USING UNDERWATER 3D KINEMATICS TO IMPROVE THE PARALYMPIC SWIMMING CLASSIFICATION SYSTEM

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Swimming is a fundamental sport at the Olympic and Paralympic games, with the Paralympic classification system being the key difference between these games. To improve the accuracy of the classification system this case study investigated differences in the underwater hand kinematics of the affected and unaffected limb of an elite Para swimmer with hemiplegic cerebral palsy. In this case study, hemiplegic cerebral palsy caused impairments in strength, motor coordination and range of motion that affected hand speeds and trajectory paths during the underwater stroke phases. This work illustrates the benefit of using objective impairment and sport-specific measurements to gain insights into the impact that health conditions have on performance to guide Para swimming classification. This biomechanical analysis lays the foundations for the future improvement in international Para classification system.

KEYWORDS: Cerebral palsy, Para classification, biomechanics, isometric strength, motor coordination.

INTRODUCTION: The sport of swimming has been part of every Paralympic program since the Games began in 1960 and is one of the most popular sports for para athletes with a physical, visual or intellectual impairment. The growing popularity of Para swimming has expanded the range of impairments that compete on the international stage which has subsequently raised questions as to the effectiveness of the current swimming classification system (Burkett et al., 2018). To address this issue the International Paralympic Committee has mandated the development of an evidence-based classification system. Within the physical impairment swimming population athletes with cerebral palsy can present the most challenging scenarios due to the variability in the nature of their impairments.

Para swimmers with cerebral palsy might have impaired strength, motor coordination and range of movement that affects their ability to generate propulsion and minimise their resistance in the water during swimming. The clinical manifestations of cerebral palsy are inconsistent as the severity of impairment and presentation across the trunk and upper and lower limb extremities varies considerably between individuals. Hemiplegic cerebral palsy is characterised as loss of motor function that predominates one side of the body. Para swimmers with hemiplegic cerebral palsy often present with asymmetrical strength, motor coordination and/or range of movement across the affected and unaffected limbs (Antunes et al., 2017), although it is unclear how these impairments impact on swimming performance.

The upper limb extremity is the main contributor of propulsion during front crawl swimming, and the majority of hydrodynamic force is produced by the hand and forearm due to the high linear velocities of these limb segments (Morouco et al., 2015; Toussaint, Hollander, van den Berg & Voronstov, 2000). Understanding the altered hand kinematics of para swimmers with health conditions will provide important insights into the impact of their impairment on swimming performance. This case study presents data on the impairment profile and underwater hand kinematics of an international para swimmer with hemiplegic cerebral palsy.

METHODS: Data were collected for a Para swimmer with hemiplegic cerebral palsy who competes in the S5 international classification based on the assessment of motor coordination as per the Para swimming classification manual. The participant had been involved in competitive swimming for 5 years at the time of testing and represented their country at the 2016 Rio Paralympic games in the freestyle discipline. Their typical weekly training regime includes four swim sessions that average two hours duration. The participant provided written informed consent to participate in a research project with institutional human research ethics approval.

The Para swimmer completed an instrumented motor coordination test and isometric strength test to provide an objective assessment of their upper limb impairment profile (Tweedy, Mann & Vanlandewijck, 2016). The motor coordination test was a unilateral upper limb tapping task, further details and images of this test are shown in the reference. The participant was instructed to tap as quickly and accurately as possible between two custom-made tapping pads. These consisted of resistive touch panels that provided a 0.195 m x 0.10 m target area and were connected to a personal computer via Bluetooth connection with a Musclelab data synchronisation unit (Ergotest, Porsgrunn, Norway). The pads were positioned with 0.195 m distance between the centre of the two pads and mean movement time between consecutive taps was recorded over a 15 s test duration. The best trial of three indicated by the lowest mean movement time was used for analysis. The test has acceptable test-retest reliability in non-disabled participants (ICC = 0.85-0.93; CV = 4.3-5.2%).

The isometric strength test assessed the participant's left and right shoulder extension strength. The participant was seated in a custom-made chair with strapping positioned at the level of the xiphoid process securing their upper torso to a back-rest. The hand of the limb being assessed was placed in a cuff that was attached to an s-type strain gauge and custom-made aluminium frame. The palm of the hand was placed downwards in the cuff, with their elbow in a neutral position and 90° of shoulder flexion. The participant was instructed to slowly build up their applied force until reaching their maximal effort and holding for 3-5 seconds. The best trial out of three indicated by the highest peak force during the contraction was used for analysis. The test has acceptable test-retest reliability in non-disabled participants (ICC = 0.94-0.97; CV = 6.9-8.5%).

