity in the affected muscles, impaired bilateral coordination, and a negative correlation between muscle stiffness and chewing efficiency (2, 7-9). However, the majority of these studies are descriptive in nature, utilizing EMG data primarily to characterize functional status rather than to design active rehabilitation interventions. Conversely, while game-based therapies and biofeedback in stroke rehabilitation have been extensively studied for improving upper limb function, balance, and motor control—with well-documented effects on increasing motivation, training intensity, and adherence (5, 6)—their application to the masticatory system, particularly in stroke survivors, has not been systematically explored. Concurrently, some studies have suggested that EMG biofeedback can be used to modulate and retrain masticatory muscle activity, although these efforts have primarily focused on managing pain, muscle tension, or abnormal activity patterns (10). Moreover, the use of game-based EMG biofeedback in the rehabilitation of swallowing and pharyngeal muscles in stroke patients has recently gained attention, yielding positive results (11). These findings suggest that combining EMG biofeedback with interactive frameworks possesses high potential for oral and facial rehabilitation interventions.

Despite these insights, based on the current literature and to the best of the authors' knowledge, a substantial gap exists in translating masticatory muscle EMG data into interactive, user-centric rehabilitation tools. Specifically, few studies have focused on

designing EMG-based biofeedback systems for masticatory function; however, the implementation of game-based frameworks specifically targeting masticatory muscle synergies in stroke patients has not been directly or systematically reported. This lacuna is particularly critical given the decisive role of chewing disorders in inducing malnutrition and diminishing the quality of life in stroke survivors.

From a physiological perspective, asymmetric stimulation of the masticatory muscles in stroke patients can lead to unilateral muscle hypertrophy, subsequently impairing coordination and chewing efficiency (3). Consequently, compared to healthy individuals, stroke patients typically exhibit a prolonged oral phase and require an increased number of chewing cycles. Accordingly, the present study designed and implemented a game-based biofeedback system utilizing EMG data from the masticatory muscles to investigate the potential for improving chewing performance in stroke survivors. This system is innovative relative to traditional rehabilitation methods, as it integrates EMG feedback within an interactive, game-driven framework, facilitating targeted, motivating, and repetitive training of the masticatory musculature. The primary objective of this study is to evaluate the efficacy of this system in enhancing chewing function and muscle coordination in stroke survivors.

Materials and Methods

A) Design of the Game-Based Biofeedback System

To ensure appropriate user engagement with the avatar, the system allows selection of gender and the affected chewing side at the beginning of the session (Figure 1). Once selected, the gameplay proceeds with the customized avatar. The cheek line (masticatory boundary) is adjusted based on the initial side selection and remains in use throughout the game.



Figure 1. Interface for gender and affected chewing side selection on the game platform

The project features a 2D game environment in which food items enter the screen at predetermined intervals and speeds. If the participant correctly executes the chewing motion when a food item is aligned with the avatar, a point is awarded. Conversely, if a "bomb" item is chewed, the user is penalized through a reduction in the "life bar" and an auditory feedback signal. Within each stage, "bonus items" (cakes) are randomly presented four times, ensuring that no two bonuses appear at the same speed level.

At the conclusion of each speed level, an overall performance summary is displayed based on the percentage of points earned. This feedback is categorized into four levels: Poor (<30%), Fair (30-60%), Good (60-80%), and Excellent (80-100%). These statuses are accompanied by specific sound effects (Figure 2), serving as a reward/punishment feedback mechanism.



Poor (<30%) Fair (30-60%) Good (60-80%) Excellent (80-100%)

Figure 2. Sample avatars illustrating gameplay performance

An example of the "Poor" feedback display is illustrated in Figure 3.



Figure 3. Representative example of feedback provided for suboptimal performance upon level completion

Furthermore, based on the accumulated score and the percentage of the maximum possible points, users can earn "Stars" for each stage. If the performance meets an ideal threshold throughout the session, a "Crown" is awarded. To ensure patient comfort and prevent fatigue, a rest period is incorporated into each stage, which can be activated according to the user's needs.

It is noteworthy that the score bar is reset at the beginning of each stage. The game concludes by displaying the total number of stars earned, the status of the "Crown" award, and a comprehensive performance report (overall score percentage).

Intra-Game Mastication Protocol

The intervention protocol consists of four independent stages, each featuring food items moving at various speeds. These speeds, representing the required mastication rate, are varied randomly. In each stage, six distinct speeds (20, 30, 40, 50, 60, and 75 cycles per minute) are executed once, each lasting 90 seconds. To prevent cognitive bias and rhythmic habituation (memorizing the game's rhythm), a "bomb" element is incorporated. The bomb appears twice in each stage, and the participant must refrain from "chewing" it. Star awards, indicating peak performance, are granted after each stage based on specific scoring thresholds: 30% for the first stage, and 60% and 90% for the second and third stages, respectively.

