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Original Research

The Effect of Propulsion Style on Wrist Movement Variability During the Push Phase After a Bout of Fatiguing Propulsion

Lisa A. Zukowski, PhD, Evangelos A. Christou, PhD, Orit Shechtman, PhD, OTR/L, Christopher J. Hass, PhD, Mark D. Tillman, PhD

Abstract

Background: Wheelchair propulsion has been linked to overuse injuries regardless of propulsion style. Many aspects of the arcing (ARC) and semicircular (SEMI) propulsion styles have been compared, but differences in intracycle movement variability, which have been linked to overuse injuries, have not been examined.
Objective: To explore how ARC and SEMI affect changes in intracycle wrist movement variability after a fatiguing bout of propulsion.
Design: Repeated measures crossover design.
Setting: Wheelchair rollers and wheelchair fatigue course in a research laboratory.
Participants: Twenty healthy, nondisabled adult men without previous wheelchair experience.
Interventions: Participants learned ARC and SEMI and used each to perform a wheelchair fatigue protocol.
Main Outcome Measurements: Thirty seconds of propulsion on rollers were recorded by motion-capture cameras before and after a fatigue protocol for each propulsion style on 2 testing days. Angular wrist orientations (flexion/extension and radial/ulnar deviation) and linear wrist trajectories (mediolateral direction) were computed, and intracycle movement variability was calculated as standard deviations of the detrended and filtered values during the push phase beginning and end. Paired samples *t* tests were used to compare ARC and SEMI based on the percent changes from pre- to postfatigue protocol.
Results: Both propulsion styles resulted in increased intracycle wrist movement variability postfatigue, but observed increases did not significantly differ between ARC and SEMI.
Conclusions: This study evinces that intersubject variability exceeded average changes in intracycle wrist movement variability for both propulsion styles. Neither propulsion style resulting in a greater change in intracycle movement variability may suggest that no single propulsion style is ideal for everyone. The large intersubject variability may indicate that the propulsion style resulting in the smallest increase in intracycle movement variability after a fatiguing bout of propulsion may differ for each person and may help explain why wheelchair users self-select to use different propulsion styles.

Introduction

More than 50% of wheelchair users eventually develop wrist pain [1,2]. Manual wheelchair propulsion is a highly repetitive task that is believed to be a contributing factor to the development of wrist overuse injuries. Arcing (ARC) and semicircular (SEMI) styles (Figure 1) [3] are 2 of the most common wheelchair propulsion styles and are known to differ in terms of wrist kinematics [4-6]. On the basis of prefatigue kinematic differences between ARC and SEMI and the fact that wheelchair propulsion in general changes with fatigue [7,8], the differences between ARC and SEMI may be exacerbated with fatigue. The exacerbated differences could be specifically attributable to greater intracycle wrist movement variability, which could contribute to wrist overuse injuries.

Indeed, the relationship between overuse injuries of the wrist and patterns of intracycle joint movement variability has been established in other populations but has not been explored in the manual wheelchair literature. The nature of the relationship between increased movement variability and overuse injuries, whether it increases or decreases the risk of developing an overuse injury, is still contested, however, and may possibly depend on the task or even on the individual. Nevertheless, increased intracycle wrist joint movement variability after fatigue may differ between ARC and

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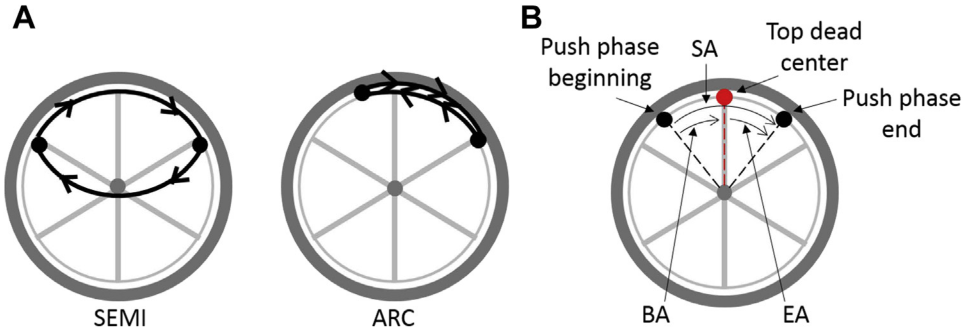

Figure 1. A depiction of (A) the hand trajectory using SEMI and ARC (adapted from Sisto [3]) and (B) how SA, BA, and EA were defined. SEMI = semicircular; ARC = arcing; SA = stroke angle; BA = begin angle; EA = end angle.

