Investigating the Effect of Cable-Driven Assistance on Wrist Abduction-Adduction in a Serious Game

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Summary

Carpal tunnel syndrome (CTS) is a common cumulative trauma disorder that affects wrist function, often requiring rehabilitation to restore mobility and strength. This study explores the integration of a serious game and a cable-driven wearable device to enhance wrist rehabilitation. A block-placing game was developed, incorporating radial and ulnar deviation movements. A wearable wrist assistive device provides external force through a cable-driven mechanism controlled by a microcontroller. A human experiment was conducted to assess the effect of lateral applied force on wrist motion and muscle activation. Results indicate that while the device does not provide significant direct assistance, it enhances performance in the serious game, suggesting its potential as an engaging rehabilitation tool. Future work aims to refine the device for improved assistance and integrate machine learning to personalize rehabilitation protocols.

Introduction

CTS is a common occupational disorder characterized by wrist pain, numbness, and muscle weakness due to median nerve compression. It is often caused by high frequent repetitive motion. Rehabilitation typically involves repetitive wrist exercises, which can be monotonous and reduce patient compliance. Emerging serious games to rehabilitation protocols have become an effective approach, increasing engagement and motivation [1]. This study investigates whether a cable-driven wearable device can enhance serious game-based wrist rehabilitation by assisting wrist movements.

Methods

A cable-driven wrist assistive device was designed to provide external force assistance during wrist movements. The device consists of a lightweight wearable structure secured to the forearm and hand, with cables actuated by a motor system. A microcontroller unit (MCU) controls motor activation, sensor data acquisition, and real-time communication with the game interface. The serious game, designed for rehabilitation, required players to place virtual blocks by executing radial and ulnar wrist deviations.

Human-subject experiments were conducted with participants performing the block-placing task under two conditions: (i) without assistance and (ii) with cable-driven force assistance. Wrist joint angles, angular velocities, and EMG signals of key forearm muscles (Flexor Carpi Ulnaris, Extensor Carpi Ulnaris, Flexor Carpi Radialis, and Extensor Carpi Radialis Longus) were recorded. Performance metrics such as task completion time and accuracy were also evaluated. Data analysis focused on comparing muscle activation levels, wrist kinematics, and game performance between conditions to determine the effectiveness of the assistive device.

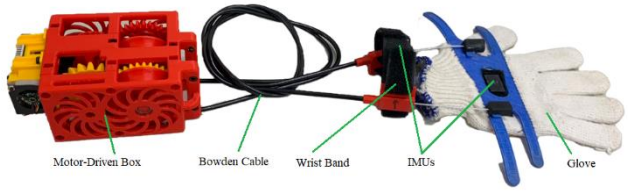

Figure 1: Cable-driven wrist assist device.

Results and Discussion

The preliminary study revealed that daily wrist movements primarily involved radial and ulnar deviation, with an average range of motion (ROM) of 21.5° ± 2.3° (radial) and 38.2° ± 3.1° (ulnar). This justified incorporating these movements into the serious game design.

In the serious game trial, participants significantly improved game performance with the assistive device. The average number of successfully placed blocks increased from 14.2 ± 2.8 (without assistance) to 18.7 ± 3.1 (with assistance) ($p < 0.05$). Task completion time was reduced by 12.5%, indicating enhanced movement efficiency.

EMG analysis showed no significant reduction in overall muscle activation when using the assistive device (Flexor Carpi Ulnaris: 112.4% ± 10.2% MVC vs. 109.7% ± 9.5% MVC, $p = 0.21$). However, participants demonstrated more consistent muscle activation patterns and reduced variability in wrist kinematics, suggesting improved movement control.

These results indicate that while the device did not significantly reduce muscle effort, it improved wrist movement stability and game performance, making it a promising supplementary tool for wrist rehabilitation.

Conclusions

This study demonstrates the feasibility of combining a serious game with a cable-driven wrist assistive device for CTS rehabilitation. Future work will focus on optimizing the device's assistance capabilities, reducing weight, and integrating machine learning algorithms for personalized rehabilitation strategies.

References

[1] Tăut, D., Pintea, S., Roovers, J. P. W., Mananas, M. A., & Băban, A. (2017). Play seriously: Effectiveness of serious games and their features in motor rehabilitation. A meta-analysis. NeuroRehabilitation, 41(1), 105-118.