MEASURING RACING WHEELCHAIR SPATIOTEMPORAL VARIABLES USING A PHONE CAMERA: A PRELIMINARY CONCURRENT VALIDITY STUDY

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The purpose of this study was to assess the measurement agreement between a low-cost system (phone camera) and a reference optoelectronic system, to measure spatiotemporal variables that may be related to wheelchair racing performance: acceleration phase time, push time, backswing time, and maximal elbow height. Three regular wheelchair racers propelled at maximal velocity on a training roller. The temporal variables had a low disagreement between both systems (bias ± 1.96 std of less than 0.01 s ± 0.02 s), while for the maximal elbow height, a higher disagreement of 0.020 m ± 0.038 m was observed. Future improvements are required especially to measure the maximal elbow height. This method may have long term benefits both for the athletes and research, by including more wheelchair racing athletes in future biomechanics studies.

KEYWORDS: Paralympic Sports, Wheelchair Racing, Measurements, Biomechanics.

INTRODUCTION: Wheelchair racing (WR) is a popular wheelchair sport that was first studied in the late eighties, mainly to figure how better biomechanics could improve performance (Cooper, 1990; Gehlsen, Davis, & Bahamonde, 1990; O'Connor, Robertson, & Cooper, 1998; Ridgway, Pope, & Wilkerson, 1988). In 1994, Higgs introduced a description of the six phases of the racing propulsion technique (Higgs, 1994), with the three longest being the acceleration phase, the push phase and the backswing phases, and the three others being transitional phases. Vanlandewijck et al. (2001) advised to increase the acceleration and backswing time when speed increases: as the push time necessarily decreases with speed, it becomes more and more difficult to generate power during this phase and therefore propulsion energy must be generated during other phases, for example as kinetic energy in trunk and arm movement. This is coherent with Cooper's recommendation (1995) to raise the elbows as high as possible between the backswing and acceleration phases. In a preliminary study on five athletes whose biomechanics were assessed at our laboratory, we observed trends between acceleration time, push time, backswing time and maximal elbow, and the athletes' maximal speeds. However, these possible relations were never measured in a large cohort, which would be difficult since few athletes have access to a biomechanics lab. Since current phone cameras now have impressive resolutions and sampling rates, it may become an instrument of choice to measure these variables systematically during training, which would allow researchers and coaches to better understand these possible relations. In this preliminary study, we assessed the measurement agreement between a phone camera and a reference optoelectronic system. We hypothesized that since the measured variables are either in the time domain (acceleration, push, backswing time) or in two dimensions (elbow height), then these measurements would be similar between both instruments.

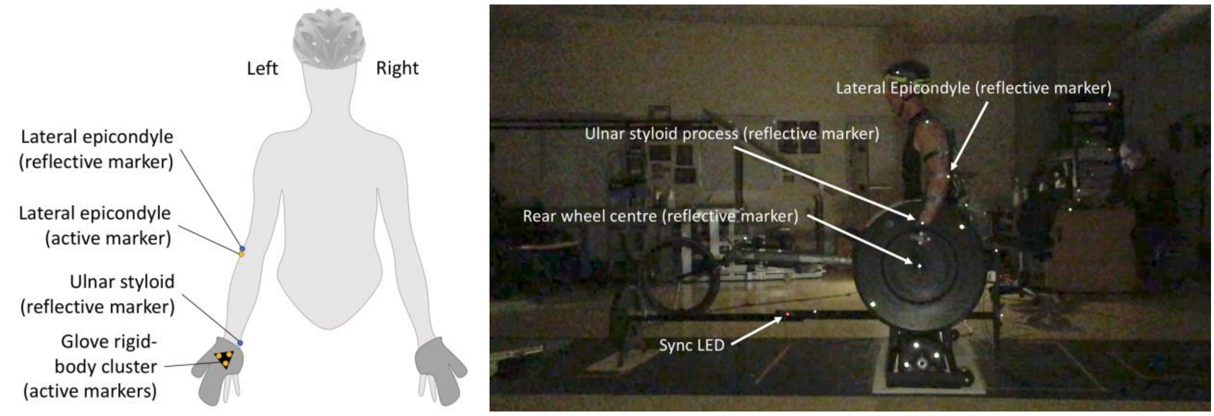
METHODS: Participants: Three athletes who have been training regularly in wheelchair racing participated in an exploratory study on racing wheelchair kinematics measurement. Their demographics are shown in Table 1. They read and signed the information and consent form approved by the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR) before the experiments.

