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The effectiveness of the swimming turn is highly influential to overall performance in competitive swimming. The push-off or wall contact, within the turn phase, is directly involved in determining the speed the swimmer leaves the wall. Therefore, it is paramount to develop reliable methods to measure the wall-contact-time during the turn phase for training and research purposes. The aim of this study was to determine the concurrent validity and reliability of the *Pool Pad* App to measure wall-contact-time during the freestyle and backstroke tumble turn. The wall-contact-times of nine elite and sub-elite participants were recorded during their regular training sessions. Concurrent validity statistics included the standardised typical error estimate, linear analysis and effect sizes while the intraclass correlating coefficient (ICC) was used for the reliability statistics. The standardised typical error estimate resulted in a moderate Cohen's *d* effect size with an R^2 value of 0.80 and the ICC between the *Pool Pad* and 2D video footage was 0.89. Despite these measurement differences, the results from this concurrent validity and reliability analyses demonstrated that the *Pool Pad* is suitable for measuring wall-contact-time during the freestyle and backstroke tumble turn within a training environment.

Keywords: freestyle, backstroke, concurrent validity, feedback

Introduction

Successful performance in competitive swimming events relies heavily on the effectiveness of the swimming turn (Chakravorti, Slawson, Cossor, Conway, & West, 2012; Slawson, Conway, Justham, Le Sage, & West, 2010a; Webster, West, Conway, & Cain, 2011). The swimming turn involves the approach to the wall, the turn or rotation to reorient the body in preparation for swimming the next lap, the push-off or wall contact, the glide phase and the stroke preparation (Cossor, Blanksby, & Elliott, 1999; Slawson et al., 2010a; Webster et al., 2011). To optimise the turn, the swimmer must keep this sequence to the shortest time possible while achieving the highest possible speed in the opposite direction (Slawson et al., 2010a; Tourny-Chollet, Chollet, Hogie, &

Papparodopoulos, 2002; Veiga, Cala, Frutos, & Navarro, 2013; Webster et al., 2011). Turn time is measured as the total duration from 5 m into the wall and 10 m out of the wall, while contact time is the period between the initial wall interaction (hand and / or foot contact with the wall) and the subsequent toe-off during the turn phase (Tourny-Chollet et al., 2002). Analysis of the 200 m women's freestyle event at the 2008 Beijing Olympics found that the turn time contribution was 21% of the total race time (Slawson et al., 2010a). Additionally, studies have indicated that the longer the swimming event, from 50 to 1500 m, the more significant the turn becomes (Chow, Hay, Wilson, & Imel, 1984; Tourny-Chollet et al., 2002; Veiga et al., 2013).

Fast and efficient turns can compensate for slower swimming phases, therefore coaches and swimmers should recognise how this can positively impact swimming performances in the competitive environment (Veiga et al., 2013). The push-off the wall has been identified to be directly involved in determining the speed at which the swimmer leaves the wall (impulse-momentum relationship) (Hay, 1993). In short, the larger the impulse (average force applied to the wall for a given time) the greater the speed the swimmer will travel away from the wall (Araujo, et al., 2010). This directly relates to wall-contact-time in swimming, which suggests it is an important technical factor in the overall turn performance. For example, in the 1500 m long course event, there are 29 turns where time differences of a tenth of a second per turn occur frequently between better and poor turners (Mason, Mackintosh, & Pease, 2012). As races are timed to a hundredth of a second, it becomes increasingly obvious how important it is for competitive swimmers to make the most out of every turn as that may make a considerable difference to where they place in a race, particularly at the elite level (Araujo, et al., 2010; Blanksby, Gathercole, & Marshall, 1996; Mason et al., 2012). This highlights the importance of monitoring the value of this swimming turn parameter in training for performance improvement (especially for long distance swimmers).

The emergence of new technologies has led to more methods of performance monitoring in sport, particularly in the training environment (Tor, Pease, & Ball, 2015). Analysis tools, in sport, aim to provide useful information to supplement coach knowledge and improve feedback in the development of athletes (Phillips, Farrow, Ball, & Helmer, 2013). Specifically in swimming, video analysis is widespread (Slawson et al., 2010a); however, post processing of video data via manual digitisation techniques is required to establish quantitative measures and does not allow for real-time feedback to the coaches and athletes (Le Sage, et al., 2012). Tourny-Chollet et al. (2002) demonstrated that through the use of recorded video footage and observing the swimmer's turn trials frame by frame (at a frequency of 50 hz), the butterfly wall-contact-time could be determined. This study, however, used multiple cameras above water whereas Blanksby et al., (1996) and Slawson et al. (2010a) used a fixed underwater camera (recording at 50 and 25 fps, respectively) to digitise the tumble turn within their study. These studies illustrate what is often adopted in the field of swimming research and training. Such techniques are often time consuming, require operator expertise to ensure reliability and are thus limited to research or isolated training sessions, where the impact of the feedback given is potentially lost.