Underwater hand kinematics were obtained for a maximal effort front crawl swim through a calibrated volume (1.5 m width x 1.2 m depth x 3.8 m length) in the middle of a 25 m pool. Video data were captured using four GigE full HD cameras (Mako G-223B, Allied Vision Technologies GmbH, Stadtroda, Germany) mounted in underwater housings (Nautilus IP68, Autovimation GmbH, Baden Württemberg, Germany). Three markers on both hands were digitised at 50 Hz using SIMI Motion 3D (SIMI Reality Motion Systems GmBH, Unterschleissheim, Germany). 2D coordinates, filtered at 7 Hz, were converted to 3D coordinates using a DLT algorithm (Abdel-Aziz and Karara, 1971). Selected hand temporal, displacement and velocity measures were then calculated for 2-3 underwater cycles of the affected and unaffected sides.

RESULTS AND DISCUSSION: The current classification system classifies Para swimmers' motor coordination impairments by assigning a score between 0 and 5 for single joint actions (e.g. shoulder extension, finger abduction) based on subjective criteria. There is a total of 130 points allocated to the upper limb extremity for the S sport class that includes freestyle. The scores obtained from the Para swimmer's classification records ranged between 0/5 to 1/5 for the affected (non-dominant) limb and 3/5 to 4/5 for the unaffected (dominant) limb totalling a score of 11/65 (17%) and 48/65 (74%), respectively. The objective tests in this study showed the Para swimmer had clear deficits in strength (-23.9%) and motor coordination (+55.1%) in their affected limb compared with their unaffected limb that can be attributed to their health condition (Figure 1). However, our findings question the validity of current classification methods of assessing motor coordination impairment. For instance, although the Para swimmer's unaffected limb was judged to present with motor coordination impairment during classification (score = 48/65), they scored in the top 25th percentile for dominant upper limb tapping in the non-disabled participant group (Figure 1A). This highlights the benefit of using instrumented tests to obtain objective measurements of impairment that can improve the validity and transparency of Para swimming classification.

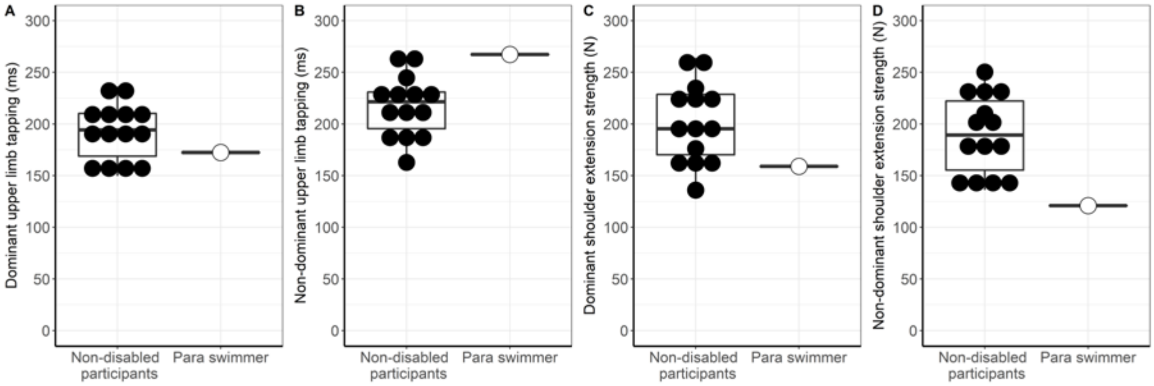

Figure 1: The Para swimmer's impairment score (white) for their unaffected (dominant) and affected (non-dominant) limb compared with scores of non-disabled (black).

The absolute duration and mean hand speeds of the Para swimmer's unaffected limb during the underwater pull (0.25 s, 1.70 $m.s^{-1}$) and push (0.26 s, 2.96 $m.s^{-1}$) phases were similar than those previously reported for able-bodied swimmers (downsweep 0.26 s, 2.06 $m.s^{-1}$; insweep 0.19 s, 2.19 $m.s^{-1}$; upsweep 0.17 s, 3.03 $m.s^{-1}$) (Samson et al., 2015). A marginal strength impairment (Figure 1C) might explain the slightly lower mean hand speeds during the underwater pull phase compared with those reported during the downsweep and insweep phases in able-bodied swimmers. It is interesting to note the absolute duration and mean hand speeds of the unaffected limb during the entry and glide phase (0.44 s, 1.62 $m.s^{-1}$) compared with able-bodied swimmers (0.20 s, 2.21 $m.s^{-1}$) (Samson et al., 2015). This might be explained by the extended exit and recovery duration of the Para swimmer's affected limb (Table 1). To allow for the affected limb to 'catch up', the Para swimmer might delay the onset of the unaffected limb's catch phase so that they can achieve higher hand speeds during the underwater pull and push phases that are most important to propulsion.

Table 1: Time, absolute hand speeds, and hand displacement during the underwater stroke.

