Applied Ergonomics 58 (2017) 190–197

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Muscle loading in exoskeletal orthotic use in an activity of daily living

Melissa M. White, Olivia N. Morejon, Shijing Liu, Mei Y. Lau, Chang S. Nam, David B. Kaber*

Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University, Raleigh, NC, USA

ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form
16 June 2016
Accepted 21 June 2016

Keywords:
Surface electromyography
Stroke rehabilitation
Orthotics

ABSTRACT

Strokes are the leading cause of major adult disability with up to 85% of U.S. survivors experiencing hemiparesis. Physical characteristics of upper-extremity exoskeletal orthotics, used in stroke rehabilitation, were evaluated in terms of performance of activities of daily living (ADL), perceived exertion, and muscle load. Simulated orthotic weight distributions, with total extremity loads of 0.81 kg, 1.25 kg and 2.27 kg, were evaluated along with a 0 kg control condition. Response measures included average shoulder/elbow muscle surface electromyography (sEMG) signal amplitude, quality of task completion and total rest time during performance, and Borg CR-10 scale ratings. Device weight distribution, or imposed shoulder moment, was found to have a significant effect on biceps brachii and anterior deltoid activation levels, percent task completion, total rest time, and perceived exertion ratings. Results suggest that heavier upper-extremity orthotics could cause undesirable effects in terms of muscle loading, performance and exertion; such adverse effects could potentially lead to lack of use during patient's rehabilitation.

1. Introduction

Current research on stroke rehabilitation indicates a need for patient-specific therapy, as rehabilitation can continue throughout a patient's life and can be labor intensive and costly. Research in this area has indicate no general optimal approach (Lo and Xie, 2012). These observations are of concern as strokes are the leading cause of major adult disability in the United States (U.S.) with the majority of survivors suffering chronic motor impairment, which can lead to physical, psychological, and social impacts on survivors (Go et al., 2014). At present, 800,000 strokes occur annually in the U.S.; however, this number is predicted to more than double over the next 40 years with the largest increase among the elderly (aged ≥75 years) and minority groups (Howard and Goff, 2012; Murphy et al., 2013). Up to 85% of the more than 7 million stroke survivors in the U.S. experienced hemiparesis, resulting in motor control impairment of an upper-extremity following stroke. Between 55 and 75% of survivors continued to experience poor dexterity in their upper-extremity (Franceschini et al., 2012; Kwakkel et al., 2003; Wolf et al., 2006). With many stroke patients suffering from hemiparesis, it is difficult for them to successfully perform many ADLs, with self-care tasks, including bathing and dressing, being the most difficult to perform (Capistrant et al., 2013; Grimby et al., 1998; van Meulen et al., 2014).

Starting therapy promptly, intensive therapy, task-based exercises, and physiotherapy have been found to contribute to motor recovery in stroke patients (Donnan et al., 2008; Teasell and Kalra, 2004, 2005). However, such rehabilitation poses high labor demands, which are expected to increase with the increasing number of stroke patients. Exoskeletal orthotic devices can allow patients to pursue rehabilitation without a therapist and provide intensive therapy for longer durations (Huang and Krakauer, 2009). Such devices are designed to operate in conjunction with a patient's limb movements, attaching at multiple locations. Many devices for upper-extremity rehabilitation are commercially available; however, few are for personal use.

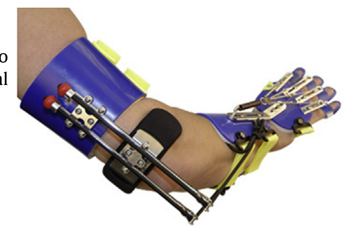
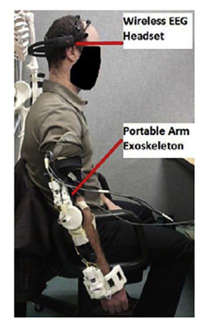
The focus of this study was to assess the impact of physical characteristics of exoskeletal orthotic devices designed for personal use by stroke patients on upper-extremity rehabilitation or ADL performance. Based on a literature search, three commercial or research exoskeletons were identified and chosen as models for this study (Table 1). The three exoskeletons were simulated by placing weights along a subject's arm at specific locations to emulate the different devices.