Recent research in feedback indicates there has been a large shift towards real-time feedback among sports (Phillips et al., 2013). Feedback at the time of the event has been shown to assist performance, given it is delivered in an approach to provide specific outcomes (e.g. Smith, Norris, & Hogg, 2002; Justham et al., 2008; Kirby, 2009; Phillips et al., 2013; Ridge & Richards, 2011). Additionally, the feedback needs to be considered from both a measurement and relevance perspective which needs be task and performer specific (Phillips et al., 2013). For example the study by Kirby (2009) on supplying feedback at the time of the event to alpine skiers resulted in 83% of participants stating that the video and verbal feedback during the training session helped them improve a particular skill set. Furthermore, in a study regarding swimming performance evaluation, Smith et al. (2002) concluded that in order for performance monitoring and feedback content to be effective, it must be incorporated into the training regime. This suggests that a key requirement for a successful change in skill performance, with the widest impact, is to ensure that feedback is specific and generated at the time of event (Kirby, 2009).

It is equally important that the measurement systems selected to monitor and provide feedback is easy to operate by a coach. This led to the development of the Superinteractive *Pool Pad* Application (App) (Superinteractive, Geelong, Australia). This system is simple to setup, completely operatable by the coach and the wall-contact-times are displayed in real-time. The *Pool Pad* connects directly into the Omega OCP5 touchpad currently used at major swimming pools and competitions. Previous pilot testing of the *Pool Pad* has already proven its functionality; however, concurrent validity and reliability of this system has not been determined or published. Concurrent validity is a type of criterion-related validity where a new instrument (e.g. *Pool Pad*) is compared with a criterion measurement (e.g. 2D video footage) (Tor, Pease, & Ball, 2015; Wundersitz, Gastin, Robertson, & Netto, 2015; Slawson., Conway, Justham, & West, 2010b). In swimming research and athlete servicing, 2D video footage has been heavily adopted (e.g. Blanksby et al., 1996; Ceseracciu et al., 2011; Kirby, 2009; Yeadon & Challis, 1994). Consequently, this study used 2D underwater video footage to identify the tumble turn wall-contact-times. Previous pilot testing of the *Pool Pad* identified that issues such as hand touches or asynchronous foot touches may affect timing data and signal switch performance of the Omega OCP5 touchpad. This needed to be assessed over several turn trial sets using multiple athletes in order to accurately determine the cause of such spurious data. More importantly, presenting athletes and coaches with a comprehensive testing and analyses of the *Pool Pad* will inform them of any limitations associated with the use of this system.

The importance of the wall-contact-time within the swimming turn was demonstrated in the research by Slawson et al. (2010a). The research by Kirby (2009) and Phillips et al. (2013) confirmed the overall benefits athletes receive from outcome-based feedback during training. Inspection of literature to date shows no research in the development of a specific swimming wall-contact-time measurement system that connects directly into the Omega OCP5 touchpads, used at major swimming competitions in Australia. Thus, there is no published research in the validation of the *Pool Pad*. The overall aim of this study was to determine the concurrent validity and reliability of the *Pool Pad*. The analyses undertaken will establish the *Pool Pad*'s response to various athletes and ability to measure wall-contact-time accurately within a swimming training environment. Since there is variance in athlete turn techniques, it was hypothesised that the *Pool Pad* may need to be modified in order to accurately compensate varying athlete push-off techniques. Further, as the *Pool Pad* connects directly into the Omega OCP5 touchpad, it was hypothesised that the *Pool Pad* would show strong reliability providing the sensors within the Omega OCP5 touchpad are functioning as designed.

Methods

Participants

Nine participants (4 male and 5 female; aged 20 ± 4 years) were recruited by the Victorian Institute of Sport (VIS). All participants were involved in the VIS scholarship program and were considered either sub elite or elite, having at least five years competitive experience, competing at the Australian National Open level. Additionally, two of these participants qualified for the 2016 Rio Olympics with one being a current gold medallist, and two medallists at the 2016 Rio Paralympics. This study was approved by the Victoria University Human Research Ethics Committee.

