ANALYZING INTRA-CYCLE VELOCITY PROFILE DURING WHEELCHAIR RACING PROPULSION: A PRELIMINARY STUDY

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Recent technological improvements made it possible to monitor manual wheelchair (MWC) racing intra-cycle velocity profile under *in-situ* conditions. Based on the hypothesis that the intra-cycle velocity profile is related to the contribution of the upper body in racing MWC propulsion, it could be used for in-situ technical analysis. Four elite MWC racing athletes were equipped with IMUs during a 400 m race, and propulsion cycles were studied once constant speed was reached. Trunk flexion angle and trunk flexion speed were monitored, as well as manual wheelchair linear velocity. This preliminary study shows that intra-cycle velocity profile appears to be athlete specific. Future research coupling such measurements with pushrim contact detection systems could help further understanding the complexity of MWC racing propulsion's technique and timing.

KEYWORDS: wheelchair sports, propulsion, racing, intra-push, velocity profile, kinematics.

INTRODUCTION: Manual wheelchair (MWC) racing propulsion is a complex form of locomotion that has been widely studied using optoelectronic motion capture systems while simulating movement on a roller ergometer. Although ergometers make it easy to perform laboratory experiments allowing the study of propulsion kinematics and kinetics, multiple papers pointed-out their limitations regarding MWC linear velocity (Moss et al. 2005; Sauret et al. 2013; van Dijk et al. 2021). Indeed, these articles highlighted the importance of the upper-body (i.e., trunk, arms, and head) inertial parameters during propulsion and their impact on MWC linear velocity (through linear momentum) (Moss et al. 2005).

In the field, experiments were made possible by technological improvements such as the development of the velocometer (Moss et al. 2005) of an instrumented wheelchair[2] or the democratization of inertial measurement units (IMU, van Dijk et al. 2021), all these solutions allowing the measurement of realistic MWC linear velocity. Using such data, intra-cycle velocity profile analysis could be used to better understand the contribution of the upper body in racing MWC propulsion. However, no in-depth study of the intra-cycle velocity profile has been produced and this variation is still often overlooked and smoothed out for a better overview of MWC average speed (Goosey-Tolfrey et al., 2012).

Based on IMU sensors, the aim of this study was to analyse the intra-cycle velocity profile and trunk flexion of various elite MWC racing athletes during a 400 m race. The main hypothesis was that, due to various level of disability, the intra-cycle velocity profile would be different between subjects, in particular between T53 and T54 athletes since athletes with a T54 classification display partial to normal trunk control, whereas T53 athletes do not have abdominal or lower spinal muscles activity.

METHODS: After receiving ethical agreement for the study (n°IRB00012476-2021-05-02-84), four male subjects (Table 1) gave informed consent to participate. Subjects A and B were national level T54 young talents and subjects C and D were Paralympic level T53 athletes.

Measurements and data processing: First, athletes were equipped with three IMUs (MTw, Xsens, Netherlands, 100Hz), placed on both rear wheels and on the subject's sternum (or on the upper back for subject D due to discomfort).

Second, a straight-line coast down acquisition was used to compute the rotation matrix enabling to convert angular velocities measured by the gyroscopes into the wheels' angular velocities around their axis of rotation.

Third, athletes were asked to perform a 400 m race from standstill at an intense but not maximal speed. The MWC linear velocity was computed using the methodology described by Pansiot et al. (2011), and the IMU placed on the torso was used to monitor both trunk flexion angle and speed, filtered through Xsens' implemented Kalman filter. Trunk flexion was expressed as the angle between the IMU's x-axis and the horizontal forward-pointing vector: a flexion of 0° indicates that the athlete is leaning forward horizontally when a 90° flexion angle corresponds to a vertical trunk position.

Table 1: Athlete demographics.

