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Original Research

Feasibility of an Exoskeleton-Based Interactive Video Game System for Upper Extremity Burn Contractures

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Abstract

Background: Burn contractures are common and difficult to treat. Measuring continuous joint motion would inform the assessment of contracture interventions; however, it is not standard clinical practice. This study examines use of an interactive gaming system to measure continuous joint motion data.
Objective: To assess the usability of an exoskeleton-based interactive gaming system in the rehabilitation of upper extremity burn contractures.
Design: Feasibility study.
Setting: Eight subjects with a history of burn injury and upper extremity contractures were recruited from the outpatient clinic of a regional inpatient rehabilitation facility.
Methods: Subjects used an exoskeleton-based interactive gaming system to play 4 different video games. Continuous joint motion data were collected at the shoulder and elbow during game play.
Main Outcome Measures: Visual analog scale for engagement, difficulty and comfort. Angular range of motion by subject, joint, and game.
Results: The study population had an age of 43 $\pm$ 16 (mean $\pm$ standard deviation) years and total body surface area burned range of 10%-90%. Subjects reported satisfactory levels of enjoyment, comfort, and difficulty. Continuous joint motion data demonstrated variable characteristics by subject, plane of motion, and game.
Conclusions: This study demonstrates the feasibility of use of an exoskeleton-based interactive gaming system in the burn population. Future studies are needed that examine the efficacy of tailoring interactive video games to the specific joint impairments of burn survivors.

Introduction

Contractures are impairments in joint range of motion that arise from a combination of skin, soft tissue. and bony pathology after burn injury. Burn contractures are common, with more than one-third of burn survivors developing contractures of large joints (elbow, shoulder, hip, and knee) and hands by hospital discharge [1,2]. Contractures have a significant impact on physical functioning, pain, and overall quality of life [3]. The effects are dependent on the joint(s) involved as well as the complex interplay of adjacent tissue impacting the motion of nearby joints [4]. Upper extremities are affected more often than the lower extremities and impact activities of daily living, fine motor tasks, and return to work [5,6].

The prevention and treatment of contractures includes splinting, early wound closure, and rehabilitation therapy, such as active and passive range of motion exercises. Inpatient rehabilitation interventions improve range of motion deficits from burn contractures [5]. Nonetheless, because contractures are common, difficult to treat, and impact function, novel approaches are needed. One reason for a paucity of contracture intervention data is that the measurement of continuous joint motion data is not standard clinical practice and uncommon in burn research.

Video gaming technology increasingly is used by burn clinicians and researchers. Initially, video games were used as a distraction technique and were shown to reduce pain during dressing changes and therapy [7-9]. On a neurophysiologic level, virtual reality (VR)

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significantly reduced brain activity in 5 areas associated with thermal-induced pain on functional magnetic resonance imaging [10]. With advances in video gaming technology, games are used commonly as an adjunct to traditional therapy, and therapists report that video games are therapeutic and engaging [11]. Nonetheless, few data exist to support its use in the burn population. In a prospective study in which the authors examined the effect of virtual reality on pain, there was no significant improvement in upper and lower extremity range of motion measured after sessions [8]. Studies in healthy, nonburn populations suggest its potential therapeutic benefit [12,13]. To date, no studies have examined continuous joint motion data in the burn population with use of an interactive gaming system for therapeutic purposes and the effect of different games used with the same gaming system.

The aim of this study was to assess the feasibility of an exoskeleton-based interactive gaming system designed for rehabilitation treatment of upper extremities in the burn population. The primary outcomes were: (1) system usability, assessed by subject reported qualitative measures and (2) measures of continuous joint motion data. To our knowledge, this study is the first to examine measures of continuous joint motion data by using an interactive gaming system for upper extremity burn contractures.

Methods

Subjects

Inclusion criteria included history of burn injury and burn-associated contractures of the upper extremity (elbow or shoulder). A convenience sample of subjects was recruited from the outpatient clinic of a regional inpatient rehabilitation facility. Subjects with open upper extremity and torso wounds that could be compromised by the padded straps of the exoskeleton were excluded. All study procedures were approved by the Institutional Review Board. All subjects provided written informed consent.

A total of 13 subjects were recruited, of whom 9 enrolled and 8 completed the study. One enrolled subject did not complete all gaming activities and therefore was excluded from analysis. Active range of motion of the shoulder and elbow joints was measured by goniometer before game play. Range of motion impairments were categorized as mild, moderate, or severe on the basis of previously published classification scheme for burn contractures [1]. For subjects with bilateral upper-extremity burns, the side most severely affected was tested.

Gaming System

The study used an exoskeleton-based interactive gaming system, the ArmeoSpring system (Hocoma AG, Volketswil, Switzerland; approximate cost $60,000 USD). The device is 3.5 m $\times$ 3.5 m $\times$ 2 m. The manufacture provides a yearly maintenance program for the device. The system works with a dedicated computer and monitor to display the games. The device is on casters and therefore easily transportable to different spaces. System software allows the exoskeleton to act in analogous capacity to a computer mouse; therefore, any commercial game played with a mouse can be adapted for use with the ArmeoSpring. The system is an adjustable arm orthosis with demonstrated feasibility in the stroke [14], spinal cord injury [15], and multiple sclerosis [16] populations. Previous research has demonstrated reliability of the system in a nonburn population [17]. When using the system, one's upper extremity is fit onto the device with Velcro straps at the forearm and upper arm (Figure 1). To ensure the appropriate fit of the exoskeleton to the subject, the length of each exoskeleton segment is adjusted to fit arm length. The system passively counterbalances the weight of the exoskeleton by using adjustable springs.

The ArmeoSpring system is equipped with 6 potentiometers and 1 grip-force sensor. These sensors collect continuous data while subjects play video games that are integrated with the system. The potentiometers are positioned on the exoskeleton to estimate the position and orientation in space of the mechanical segments of the exoskeleton. Movements of the exoskeleton are used to control specific actions in each video game whereby the exoskeleton acts as a joystick.

With subject comfortably positioned in the system, the workspace for interactive gaming is calibrated. During calibration and game play, subjects were instructed to maintain their backs against the back of the chair to minimize torso movement. The subjects are asked to move the arm to the far ends of the workspace with reasonable level of comfort. The coordinates of these positions are recorded by the ArmeoSpring system software to determine the virtual workspace. The

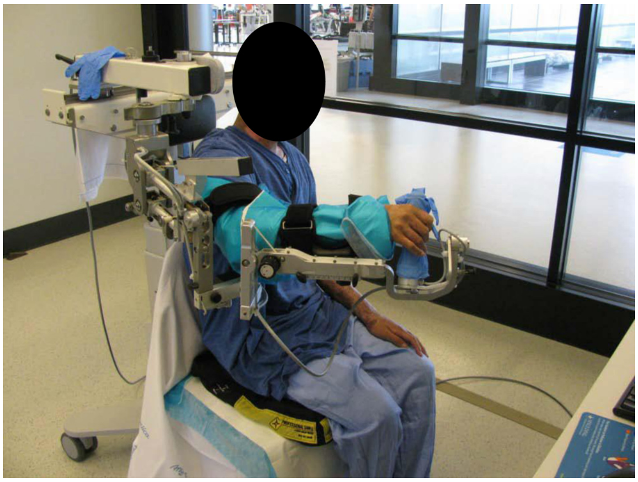

Figure 1. Study subject during ArmeoSpring training (Hocoma).