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Shoulder pain and time dependent structure in wheelchair propulsion variability

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ABSTRACT

Manual wheelchair propulsion places considerable repetitive mechanical strain on the upper limbs leading to shoulder injury and pain. While recent research indicates that the amount of variability in wheelchair propulsion and shoulder pain may be related. There has been minimal inquiry into the fluctuation over time (i.e. time-dependent structure) in wheelchair propulsion variability. Consequently the purpose of this investigation was to examine if the time-dependent structure in the wheelchair propulsion parameters are related to shoulder pain. 27 experienced wheelchair users manually propelled their own wheelchair fitted with a SMARTWheel on a roller at 1.1 m/s for 3 min. Time-dependent structure of cycle-to-cycle fluctuations in contact angle and inter push time interval was quantified using sample entropy (SampEn) and compared between the groups with/without shoulder pain using non-parametric statistics. Overall findings were, (1) variability observed in contact angle fluctuations during manual wheelchair propulsion is structured ($Z=3.15; p<0.05$), (2) individuals with shoulder pain exhibited higher SampEn magnitude for contact angle during wheelchair propulsion than those without pain ($\chi^2(1)=6.12; p<0.05$); and (3) SampEn of contact angle correlated significantly with self-reported shoulder pain ($r_{s\,(WUSPI)}=0.41; r_{s\,(VAS)}=0.56; p<0.05$). It was concluded that the time-dependent structure in wheelchair propulsion may provide novel information for tracking and monitoring shoulder pain.

1. Introduction

Nearly 90% of the 3.6 million wheelchair users in the United States use a manual wheelchair for their mobility needs [1]. The use of a manual wheelchair places considerable mechanical strain on the upper limbs. Unfortunately, the human upper limb is not suited for such repetitive loading. The repetitive loading predisposes manual wheelchair users (mWCUs) for upper limb pathology. Indeed it has been shown that up to 70% of mWCUs report upper limb pain [2–5]. Furthermore, even in mWCUs who do not report pain, there is evidence of degenerative changes in the shoulder [6] suggesting that it is just a matter of time before these asymptomatic individuals will experience pain.

Upper limb pain in mWCUs has been linked to difficulty performing activities of daily living [5], decreased physical activity and decreased quality of life [7]. Overall, any loss of upper limb function due to pain adversely impacts the independence and mobility of manual wheelchair users. It has been speculated that a decrease in independence and mobility results in greater health care costs and an increased risk for secondary morbidity (cardiovascular disease, obesity, etc.) [8, 9].

Although it has been proposed that propulsion biomechanics are related to shoulder pain in MWCUs, evidence is inconclusive [10]. Average spatiotemporal parameters of wheelchair propulsion (e.g. contact angle and push time) do not distinguish between those with and without pain. However, recent research indicates that spatial-temporal variability in wheelchair propulsion mechanics (e.g. push time and peak force during push) is related to shoulder pain [11]. This association between motor variability and pain is consistent with observations from occupation biomechanics and human motor control literature [12–15]. Although promising, a limitation of this research [11], is that it has only focused on the amount of variability in wheelchair propulsion. This approach seemingly ignores fluctuations over time (i.e. time-dependent structure) inherent in physiological output [16].

Based on the tenets of the loss of complexity hypothesis of aging [16], it has been theorized that the time-dependent structure of motor output is a marker of physiological complexity and provides novel information concerning the health of the musculoskeletal system [14,17]. Specifically, it has been proposed that musculoskeletal injury leads to fluctuations in movement that are

Abbreviations: SampEn, Sample Entropy; MWCUs, Manual wheelchair users; WUSPI, Wheelchair user shoulder pain index; VAS, Visual analog scale.

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Table 1
Demographic information. Comparison of demographic information between the groups with and without pain. Statistically significant group differences were observed for the pain scores between the groups ($p<0.05$). No significant group differences was observed between the groups in age, body weight, gender and experience using wheelchair.