Athlete	A	B	C	D
Gender	M	M	M	M
Age	20	18	50	32
Classification	T54	T54	T53	T53
Camber (°)	13	12	11	11.5
Rear wheel diameter (cm)	67	67	67	66
Front wheel diameter (cm)	47	48	46	45
Handrim diameter (cm)	40	38	34	38
Yaw moment of inertia (kg.m^2)	2.1	2	2.5	2.3
Wheelbase (m)	1.3	1.2	1.3	1.3

Data analysis: Propulsion cycles, delimited by local minimums of the linear velocity, were manually identified from the time the athletes reached a constant average velocity until the finish line or the instant the average velocity drops. Manual identification of the cycles allowed for the exclusion of transitional strokes observed when operating steering (i.e., when initiating or completing a turn).

Cycles were then normalized (from 0% to 100% of cycle time) and outcome parameters (MWC velocity, trunk flexion, speed of trunk flexion) were averaged over the total number of cycles recorded per subject. Due to technical issues encountered with the IMUs during the experiments, the number of cycles studied varies considerably between subjects (Table 2).

RESULTS: Figure 1 illustrates each athlete's average propulsion cycle in terms of MWC linear velocity, trunk flexion angle and speed. Standard deviations are added as shaded areas. For comparison purposes, MWC linear velocity was plotted as variation from the propulsion cycle average speed, which is specified in Table 2 for each subject. It clearly appears that MWC velocity is not constant during a propulsion cycle and that the four subjects display four unique velocity profiles, either with 1 (B), 2 (A and D) or 3 (C) peaks. Additionally, the absolute velocity variation, representing the amplitude of speed variation during the average propulsion cycle of each athlete differs and ranges from 0.39 m/s (D) to 0.73 m/s (B).

Trunk flexion is expected to impact MWC linear velocity. Both T54 athletes (A and B) exhibited a similarly important flexion amplitude (up to 35° for B) with subject B oscillating around a more inclined position. Subjects C and D, classified T53, exhibited lower trunk flexion amplitude with almost no flexion movement for subject D (amplitude = 3°).

Table 2: Athletes' performances and trunk flexion.

Athlete	A	B	C	D
Number of cycles studied	28	50	12	28
400 m performance (s)	61.81	56.20	54.68	58.52
Average cycle time (s)	0.60	0.60	0.58	0.58
Propulsion cycle average speed (m/s)	6.84	7.54	7.89	7.24
Absolute linear velocity variation (m/s)	0.54	0.73	0.49	0.39
Trunk average flexion (°)	25	5	0	13

Trunk minimal flexion (°)	38	24	10	14
Trunk maximal flexion (°)	9	-11	-10	11
Trunk flexion amplitude (°)	29	35	20	3
Maximal trunk flexion speed (°/s)	183	293	114	21