At the end of the session, scoring data is recorded in a text file as binary/trinary values: 1 for successful food consumption, 0 for misses, and -1 for bomb consumption. A separate event-log file records the timing of stimuli: food appearance (Code 3), bomb appearance (Code 2), interruptions/pauses (Code 1), and baseline state (Code 0). These two files are synchronized and share the same sampling frequency to facilitate future data processing and analysis.

Game-Based Biofeedback System Design using Muscle Synergy Contributions

To facilitate the implementation of the biofeedback game and the configuration of the requisite parameters, a calibration phase is conducted at the onset of the initial therapeutic session, preceding the gameplay. In the proposed system (Figure 4), EMG signal processing and the delivery of game feedback are predicated on several key parameters. These parameters comprise extracted indices for the detection of chewing cycles, statistical signal metrics (such as mean and standard deviation), the synergy contribution ratio index (λ_Ratio) and the baseline score—all of which are utilized to evaluate user performance and generate corresponding reward or punishment feedback. These parameters are computed and employed across both the calibration and game execution phases.

To establish the parameters required to detect each chewing cycle and determine the baseline score, a calibration phase was conducted prior to the game-based biofeedback therapy sessions.

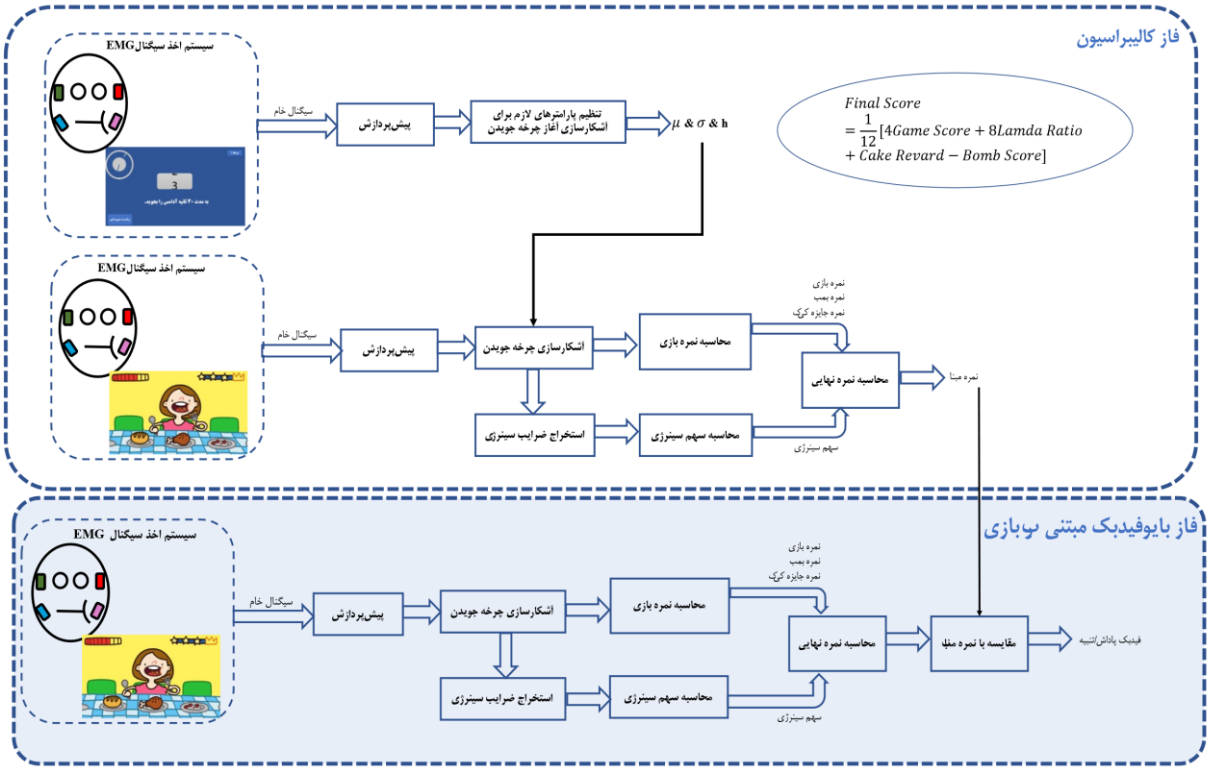


Figure 4. General workflow of the biofeedback game, comprising the calibration and gameplay phases

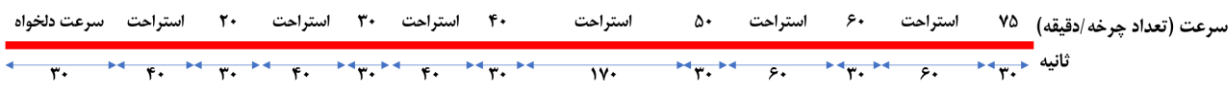


Figure 5. Timeline of chewing at various speeds

This calibration process was designed as a two-step procedure: in the first step, participant-specific parameters for cycle detection were determined; in the second step, parameters for calculating the user's score and delivering appropriate feedback were configured.