Demographic variables	Pain (n=13) Mean(SD)	No Pain (n=14) Mean(SD)
Age (Yrs)	28.23(12.52)	21.21(4.92)
Body weight (LB)	164.50(56.39)	131.17(36.96)
Experience using wheelchair (Yrs)	15.84(11.25)	13.64(5.15)
Gender	6/7	6/8
(F/M)	Spina Bifida(n=5)	Spina Bifida (n=4)
	T6-T12 (n=5)	T6-T12 (n=6)
	L1-L4 (n=1)	L1-L4 (n=1)
	Amputee- double (n=1)	Amputee-single (n=1) Arthrogryposis
Injury demographics	Sacral agenisis (n=1)	(n=1) C7 (n=1)
WUSPI*	22.84(21.27)	3.28(5.02)
VAS*	4.24(2.8)	0.36(0.96)

* $p<0.05$

more structured. Two widely reported methods to measure the structure in fluctuation of movements are approximate entropy and sample entropy (SampEn) [18]. For instance, Tochigi et al., 2012, [19], utilized SampEn to analyze the structure of variability in gait in individuals with knee osteoarthritis with and without pain. Consistent with the loss of complexity hypothesis, it was reported that the pain group had significantly lower SampEn values when compared to those without pain. In a similar fashion, researchers have successfully employed approximate entropy to study the gait pattern related to anterior cruciate ligament (ACL) injury [20] and reported lower approximate entropy values in the knee with ACL deficiency compared to the healthy knee.

Presently there is no information regarding the time-dependent structure of variability in the context of shoulder pain in mWCUs. Consequently the purpose of this investigation was to examine if the time-dependent structure in wheelchair propulsion parameters are related to shoulder pain.

The goals of this investigation were twofold, (H1) to determine whether the time-dependent structure observed in wheelchair propulsion variability is structured, and (H2) to determine if individuals propelling a manual wheelchair with shoulder pain will demonstrate lower degree of time-dependent structure in fluctuations in their wheelchair propulsion parameters than those without shoulder pain. To test these hypotheses, two wheelchair propulsion parameters were analyzed, namely, contact angle and inter push time interval.

2. Methods

2.1. Participants

Wheelchair propulsion data from 27 experienced adult mWCUs was analyzed for this study. This dataset is a subset of data collected for a larger study focusing on wheelchair propulsion and shoulder pain [11]. Inclusion criteria for this secondary analysis were (1) more than one year of manual wheelchair experience; (2) between 18–64 years of age; and (3) trials data containing at least 106 wheelchair propulsion cycles. All procedures were approved by the local institutional review board at University of Illinois, Urbana-Champaign.

Upon arrival to the laboratory, the data collection procedures were thoroughly explained and any questions the participants had regarding the protocol were addressed. Participants were informed that participation in the study was voluntary. The participants then provided their written informed consent and demographic information (Table 1).

The participants were categorized as belonging to pain/no pain group based on the self-reported shoulder pain status (“Yes”/”No”). Participants also rated their current level of shoulder pain for each shoulder using a 10 cm visual analog scale (VAS) [21]. A VAS score of zero indicated no shoulder pain and higher score indicate greater shoulder pain at the time of testing. Participants also rated their shoulder pain using the wheelchair user’s shoulder pain index (WUSPI) [22]. WUSPI is a 15-item questionnaire. Each item is rated between 0 and 10, with 0 representing no interference with daily living functional activities and 10 representing complete interference with functional activities during the past week due to shoulder pain. The total score is the sum of scores of all the 15 items put together. Total score ranges from 0 (no pain)-150 (maximum limitations to daily activities due to pain) [22].

2.2. Data collection and instrumentation

2.2.1. Kinetics

On completion of the informed consent procedures, each participant’s wheelchair was fitted bilaterally with SMARTwheels (Three Rivers Holdings, LLC, Mesa, AZ, USA) and secured to a single roller dynamometer system using a four-point tie-down system and a flywheel system [23]. The SMARTwheels measures three-dimensional forces and torques applied to the push rim. Participants were provided sufficient time to acclimate themselves with the dynamometer setup prior to the actual trial. Participants were asked to propel at constant speed of 1.1 m/s for 3 min [24,25]. A speedometer was used to provide real-time feedback to the participants during the three minute propulsion. The SMARTwheel data was post-processed using a custom developed MATLAB routine.

2.3. Data post-processing

SmartWheel data were collected at a sampling rate of 100 Hz and digitally filtered with an eighth-order, zero-phase, low-pass Butterworth filter with 20 Hz cutoff frequency [10]. The start and end of a propulsion cycle was defined when the push-rim moment (Mz) was above and below 1 Nm respectively [26]. To reduce the transient effects, data belonging to the first five propulsion cycles were not included for this analysis [27]. For consistency, the number of data cycles analyzed for each participant was maintained constant at 100 cycles (i.e. starting from the 6th cycle to 105th cycle of a SmartWheel data, Fig. 1(a)). The contact angle and resultant forces at hand-rim were extracted for each participant (Fig. 1(b)). Following this, the inter push time interval between peak resultant force between pushes were extracted (Fig. 1(b)). Thus, this process yielded two time series from each participant wheelchair