Driving on rough terrain: Wheelchair control and brain activity

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Mobility skills, analysis and domains regarding gait/ambulation and coordination are well defined for able-bodied individuals (Lord et al., 2013; Psotta and Abdollahipour, 2017) but are lacking in those who use wheelchairs or have a physical disability or motor-impairment. Providing a manual wheelchair for people who need it is important, as it leads to numerous positive social and autonomous impacts – however, it falls short of what may be needed within disability communities. Without adequate wheelchair provision and mobility skills training, users face limitations in social equality resulting in a reduced quality of life for many disabled individuals continues to persist (LaPlante and Kaye, 2010; Martins et al., 2016; van der Woude et al., 2006). Furthermore, the outcome measures that are defined to assess mobility and ambulation for wheelchair user are ill-defined and heterogenous impacting the assessment of wheelchair skill training (Kilkens et al., 2003; Sol et al., 2017). Few systems consider the effort required to be 1) clear domains/terrains defining and testing important aspects of wheelchair mobility, and 2) a singular, objective, and trackable outcome measure detailing potential skill acquirement/achievement and improvement.

A wide variety of wheelchair training guidelines and resources are available for manual wheelchair users, however, there is little consensus to the most important aspects of training and often evaluate specific skills rather than broad measurable domains/categories of mobility skill (Kirby et al., 2004; Morgan et al., 2017). Perhaps the most frequently used protocol is the Wheelchair Skills Training (WST), which engages training on less typical skills (Kirby et al., 2004; MacPhee et al., 2004). Although, the WST program encourages training in some of the most important wheelchair skills defined by both clinicians and actual wheelchair users, which can include several kinds of obstacle maneuverability (Morgan et al., 2017). Within this study, while we assess wheelchair skills on terrain maneuverability, we demonstrate a methodology that can be used to combine assessments of specific skills into broader domains important to wheelchair skill.

Determining an outcome measure to assess wheelchair skills training/proficiency is a complex issue, as the current methods are inconsistent and heterogenous (Kilkens et al., 2003; MacPhee et al., 2004). At the simplest level, performance/skill acquirement assessment can rely on subjective means (Cain, 2004), such asthe self-rating for task difficulty. However, these methods also rely on retrospective assessment recall/memory and or interfere with the task compared to a continuous assessment (Mehta and Parasuraman, 2013; Tattersall and Foord, 1996; Yeh and Wickens, 1984). Some outcome measures are variable, and are often task-specific and dependent making comparability between tasks/wheelchair domains difficult (i.e., performance timing, speed, errors etc.) (MacPhee et al., 2004), or requiring external evaluator expertise. Cognitive Workload has been utilized as a valid, and sensitive measure for skill acquisition and task difficulty, and can be measured by physiological and neurophysiological means (Brookings et al., 1996; Fournier et al., 1999; Gevins et al., 1995; Miller, 2001). However, as wheelchair users are often plagued by secondary medical issues related to inactivity (i.e., cardiovascular issues), neurophysiological measures of cognitive workload may be more appropriate as a comparable marker for assessment of the performance and underlying effort to achieve wheelchair skill (Consortium for Spinal Cord Medicine, 2008; Joshi et al., 2019, 2020; van der Woude et al., 2006). Therefore, within this study we assess wheelchair skills on specific obstacles/domains through functional Near Infrared Spectroscopy (fNIRS) and demonstrate comparability and objectivity of these outcome measures between wheelchair skill terrains.

As part of a larger project, twenty-nine novice wheelchair users (n = 29; 31.8 ± 9.0 yrs) completed a wheelchair obstacle course designed to assess simple propulsion, obstacles/terrain that require power/strength (high friction and incline ramp), and obstacles that required more control (curbs and weaving) while wearing an fNIRS device to monitor prefrontal cortical activity/cognitive workload. A pseudorandomized predetermined circuit order (balanced for clockwise and counterclockwise directions) per participant was conducted to reduce a repetitive learning effect while a self-selected pace (±5s) was determined to account for fatigue, asymmetrical strain, and and learning. Rest periods prior to the start of each circuit included randomly ranged between 30-50s.

The data followed a two-stage processing/analysis method (found in Joshi et. al 2020), where the first stage (Subject-Level) analysis generated Beta values through Autoregressive General Linear Modeling that indicated increased Oxygenated Hemoglobin (HbO) for each terrain (Joshi et al., 2020). The 2nd stage (Group-Level) analysis employed a mixed effects model with repeated measures, treating subject as a random factor drawn from a larger population, while the fixed effects were conditions of terrain. These methods are determined to resolve high frequency noise, motion artifacts, cardiovascular effects, and signal drift using an autoregressive model (Barker, Aarabi, & Huppert, 2013).

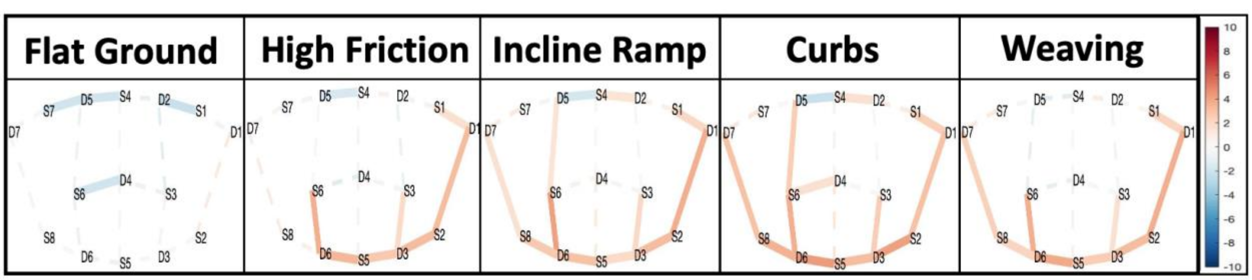

Figure 1. Functional Near Infrared Spectroscopy Results of the Prefrontal Cortex (PFC) for novice participants within different wheelchair terrains. Red regions indicated increased Oxygenated Hemoglobin (HbO), while blue regions indicated decreased HbO amplitudes. Each terrain revealed a unique PFC activity profile, with Flat Ground being the simplest, requiring the least cognitive resources. (FDR corrected, q<0.05)

Results indicate that each specialty wheelchair terrain had higher Prefrontal Cortex activity than the simplest flat ground. Overall, results suggest that cognitive workload profile can be tracked with wheelchair expertise, assistive devices, or other subject or external factors. These results demonstrate the potential for wheelchair skills to be broadly assessed, and a universal measure regardless of the domain/skill to be assessed. Simpler wheelchair skills (i.e., Flat Ground), required the least cognitive resources as was expected. Along similar lines as the WST, Curbs were revealed to be the most difficult terrain, followed by the Incline Ramp, and then High Friction terrain (Kirby et al., 2004). While WST did not assess tight turns or weaving as was done in this study, the results were congruent to individual perceptions of terrain difficulty (Herrera et al., 2019).

These raise the potential to utilize cognitive workload theory, and functional brain imaging as an objective measure of terrain difficulty and assessment of wheelchair skill experience. Furthermore, it provides evidence that wheelchair skills training assessments can move beyond subjective, highly attentive raters involved in evaluating specific wheelchair skills, into more comprehensive and broader categories evaluating important wheelchair terrains through objective, neurophysiological means.

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