Step 1 of the Calibration Phase: In this stage, participants were enrolled in a protocol based on a previously established study [10]. Bipolar surface electrodes were placed on the bilateral masseter and temporalis muscles, with a ground electrode attached to the forehead [11]. To ensure optimal electrode placement, participants were instructed to clench their teeth, enabling the examiner to identify precise anatomical sites by palpation [11]. Prior to electrode attachment, the skin was thoroughly cleansed with alcohol pads to minimize skin impedance. Electromyographic (EMG) signals were acquired using the FlexComp Infiniti system (Thought Technology Ltd, Canada) at a sampling rate of 2400 Hz.

Participants were provided with a piece of chewing gum (30 mm, Biodent, Iran) and instructed to chew on either the right or left side for approximately two minutes at a natural pace until an appropriate softness was achieved. The use of gum and the restriction of chewing to one side of the dental arch were implemented to minimize external confounding variables, such as variations in food texture and tongue movements associated with bolus transport.

The experimental procedure consisted of two blocks, each featuring six chewing speeds (20, 30, 40, 50, 60, and 75 cycles per minute), regulated by a timing program. Chewing was performed on the right and left sides during the first and second blocks, respectively; the detailed chewing schedule for each block is illustrated in Figure 5. All participants were seated comfortably in front of a monitor and instructed to synchronize their chewing speed with audiovisual cues that signaled the onset of each cycle.

To eliminate motion artifacts and maximize the signal-to-noise ratio (SNR), a 4th-order Chebyshev Type I band-pass filter with a cutoff frequency range of 30-300 Hz was applied [12]. Power-line interference was subsequently removed using an IIR notch filter centered at 50 Hz.

The onset of each chewing cycle across different speeds was detected using the Teager-Kaiser Energy Operator (TKEO) applied to the EMG signal of the masseter muscle on the chewing side [13, 14]. Following the application of the TKEO, the EMG signal was smoothed using a 4th-order zero-phase low-pass filter with a cutoff frequency of 50 Hz. Finally, the detection threshold (Th) for each chewing cycle was calculated based on the mean (μ) and standard deviation (σ) of the resulting signal, as defined in Equation 1:

$$Th = \mu + h\sigma$$

In Equation 1, h is a predefined constant set to 20 in this study, as it empirically yielded the highest detection accuracy and the lowest error rates.

Step 2 of the Calibration Phase: In the second step of the calibration phase, the participant engaged in the game to determine a baseline score. Chewing cycles were detected in real-time; specifically, every 100 ms of the recorded EMG signal was analyzed using the TKEO to identify the onset of each chewing cycle.

Subsequently, muscle synergy information was extracted upon the completion of each chewing speed within the game. To achieve this, the rectified EMG signals were smoothed with a 10 Hz low-pass filter to obtain the linear envelope of muscle activity, which was then downsampled to 240 Hz. The activity of each muscle was normalized between 0 and 1 relative to its maximum value across all cycles. Non-negative Matrix Factorization (NMF) was then employed to extract the simultaneous synergies of consecutive chewing cycles. Owing to the non-negative nature of muscle activity and its capacity to extract interpretable muscle synergies, this method has been extensively utilized in muscle activity analysis studies (18). Consequently, matrix M, which represents the activity of muscles overt time points, is decomposed into spatial synergy weights W and temporal activation profiles C (Eq. 2).

$$M = W.C + E$$

In Equation 2, the matrices are defined $M \in \mathbb{R}^{m\times t}$, $W \in \mathbb{R}^{m\times k}$, $C \in \mathbb{R}^{k\times t}$and, where k denotes the number of muscle synergies, determined to maximize the explained variance of the data. Finally, E represents the residual error matrix. Based on the findings of previous research (12), two synergies were selected as the optimal number for the present study.

To quantify the relative contribution of each

muscle synergy and utilize it in calculating the baseline score during the calibration phase, the synergy contribution coefficients (λ_{Ratio}), extracted from the EMG signals, were employed. These coefficients encompass the temporal activation profiles of each synergy, enabling the analysis of muscle activity variations during gameplay.