Testing Procedure

The design of this study was to test the *Pool Pad* during the participants' regular training sessions and the data was collected by the VIS in conjunction with athlete servicing. This was to ensure the concurrent validity and reliability of the *Pool Pad* in its designed environment. Part of the testing protocol was to recruit participants that swam either freestyle or backstroke as their main stroke as the tumble turn technique is adopted for both of these events. Before individual wall-contact-times were recorded, participants had already performed their usual warm-up routine set by their coach for that particular session. As the *Pool Pad* was tested in the elite training environment, the coach had two separate sessions prescribed where one participant swam 'freely' while the remaining eight participants began approximately 15 m from the wall. 'Free' swimming referred to swimming laps of the 50 m pool continuously according to the training set. Those participants that began 15 m from the pool wall were specifically working on their tumble turn technique and this set distance allowed them to perform a few strokes before the turn. Specifically, all participants (those that began approximately 15 m away from the pool wall or swam 'freely') swam towards the Omega OCP5 touchpad where he/she completed the tumble turn and then would glide / recover back to the 15 m mark or continue swimming according to their training regime. The varying number of turn trials per participant was considered acceptable for this study as the aim was to assess the *Pool Pad*'s ability to measure wall-contact-time in the training environment compared to a criterion measurement (wall-contact-times identified from the 2D video footage).

Data Collection

The turn trials were filmed using an underwater iPhone 6s (iOS 9.3.5, Apple Inc., California, USA) camera and subsequently, the wall-contact-times displayed on the *Pool Pad* App were recorded. Four separate Omega OCP5 touchpads were used within the prescribed training sessions. The same Omega OCP5 touchpad was used for the eight participants that began 15 m from the pool wall; whereas for the one participant that swam ‘freely’, a different Omega OCP5 touchpad was used at each of the participant’s three individual training sessions.

For this reason, this study was divided into two sub-studies: (1) determining the concurrent validity of the *Pool Pad* using three different Omega OCP5 touchpads and the same participant (participant A) and, (2) determining the concurrent validity and reliability of the *Pool Pad* using a single Omega OCP5 touchpad with multiple participants (participants B to I). For the first sub-study, wall-contact turn times were recorded over three separate training sessions where the number of recorded turn trials varied from 12 to 22 depending on the prescribed session. Conversely, in the second sub-study, the participants completed 10 wall-contact turn trials starting 15 m from the pool wall.

Touchpad Setup

The Omega OCP5 touchpad has an upside-down L-shaped frame allowing it to mount onto the ledge of the pool while sitting flush with the pool wall. The two male banana plugs are attached to the Omega OCP5 touchpad and connect into the Superinteractive male TRS to 2x female banana plug adaptor cable. This Superinteractive male TRS to 2x female banana plug adaptor cable plugs into the Superinteractive Stomp Pad USB MIDI cable and then into the 9.7-inch iPad Air 2 (Apple Inc., California, USA) via an Apple lightning to USB camera adaptor (refer to Figure 1). The three contact strips within the

Omega OCP5 touchpad, behind the individual yellow / black PVC slates, close when 2 to 3 kg of localised pressure is applied to the pad. These three contact strips run along the full length of the touchpad frame. Each are placed a specific distance apart set by Swiss Timing (http://www.swisstiming.com/) so that a timing signal will trigger regardless of where the pressure is applied on the pad.

Figure 1. *Pool Pad* Setup

The switch performance of the Omega OCP5 touchpad (sampling at 250 Hz) was tracked via the LabJack U12 Series (LabJack Corporation, Lakewood, USA) data acquisition device and saved directly onto a 13-inch MacBook Pro (Apple Inc., California, USA) running Microsoft Windows 8 with a custom LabVIEW (National Instruments Corporation, Texas, USA) data acquisition App. Tracing the switch performance of the Omega OCP5 touchpad was undertaken to understand the switching signal and sensor function within the Omega OCP5 touchpad. Figure 2 illustrates the testing setup employed by the VIS and Superinteractive.

Figure 2. *Pool Pad* Testing Setup

Camera Setup

The iPhone 6s (inside a waterproof housing attached to a wall mount) was used to film the wall-contact turn trials via the Coach's Eye App (version 5.3.4, TechSmith Corporation, Okemos, USA) and recorded using slow-motion video support operating at 240 frames-per-second (fps). The customised upside-down L-shaped wall mount was positioned on top of two swimming kick boards on the ledge of the pool while allowing the attached camera to sit flush with the side wall. The two kick boards, each having a thickness of 3.20 cm, were used to ensure that the entire foot contact was in camera view. Thus, the camera was perpendicularly positioned at 14.1 cm out from the pool start wall and 29.6 cm below the surface of the water (refer to Figure 3).

Figure 3. Diagram of Front and Top View of Camera Setup

Following the individual testing, the recorded wall-contact turn trial footage was imported into Siliconcoach Pro8 (version 8.0, The Tarn Group Limited, Dunedin, New Zealand) (Bishop, Smith, Smith, & Rigby, 2009). Here, wall-contact-time was derived for each of the individually recorded trials using the timing tool in Siliconcoach Pro8. This was achieved by identifying first frame of foot touch on the wall to the frame of toe-off the wall (Tourny-Chollet et al., 2002) and calculating the time between these two events.