Table 1: Athletes' demographics

Athlete	Sex	Age	Height	Pathology	Racing Class	Racing experience	Max speed on rollers
1	F	28	1.61 m	SCI T6 AIS A	T53	2 years	5.3 m/s
2	F	38	1.60 m	SCI T10 AIS B	T54	5.5 years	6.6 m/s
3	M	31	1.74 m	Right Tibial Amputee	T54	12 years	12.2 m/s

Task: The athletes propelled their own unmodified racing wheelchair on a training roller identical to the one they use during their regular training. They were told to accelerate as fast as they can and attempt to maintain a maximal speed for at least 30 seconds.

Instrumentation: *Reference system*: Active markers were placed on the athletes' left lateral elbow epicondyle and glove, as shown in Figure 1a. The tridimensional position of the active markers was measured at a sampling frequency of 70 Hz using four Optotrak bars (NDI) placed in front, behind and on both sides of the training roller. Prior to the task, the left ulnar styloid process and the left rear wheel's centre were probed and expressed relative to the glove markers and to the global reference frame, respectively. *Low-cost system*: Reflective markers were placed on the athletes' left lateral elbow epicondyle and left ulnar styloid process as shown in Figure 1a. The bidimensional position of the reflective markers was measured in the sagittal plane at a resolution of 720p and at a sampling frequency of 240 Hz using an iPhone SE placed on a tripod at a distance of 3.66 meters from the training roller's midline. Figure 1b shows an excerpt of the phone camera's field of view. Both systems were synchronized using a sync LED controlled by the Optotrak software and recorded by the phone camera.



(a) (b)

Figure 1: Experimental setup. (a) Placement of the reflective and active markers on the athletes. (b) Excerpt from the slow-motion video filmed by the phone camera.

Data processing: *Reference system:* The position of the ulnar styloid process was calculated from the position of the glove's rigid-body cluster, and the position of the lateral elbow epicondyle was measured directly. Both markers' positions were expressed relative to the left rear wheel's centre. *Low-cost system:* The positions of the ulnar styloid process and lateral epicondyle were measured with Kinovea 0.8.25 (Charmant, 2017) using the phone videos. The length calibration was based on the known diameter of the rear wheel, and the origin of the coordinate system was set to the left rear wheel's centre. *Data analysis:* Data from both systems were analysed using the same method in Matlab (Mathworks). The push cycles were divided automatically into three phases: 1) acceleration phase, which started when the elbow reached its highest position; 2) push phase, which started when the sagittal distance between the ulnar styloid and the pushrim reached less than to 2 cm; and 3) backswing phase, which started when the same distance reached more than to 2 cm. Only the pushes 15 to 45, which generally corresponded to steady-state maximal velocity, were analysed. The acceleration time, push time, backswing time and maximal elbow height were calculated for the 30 cycles × 3 athletes and compared between both systems using Bland-Altman plots.

RESULTS: The Bland-Altman plots are shown in Figure 2. For the acceleration time, both systems had an absolute disagreement (bias ± 1.96 std) of (0.003 s ± 0.023 s) and a relative disagreement of (3.1% ± 23.5%). The absolute and relative disagreements were of (0.004 s ± 0.017 s) and (1.5% ± 7.9%) for the push time, of (-0.006 s ± 0.017 s) and (-2.9% ± 7.6%) for the backswing time, and of (0.020 m ± 0.038 m) and (3.4% ± 6.5%) for the elbow height.