Like stroke victims experiencing hemiparesis, amputees can make use of exoskeletons to aid in the completion of ADLs. For both

* Corresponding author. Edward P. Fitts Department of Industrial & Systems Engineering, North Carolina State University, 400 Daniels Hall, 111 Lampe Dr., Raleigh, NC 27695-7906, USA.
E-mail address: dbkaber@ncsu.edu (D.B. Kaber).

http://dx.doi.org/10.1016/j.apergo.2016.06.010
0003-6870/

Table 1
Current research devices and products on the market for self-use in upper-arm rehabilitation.

Device	Researcher or company	Weight (kg)	Description	Pictures
myoPro	Myomo Inc., Cambridge, MA	1.25	A one-degree of freedom portable brace enabling flexion and extension at a patient's elbow joint (Lo and Xie, 2012). The device uses EMG control software to monitor patient movements and muscle activities. It does not stimulate patient muscles. The brace helps paralyzed or disabled persons perform ADLs involving reaching and lifting.	 (www.myopro.com)
SaeboReach	Saebo Inc., Charlotte, NC	2.27	This device supports both the affected wrist and elbow. The product combines wrist flexion technology with an above-elbow cuff enabling dynamic elbow extension. The device also positions the wrist and fingers into extension in order to achieve functional activities using a purely mechanical system. The device maximizes hand and arm movement recovery through repetitive, task oriented activities specifically those focusing on grasp and release activities.	 (www.saebo.com)
Brain computer interface (BCI) research device	MENRVA Group, Simon Fraser University	0.81	This device uses a BCI system to allow for personal rehabilitation after a stroke. Electrical and chemical changes in the brain are detected by the system. In specific, electroencephalography (EEG) is used as a non-invasive technique to detect electrical changes (Webb et al., 2012).The system identifies electrical and chemical activity patterns that are associated with specific thought patterns. A trigger is sent to a control device if a pattern is detected.	 (Webb et al., 2012)

populations, the exoskeleton weight is perceived as an external load on the body due to the lack of an intimate connection between the device and body. The exoskeleton's weight and weight distribution may cause strain and discomfort (Weir, 2004). Strain over an extended period can lead to muscle fatigue, defined as "any reduction in the ability to exert force in response to voluntary effort" (Chaffin and Andersson, 2006). Fatigue has been found to increase the risk of musculoskeletal problems such as red ragged fibers, trigger points, and impaired blood flow (Visser and van Dieën, 2006); fatigue also shares a link with musculoskeletal disorders (MSDs) such as thoracic outlet syndrome and tendinitis (Armstrong et al., 1993; Bridger, 2003; Chaffin and Andersson, 2006). Davidson (2002), in a survey of 70 amputees, found that 56% wore prosthetic devices "once in a while" or "never." They also observed that 85% of prosthesis users experience high levels of pain, including phantom pain, phantom sensation, stump pain, tingling, and poorly fitted prosthesis pain. Many respondents (42%) stated the pain interfered with their ability to wear a prosthesis. Abandonment of prostheses was found to be due to limited usefulness, the weight of the prosthetic device, stump socket discomfort, decreased shoulder motion, stump pain, and loss of non-dominant limb. McFarland et al. (2010) examined amputated veterans who had experienced an upper limb amputation and found that 30% of Vietnam veterans completely abandoned their prosthetic with 65% of those veterans reporting a cumulative trauma disorder (CTD). Taken together, these studies suggest a correlation between usage of exoskeletons and musculoskeletal loading, fatigue and disorders.

Previous work has yet to study impacts of exoskeleton weight distribution on measures for activity performance, biomechanical loading/muscular use, or perceived exertion. This study evaluated the effects of simulated device physical characteristics (weight and weight distribution) of exoskeletal orthotic devices used in stroke rehabilitation on success in ADL performance, muscular loading, and perceived exertion. This collection of measures was expected to provide insight on the potential for muscular fatigue as a result of exoskeleton use as well as the potential for MSDs.

2. Methods

2.1. Participants

Ten elderly people (five male, five female) with a mean age of 83 years (SD = 9.15) who self-identified to be in overall good health with no known history of strokes or shoulder trauma/disease participated in the experiment. Recruiting was limited to persons over 55 years of age as prior research shows that the risk of ischemic stroke and intracerebral hemorrhage doubles each decade after age 55 (Ariesen et al., 2003; Brown et al., 1996; Carandang et al., 2006). All participants resided in a senior living community in North Carolina at the time of the experiment. In order to simulate minor motor impairment/disability from a stroke in these healthy participants, the experiment required completion of the ADL using the non-dominant arm. Self-reported left-hand dominant individuals were excluded as prior research has shown little difference in strength between dominant and non-dominant hands for