To this end, Principal Component Analysis (PCA) was applied to the synergy activation coefficient matrix. Based on the eigenvalues derived from PCA, the contribution of each synergy to the reconstruction of the EMG signal can be determined (19). According to Equation 3, following the computation of the eigenvalues e_i, the normalized contribution rate of each synergy (λ_i) is defined as:

Equation 3:

$$[e_1, e_2, \dots, e_n] = PCA(C)$$
$$\lambda_i = \frac{e_i}{\sum_{i=1}^{n} e_i}, (i = 1,2, \dots, n$$

Where e_i denotes the eigenvalues extracted from the synergy activation coefficient matrix. Subsequently, to establish a quantitative index for the baseline score, the ratio of the contributions of the first and second dominant synergies was defined as the parameterλ_{Ratio}, calculated as follows:

Equation 4:

$$\lambda_{Ratio} = \frac{\lambda_2}{\lambda_1}$$

Where $\lambda_2$and $\lambda_1$represent the contributions of the first and second synergies, respectively. Finally, the game's processing architecture—utilizing the detection of each chewing cycle corresponding to the consumption of game elements—provides the game score, the number of bombs consumed, and the cake rewards. Consequently, the calculation of the final score, which integrates both the individual's muscle synergy data and the game outputs, is proposed as follows:

Equation 5:

$$FinalScore = \frac{1}{12}[4GameScore + 8LamdaRatio + CakeReward - BombScore]$$

Game-Based Biofeedback Phase

Following the establishment of the necessary parameters for the threshold and baseline score, the game-based biofeedback therapy sessions were initiated. The system analyzed the signals in 100-ms windows to detect the onset of each chewing cycle in real-time. After each designated chewing speed, the game scores were extracted in conjunction with the λ_{Ratio} derived from the muscle synergies.

The current game performance was then compared with the baseline score to determine the appropriate reward or penalty for the participant. This feedback was conveyed via an avatar with a smiling or sad facial expression, depending on the score's deviation from the baseline. Furthermore, upon completing all speeds in a stage, the participant received a "Crown" reward if the final score exceeded 90%.

Results

Participant: The participant was a 39-year-old female who had suffered a right-hemisphere hemorrhagic stroke 30 months prior to the study. The therapeutic interventions were structured as five consecutive daily sessions. Assessment recordings, conducted in accordance with the established protocol [10], were acquired immediately after the game. Since the stroke resulted in motor impairment on the left side of the body, both the in-game chewing and the subsequent EMG recordings were performed exclusively on the left side. Additionally, qualitative data regarding the patient's mandibular status during speech and chewing were collected via oral reports to supplement the analysis.

Prior to the intervention, the study procedures were explained in detail to the participant, and written informed consent was obtained. Furthermore, this study was approved by the Ethics Committee of Islamic Azad University, Mashhad Branch.

B) Quantitative Analysis of the Effects of Rehabilitation Biofeedback

Quantitative Game Output Results: The game incorporated three distinct scoring metrics to evaluate the game-based rehabilitation sessions. The first metric was the maximum game score achieved, contingent on adhering to the prescribed chewing speed while consuming in-game food items. The second metric indicated the number of bombs that were incorrectly consumed (error rate). The third metric, a binary indicator, represented the participant's ability to acquire the reward (the cake) successfully. The participant's scores across the various sessions are shown in Figure 6.

As illustrated in Figure 6, a consistent upward trend in the participant's performance is evident across all chewing speeds, as indicated by the food consumption scores. A notable reduction in the number of incorrectly consumed bombs was observed at higher speeds (60 and 75 cycles/min); this may be attributed to the participant's improved synchronization with the prescribed speed, which may reduce the demand for high-precision control during chewing.