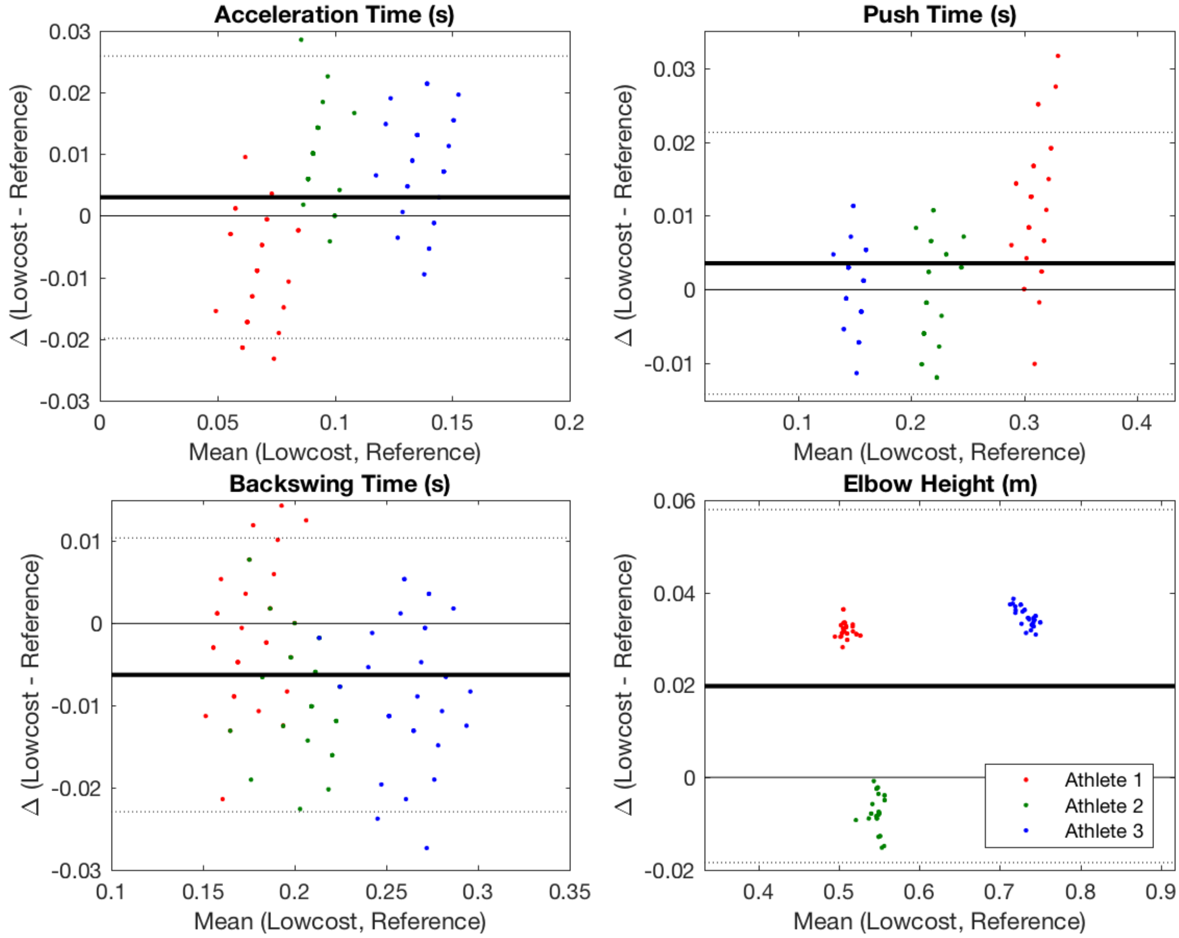


Figure 2: Bland-Altman plots showing the measurement agreement between from both systems. The bold line is the bias and the dotted lines are ±1.96 standard deviation (which include 95% of the points).

DISCUSSION:

The highest disagreement in time measurement was with the acceleration time, with a 1.96 × standard value of 0.023 s. This time is in a similar order than the sampling time of the Optotrak (1/70 Hz = 0.014 s) and suggests that using a phone camera is nearly equivalent to using an Optotrak to measure these temporal variables. However, since the acceleration time is so short, even the Optotrak may not be sufficiently precise to measure differences of acceleration time, at least on a push-by-push basis. Indeed, an absolute disagreement of 0.023 s created a relative disagreement of 23.5% during this phase, which prevents measuring subtle improvements in the athlete’s propulsion technique. However, if only the average propulsion pattern needs to be assessed, the disagreement falls considerably (to 3.1% in our results), which may be sufficient to compare different athletes or to evaluate their average propulsion technique.