SEMI and may be a potential mechanism by which wheelchair propulsion contributes to wrist overuse injuries.

ARC and SEMI are associated with numerous advantages and disadvantages. Pushrim forces have not been shown to differ [9], yet SEMI uses a longer propulsive phase [4,5,9-11], slower cadence [4,9,10], increased wrist range of motion [4,5], and less extreme wrist ulnar deviation [6]. Conversely, ARC is more mechanically efficient [4] and requires less muscular activity [5]. Despite the many prefatigue differences between the styles, to date, no study has examined how ARC and SEMI change with fatigue, when the wrist is more susceptible to developing an overuse injury.

As stated previously, the impact of increasing movement variability is contested and may depend on the task or even on the individual, but one theory is that movement variability can be interpreted as detrimental noise from the nervous system [12,13]. As an individual fatigues, the nervous system produces more noise, resulting in an increase in movement variability. Typically with repetitive movements, as muscular fatigue sets in, compensations or reorganizations of the movement occur, including decreases in range of motion, movement velocity, and muscle force [14,15]. In highly constrained, repetitive movements, like wheelchair propulsion, where the hand is forced to follow along the rim during the propulsive portion of the push, some reorganization may occur, but peak pushrim forces have been shown to increase rather than decrease as wheelchair users fatigue [7]. Therefore, a reorganization of movement, including increased intracycle wrist movement variability, combined with increased forces transmitted through the wrist could put wheelchair users at high risk of developing wrist overuse injuries of the ligaments and tendons.

Wheelchair propulsion is a highly repetitive movement, with typical wheelchair users completing at least 2500 pushes daily [16], that imposes large loads by ergonomic standards and frictional forces on the ligaments and tendons of the wrist. These upper extremity structures can adapt to repetitive movements through a process of minor tissue damage and remodeling without injury. Specifically, small amounts of variability can be helpful in distributing stresses over a greater number of tissues and allowing for more reparative remodeling time for all involved structures [17]. When the magnitude or the direction of the stress suddenly changes, as with increased movement variability, however, the rate of remodeling cannot always keep pace with the rate of microdamage to the tendons and ligaments [12,18], resulting in permanent damage and an overuse injury. Ergonomics literature has in fact reported a relationship between the presence of acute pain and an increase in movement variability while performing a repetitive arm movement [19]. Although the impact of increasing movement variability may change depending on the task or even on the individual, increased wrist movement variability during wheelchair propulsion may be a potential mechanism that induces pathologic levels of inflammation and tissue damage of the tendons and ligaments of the wrist [1,20,21]. Therefore, this study explored how propulsion styles affect changes in intracycle wrist movement variability after a fatiguing bout of propulsion. We hypothesized that SEMI and ARC would exhibit comparatively different increases in linear and angular intracycle wrist motion variability after the fatigue protocol.

Methods

Participants

Twenty healthy, nondisabled adult men (20.4 $\pm$ 1.2 years, 83.9 $\pm$ 13.9 kg, 178.1 $\pm$ 7.1 cm) without previous wheelchair experience volunteered to participate. This sample size was determined on the basis of a power analysis with a power of 0.80 and a 2-sided alpha of 0.01 (adjusted for multiple comparisons) using effect sizes from previously reported differences between ARC and SEMI [5,9]. Previous research shows that wheelchair users and nondisabled individuals exhibit similar wrist kinematics, kinetics, and power shifts during a fatiguing protocol [8,22,23]. Therefore, nonwheelchair users were recruited to prevent previous experience in using a wheelchair from affecting the results. Individuals were