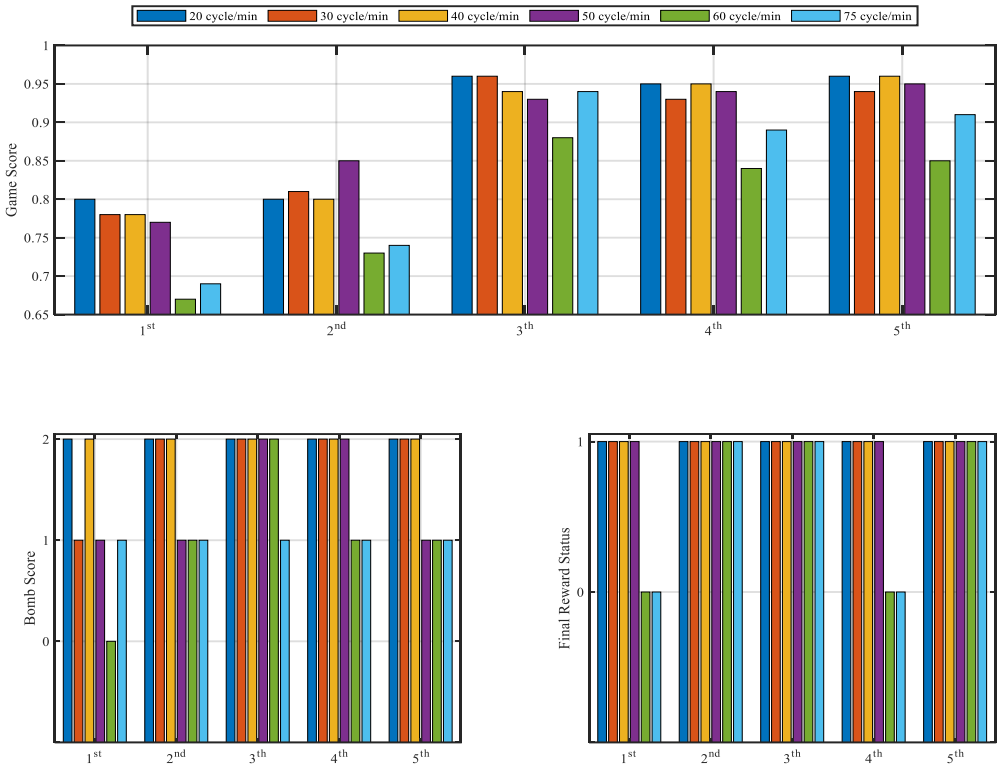


Figure 6. Trends in food consumption scores across different game sessions (top), the number of incorrectly consumed bombs (bottom-left), and the reward acquisition status (bottom-right)

The participant successfully acquired the rewards in all sessions except the first and fourth sessions at speeds of 60 and 75 cycles/min, respectively.

C) Analysis of Muscle Synergy Information during Game-Based Therapy

Analysis of Synergy Vector Coefficients: The temporal variations in the synergy coefficient vectors for the bilateral temporalis and masseter muscles—across all sessions and chewing speeds for both the first and second synergies—are presented in Figures 7 and 8.

Since the participant performed chewing on the left side, the synergy coefficients—particularly for the first synergy—remained minimal, and no discernible trend in these values was observed across the game sessions, as illustrated in Figures 7 and 8.

Based on Figure 7, the first synergy coefficients for the left temporalis muscle showed a marginal increase during the therapeutic sessions. In contrast, the coefficients for the left masseter muscle showed a declining trend. Similarly, Figure 8 indicates that the second synergy coefficients of the left temporalis and masseter muscles followed comparable ascending and descending patterns. Notably, these variations were not evident at 20 cycles/min, which may be attributed to the significant deviation of this speed from the physiological chewing rhythm.

Analysis of Synergy Activity Coefficients: To evaluate variations in muscle activity during the game-based therapy sessions, synergy contribution ratios (Equations 3 and 4) were used as a quantitative metric to assess the efficacy of the biofeedback rehabilitation. The contribution rates of the two synergies across the sessions are presented in Figure 9.

As demonstrated in Figure 9, except at 20 cycles/min, the contribution of the first synergy decreased while the contribution of the second synergy increased throughout the rehabilitation sessions. Notably, the masseter muscle was more dominant in the first synergy, whereas the temporalis muscle was more prominent in the second; these findings are consistent with the results presented in Figures 7 and 8.

Investigation of the Correlation Between Quantitative Game Performance and Muscle Synergy: To evaluate whether a significant correlation exists between the quantitative data derived from the game output and the muscle synergies across different sessions, the scatter plots of the contribution rates for the first and second synergies relative to the maximum game scores achieved at various speeds are presented in Figure 10.