		Entry + Glide	Pull and Push	Exit + Recovery
Affected limb	Time (s)	0.27	0.39	0.82
	Mean hand speed ($m \cdot s^{-1}$)	1.69	2.22	
	Maximum hand speed ($m \cdot s^{-1}$)	1.86	2.82	
	Hand displacement (m)	0.45	0.86	
Unaffected limb	Time (s)	0.44	0.51	0.48
	Mean hand speed ($m \cdot s^{-1}$)	1.62	2.35	
	Maximum hand speed ($m \cdot s^{-1}$)	1.75	3.34	
	Hand displacement (m)	0.71	1.21	

There were clear differences in the mean and maximum hand speeds during the underwater stroke phase between the Para swimmer's affected (2.22 m.s-1 and 2.82 m.s-1) and unaffected limb (2.35 m.s-1 and 3.34 m.s-1). The Para swimmer's hand trajectory paths suggest that they were affected more by limited range of motion than by impairments in strength and motor coordination. The affected and unaffected limbs appear to have similar hand speeds during the initial phase of the underwater stroke, and the unaffected limb only achieves higher hand speeds during the later underwater push phase (Figure 2A). The affected limb has an altered hand trajectory path characterised by a lower maximum hand depth (Figure 2B), and reduced absolute hand displacement during the glide and entry and underwater pull and push phases (Table 1). The altered hand trajectory path shows the affected limb is applying force to the water over a reduced range of motion and impaired limb orientation causes greater 'slippage' and decreased stroke length (Figure 2C). The trajectory of the hand is often considered a key component of the swimming stroke as the path the hand travels directly relates the propulsion generated and the resistance created, when swimming. Unfortunately, the Para swimmer's dry-land range of motion was not assessed although muscle contractures caused by spasticity most likely explains the affected limbs altered hand trajectory path. These results highlight the complexity of cerebral palsy, and suggest that a combination of objective measures related to strength, motor coordination, and range of movement is required to classify these Para swimmers rather than limiting assessment of impairment to any one of these.

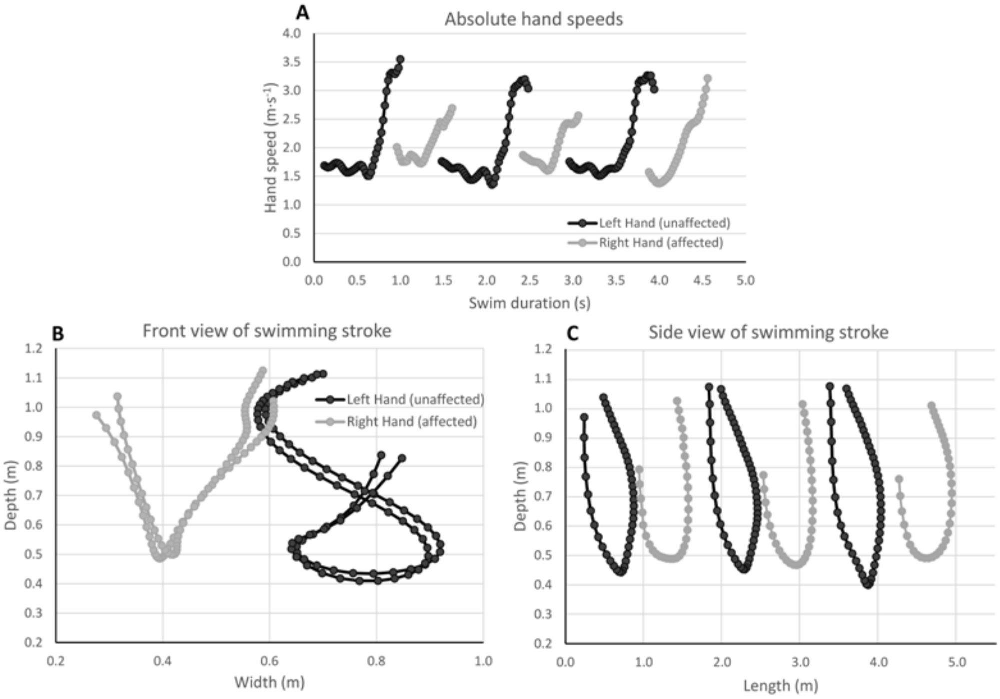

Figure 2: The Para swimmer's absolute hand speeds (A) and hand trajectory paths (B and C) during the underwater stroke phase for the affected and unaffected limbs.

CONCLUSION: In this case study, hemiplegic cerebral palsy caused impairments in strength, motor coordination and range of motion that affected hand speeds and trajectory paths during the underwater stroke phases. This work illustrates the benefit of using objective impairment and sport-specific measurements to gain insights into the impact that health conditions have on performance to guide Para swimming classification.

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