For the maximal elbow height, the disagreement was somewhat elevated with 0.020 m ± 0.038 m. However, for each athlete, the precision was clearly good (<1 cm), but the bias varied from -1 to 3 cm between the athletes. These differences could be due to scaling errors related to parallax. In a first time, we calibrated the videos using a 1-meter calibration line on the training roller's midline. However, since the elbows are closer to the phone camera than the roller's midline, this method overestimated the maximal elbow height. Using the rear wheel diameter as a calibration measure instead of the roller's midline yielded much closer results between both methods but may not have resolved the parallax error completely. In this study, the camera was at a distance of 3.66 m from the roller's midline, but in our future studies, we will increase this distance to more than 5 m when possible to reduce the parallax error. The elbow height mismatch observed in this study can also be partly caused by our comparison method. We chose to place both a reflective marker and an active marker on the same bony location (the lateral elbow epicondyle). Although we used the smallest available marker bases and attempted to put them as close as possible, there was indeed a distance of about 1 cm between both markers, that may have contributed to the observed discrepancies (more importantly if the markers were aligned vertically when the elbow was at its highest). In a future validation study, it will be important to use a reference system that also uses reflective markers so that a same marker's position can be measured with both systems. Moreover, more athletes should be assessed since the low number of athletes (3) assessed for this project is clearly a main limitation of the study.

CONCLUSION: In this study, a low-cost system consisting of a phone camera and of the free Kinovea software was tested against a reference Optotrak system to measure the acceleration phase time, the push time, the backswing time and the maximal elbow height, four variable that may be related to performance in wheelchair racing. The low-cost system had a low disagreement of less than (0.01 ± 0.02 s) with the reference system for the timing measurements. Although this disagreement is low, it revealed that neither the reference or the low-cost system is precise enough to measure improvements on a push-by-push basis. For the maximal elbow height, a high disagreement of 0.020 m ± 0.038 m was observed, which was caused by high biases in individual athletes. In subsequent studies, the causes for these biases will be investigated and hopefully corrected. In the future, a low-cost system may then be used to confirm or infirm the relation between the four assessed variables and performance, and allow coaches to systematically monitor these variables during training.

REFERENCES

Charmant, J. (2017). Kinovea (Version 0.8.25). Retrieved from http://kinovea.org

Cooper, R. A. (1990). An Exploratory Study of Racing Wheelchair Propulsion Dynamics. *Adapted Physical Activity Quarterly*, *7*(1), 74–85.

Cooper, R. A. (1995). *Rehabilitation engineering applied to mobility and manipulation*. Bristol ; Philadelphia: Institute of Physics Publishing.

Gehlsen, G. M., Davis, R. W., & Bahamonde, R. (1990). Intermittent Velocity and Wheelchair Performance Characteristics. *Adapted Physical Activity Quarterly*, *7*(3), 219–230.

Higgs, C. (1994). Sport performance: Technical developments. In *The Proceedings from VISTA'93, an International Conference on High Performance Sport for Athletes with Disabilities*.

O'Connor, T. J., Robertson, R. N., & Cooper, R. A. (1998). Three-Dimensional Kinematic Analysis and Physiologic Assessment of Racing Wheelchair Propulsion. *Adapted Physical Activity Quarterly*, *15*(1), 1–14.

Ridgway, M., Pope, C., & Wilkerson, J. (1988). A Kinematic Analysis of 800-Meter Wheelchair-Racing Techniques. *Adapted Physical Activity Quarterly*, *5*(2), 96–107.

Vanlandewijck, Y., Theisen, D., & Daly, D. (2001). Wheelchair propulsion biomechanics: implications for wheelchair sports. *Sports Medicine*, *31*(5), 339–367.

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