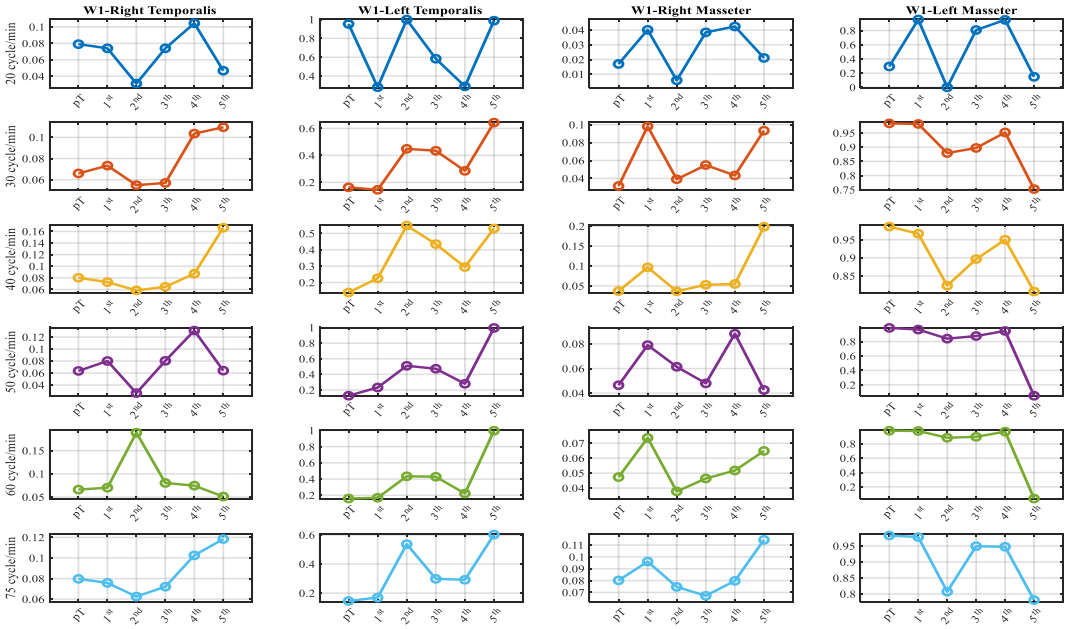


Figure 7. First synergy coefficients of the bilateral temporalis and masseter muscles during left-sided chewing. Each column represents the synergy coefficients at speeds of 20, 30, 40, 50, 60, and 75 cycles/min. pT (pre-train) denotes the session prior to the commencement of the game

The best-fit slope for the first synergy contribution rate was -0.34 ($p < 0.05$). Consequently, it can be concluded that the contribution rate of the first synergy decreased linearly and statistically significantly as the game scores increased throughout the therapeutic sessions.

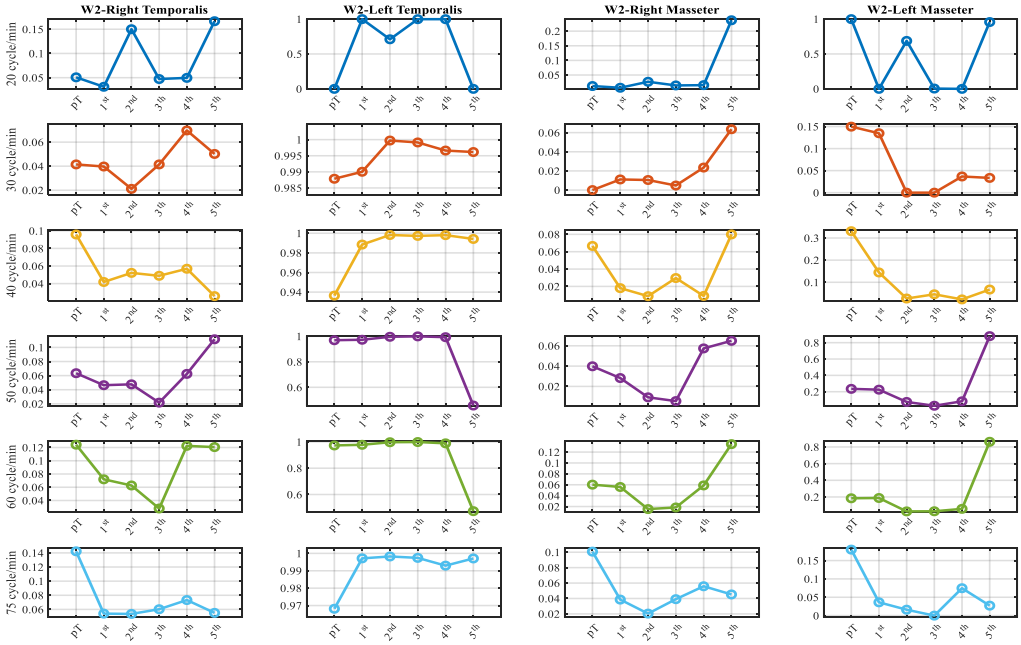


Figure 8. Second synergy coefficients of the bilateral temporalis and masseter muscles during left-sided chewing. Each column represents the synergy coefficients at speeds of 20, 30, 40, 50, 60, and 75 cycles/min. pT (pre-train) denotes the session prior to the commencement of the game