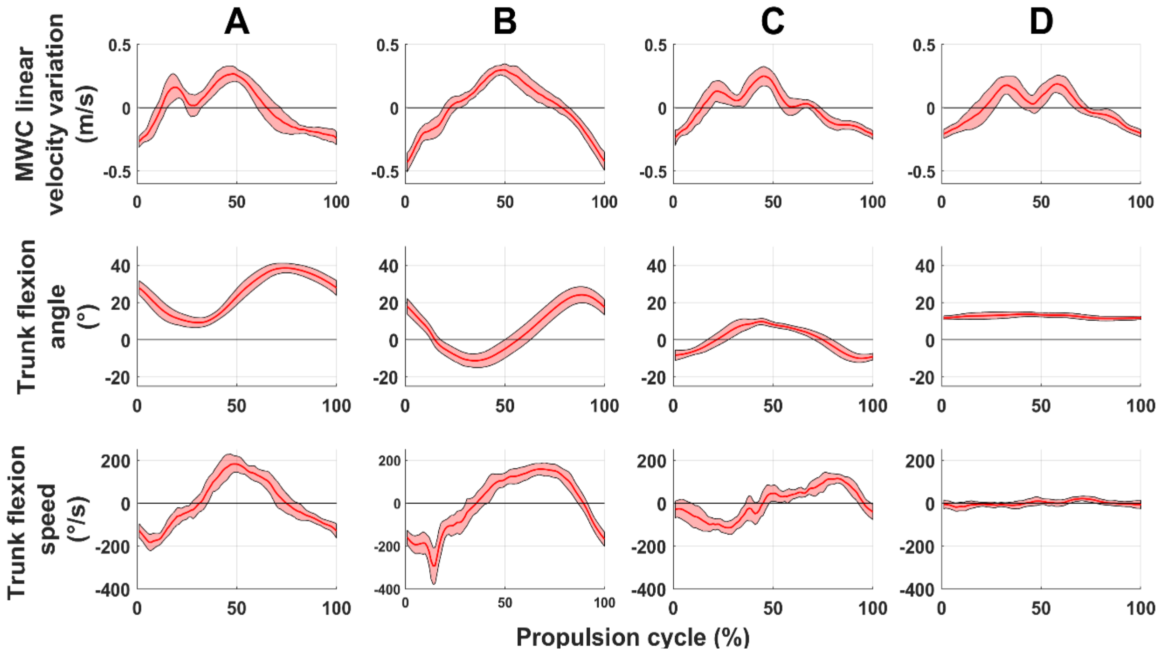

Figure 1: Average propulsion cycle of each athlete: MWC linear velocity (centred on the average cycle speed), trunk flexion, and trunk flexion speed

DISCUSSION: As expected, intra-cycle velocity profiles were different for T53 and T54 athletes and with variation magnitude that was higher for T54 athletes with respect to T53 athletes while T53 athletes of our cohort exhibited similar or even higher performance than T54 athletes (paralympics levels *vs* junior world level). The results above also showed a clear distinction between T54 and T53 athletes in both trunk flexion amplitude (29 and 35° vs 20 and 3°) and trunk flexion speed (183 and 293°/s vs 114 and 21°/s), as it was expected with respect to their classification. Indeed, these differences can be explained by the different levels of trunk control exhibited by each athlete. Coupled with their lower trunk activity, this result supports the observations made in the literature stating the importance of upper-body inertial parameters in MWC velocity variability.

Beyond those differences observed between T54 and T53 classifications, the four athletes exhibit four unique velocity profiles. Indeed, despite very limited trunk motion, subject D still displays a velocity profile with two peaks, arguably due to his propulsion pattern and to discontinuity of thrust during propulsion This shows that velocity profiles reflect each athlete's personal propulsion technique (trunk inclination, continuity of thrust, propulsion pattern, etc.).

To our knowledge, this is the first study providing such detailed information about MWC racing athlete intra-cycle velocity profile for different athletes with various level of disability and racing technique, but some limitations should be considered. First, the sample size was small and additional measurements on broader cohorts would be interesting. Second, T54 and T53 cohorts had significative differences in age and in years competing at the highest level, which could lead to imbalances. However, despite the low number of subject and their difference in level, our results have gone beyond our expectations with individual pattern that are not only related to the classification level. This opens the perspective of making technical analysis in-situ based on IMU sensors to assist coaches in identifying technical error from the intra-cycle velocity profile. However, previous to this perspective, a detailed analysis, including contact and release times as well as upper-limbs motions in addition to the trunk would be interesting to learn from their consequences on the intra-cycle velocity profile. Technologically, upper-bodies' centre of mass linear velocity might be more relevant than bodies angular velocity, but this will require the ability of both defining the upper-bodies centres of mass position and the location of the IMU sensors on the bodies reference frames in which the centres of mass will be defined.

CONCLUSION: The current preliminary study investigated the intra-cycle velocity profile during wheelchair racing propulsion between T54 and T53 athletes. In addition to demonstrating the feasibility of such “in-situ” measurements and to the expected differences between the classifications, this study revealed that multiple velocity profiles reflecting individual technique could be found among elite racers of a same classification. Within this research, trunk inclination was observed to be related to this velocity profile, but its exact contribution needs to be clarified to further assist coaches in the technical analysis from intra-cycle velocity profiles.

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FUNDINGS: This study was supported by the French ministry of sports (grant 19r27).