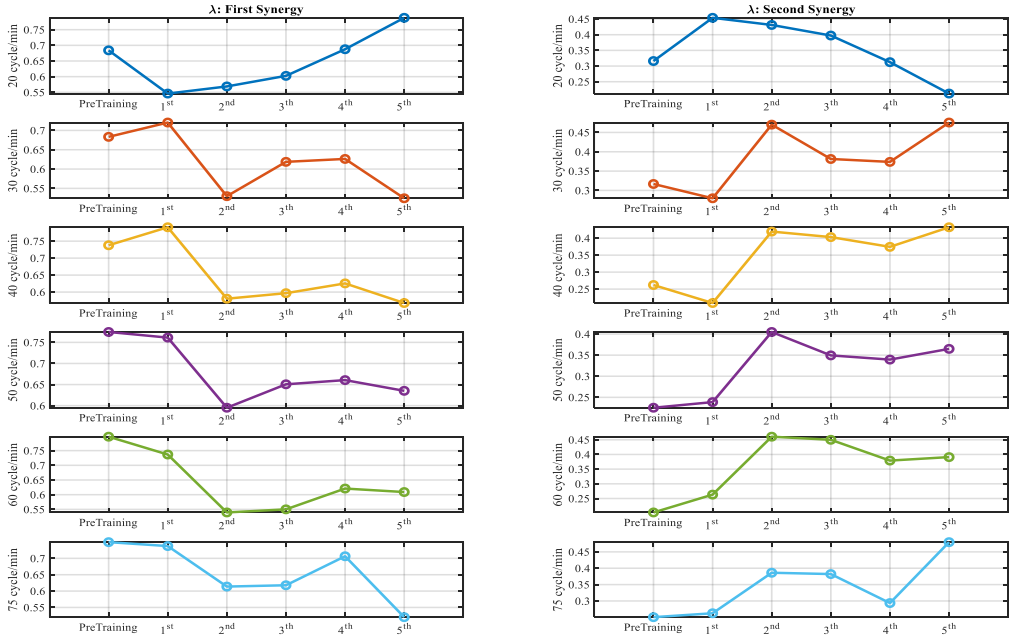


Figure 9. Variations in the contribution rates of the first (left) and second (right) synergies across various speeds during game-based biofeedback therapy sessions

For the second synergy, the best-fit slope was calculated as +0.34 ($p < 0.05$). This indicates that the contribution rate of the second synergy increased linearly and statistically significantly in correlation with increases in game scores during the biofeedback rehabilitation sessions. These findings from the scatter plot analysis and the evaluation of the linear relationship between the game scores and synergy contribution rates are consistent with the results illustrated in Figure 9.

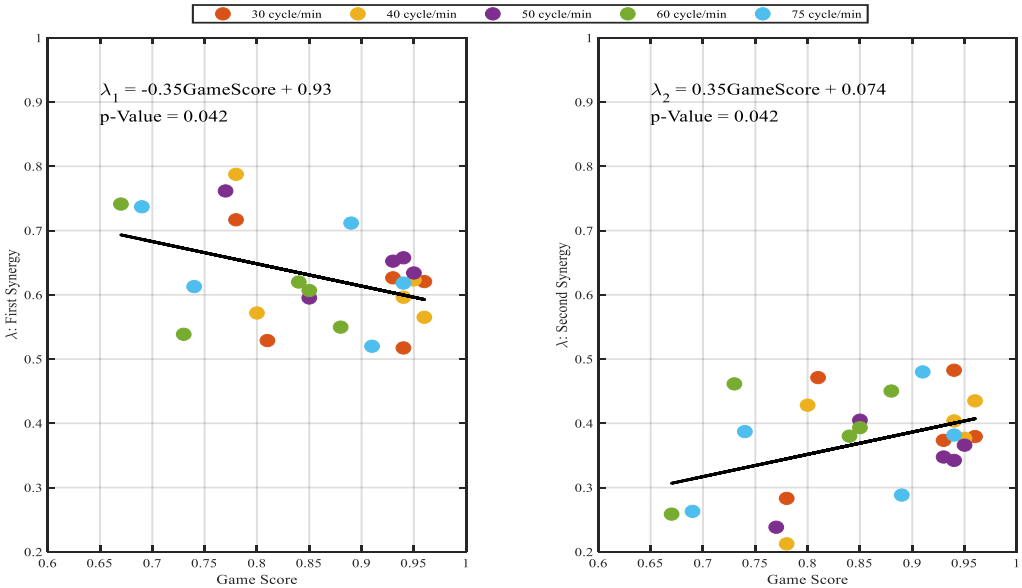


Figure 10. Scatter plots of the contribution rates for the first (left) and second (right) synergies relative to the maximum score achieved in the game across various speeds. The best-fit lines are indicated in black, with the corresponding slope, intercept, and p-value displayed within each plot

Discussion

Based on the results of this case study regarding the impact of the game on a stroke patient, both quantitative and qualitative improvements were evident throughout the therapeutic sessions. Following the second session, the patient expressed relative satisfaction with the facial appearance and chewing function of the left side (impaired) compared with the pre-treatment baseline. Quantitatively, the game scores and the ability to avoid "bombs" exhibited a consistent upward trend after each session.

The evolutionary trend of the two synergies—previously analyzed in healthy individuals—demonstrated a progressive improvement in the patient during the game-based sessions. Specifically, the contribution of the first synergy decreased over successive sessions, while the contribution of the second synergy increased. The reduction in the first synergy's contribution (primarily the masseter muscle) during biofeedback gaming aligns with the findings of the study (16), which investigated the efficacy of therapeutic methods for deep-bite malocclusion.

Consequently, the biofeedback game allows the patient to regain control of the chewing movement center, potentially mitigating the effects of spasticity (17) and thereby shifting the muscular workload. In this manner, the activity load on the left masseter muscle was reduced to achieve better coordination, while the workload was transferred to the temporalis muscle. This redistribution of activity resulted in reduced fatigue and more natural chewing patterns for the patient's impaired side.

A pivotal aspect of this study is the utilization of quantified muscle synergy data to generate biofeedback. Despite the high variability of raw EMG signals, synergy information provides a common control pattern for chewing movements that remains stable across a wide range of typical speeds (10).

Finally, integrating audiovisual feedback based on the patient's biological data enables a better understanding of physiological changes, thereby facilitating the acquisition of chewing skills. Given that the repetition of directed activities and patient motivation are critical in stroke recovery, engaging, challenging, and rewarding educational methods—including competitive elements—can significantly enhance rehabilitation motivation. Therefore, delivering therapy as a game, rather than through monotonous exercises, may help patients achieve goals that initially seemed unattainable. Furthermore, the use of real-time positive verbal feedback (e.g., "Good!", "Very Good!", "Excellent!") encourages patients to exert more effort and improve their performance [6]. Thus, the design of this biofeedback game emphasized competition and high levels of interaction. Such an approach may enhance patient awareness and motivation, potentially allowing them to modulate psychophysiological responses and achieve superior physiological functions, both consciously and unconsciously.

Limitations

A primary limitation of this study was the requirement for chewing gum. Constraints related to dental conditions, individual willingness to chew, and the rheological properties (such as hardness and adhesiveness) of the gum—particularly in patients with dental prostheses—may pose challenges across different patient populations. Therefore, the use of other food items or even simulated chewing is recommended for future studies.

Recommendations

Integrating real-time video feed of the patient's chewing movements with the game's digital avatar could be a promising future enhancement, potentially multiplying the efficacy of the biofeedback. Such an integration would benefit from combining the positive outcomes of traditional mirror-based rehabilitation with technology-driven therapeutic approaches [18, 19].

Conclusion

The findings of this case study underscore the significant potential of integrating game-based biofeedback into rehabilitation protocols for stroke patients. Furthermore, the results demonstrate the efficacy of this innovative approach in addressing specific challenges related to chewing function and highlight its broader applications in oral motor rehabilitation. This method is simple, safe, and cost-effective, eliminating the need for constant specialist supervision and clinical environments. Consequently, it serves as an empowering tool that can be highly effective in recovering from stroke-induced complications and advancing neurorehabilitation.

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This study was conducted and implemented in the Islamic Azad University of Mashhad with the code of ethics IR.IAU.MSHD.REC.1400.073.

Authors' Contribution

Project design and ideation: Marzieh Allami Sanjani, Ehsan Tahami

Providing financial resources for the project: Marzieh Allami Sanjani

Scientific and executive support of the project:

Marzieh Allami Sanjani, Ehsan Tahami
Providing equipment and statistical sample: Marzieh Allami Sanjani, Ehsan Tahami, Payam Sasannezhad
Data collection: Marzieh Allami Sanjani, Payam Sasannezhad
Analysis and interpretation of the results: Marzieh Allami Sanjani, Ehsan Tahami, Gelareh Veisi, Payam Sasannezhad
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Manuscript preparation: Marzieh Allami Sanjani, Ehsan Tahami, Gelareh Veisi, Payam Sasannezhad
Specialized scientific evaluation of the manuscript: Marzieh Allami Sanjani, Ehsan Tahami, Gelareh Veisi, Payam Sasannezhad
Confirm the final manuscript to be submitted to the journal: Marzieh Allami Sanjani, Ehsan Tahami, Gelareh Veisi, Payam Sasannezhad
Maintaining the integrity of the study process from the beginning to publication, and responding to the reviewers' comments: Marzieh Allami Sanjani, Ehsan Tahami, Gelareh Veisi, Payam Sasannezhad

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Conflict of Interest

The authors did not have a conflict of interest.

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