The iPhone 6s camera footage was validated to ensure that the footage was indeed recording at 240 fps and that this frame rate remained constant and invariable (no footage drift). The validation procedure consisted of using the iPhone 6s to film (at 240 fps) a stopwatch timer (counting to a hundredth of a second) over a 10 s period. Filming the stopwatch ascend to 10.00 s was selected as a single turn trial would be much less than 10 s. The filmed footage was imported into Siliconcoach Pro8 where it was found that from the point the stop watch started (0.00 s) to it reaching 10.00 s was indeed 10.00 s long via the recorded footage. Using this test, the method of video capture was deemed suitable for this study as no frame-rate inaccuracies (inconsistency or drift in footage) and the video start-up time were present.

Statistical Analysis

Intra- and inter-individual statistical analyses were used to assess the concurrent validity and reliability of the *Pool Pad*'s ability to measure wall-contact-time during the tumble turn. In this study, the definition of concurrent validity was to determine the relationship between the practical (wall-contact-time displayed on the *Pool Pad*) and the criterion (wall-contact-time derived from the video footage) measure; whereas reliability was to determine the *Pool Pad*'s consistency and reproducibility to measuring wall-contact-time. The wall-contact-times identified from the 2D video footage was used as the criterion measurement as this is standard and widespread in swimming (Bishop et al., 2009, Slawson et al., 2010a). Ammann (2016) also stated that from previous research on measuring ground contact time in running, video techniques were recommended.

The concurrent validity of the *Pool Pad* was investigated using a custom-made concurrent validity Microsoft Excel 2013 spreadsheet created by Hopkins (2015). Pearson's correlation and overall bias were generated from this spreadsheet. Using a modified Cohen's *d* scale created by Hopkins (2015), meaningfulness of the difference were interpreted. The effect sizes of < 0.20; 0.2-0.6, 0.6-1.2, 1.2-2.0 and > 2.0 were regarded as trivial, small, moderate; large and very large respectively. The reliability of the *Pool Pad* was determined using another Microsoft Excel 2013 spreadsheet also created by Hopkins (2015) where the intraclass correlations coefficient (ICC) was calculated using 95% limits of agreement. This reliability analysis was only conducted in the second sub-study as the use of three different Omega OCP5 touchpads in the first sub-study would affect the true reproducibility of the *Pool Pad*'s wall-contact-time measurement.

Results

Following the removal of univariate and bivariate outliers, the overall ICC between the *Pool Pad* (practical) and 2D video footage (criterion) was very strong for the second sub-study using a single touchpad and multiple participants (participants B to I) (ICC = 0.89 with limits of agreement = 95% n = 74). Figure 4 and Figure 5 illustrates the relationship between the criterion and practical wall-contact-times for the two sub-studies (multiple touchpads with single participant and single touchpad with multiple participants, respectively). Pearson's correlation, typical error of estimate, Bland and Altman Estimate with ± 95% limits of agreement and overall bias were generated from the concurrent validity spreadsheet for the two sub studies and the results are displayed in Table I.

Figure 4. Wall-Contact-Times Identified from 2D Video Footage vs. *Pool Pad* Concurrent Validity Plot – Multiple Touchpads, Single Participant (Participant A)

Figure 5. Wall-Contact-Times Identified from 2D Video Footage vs. *Pool Pad* Concurrent Validity Plot – Single Touchpad, Multiple Participants (Participant B to I)

Table I. Concurrent Validity Results

Inter-individual analysis revealed the concurrent validity and reliability of the *Pool Pad* per individual participant within the two sub-studies. The mean wall-contact-times from the *Pool Pad* and the 2D video footage are displayed in Table II including Pearson's correlation and R^2 generated from the validity spreadsheet for each individual participant.

Table II. Individual Participant Trial Results Following Removal of Outliers

Discussion and Implications

Previous pilot and repeatability testing of the *Pool Pad* App has proven its functionality yet its reliability and concurrent validity in a training environment had not yet been assessed or reported. This study sought to examine the reliability and concurrent validity of the *Pool Pad* App to measure freestyle and backstroke tumble turn wall-contact-time during regular training sessions.

Pool Pad Concurrent Validity

The regression equation from Figure 5 returned an R^2 value of 0.80 which was interpreted as a very high correlation according to Hopkins (2015). Also, the standardised typical error estimate of 0.46 was interpreted as moderate according to Cohen's *d* effect size and small according to Hopkins (2015). This indicated that the differences between the times identified from the 2D video footage and the *Pool Pad* will have a small practical significance to the wall-contact-time measurement displayed on the *Pool Pad* App (Hopkins, 2015).

Individual Participant Analysis Using Multiple Touchpads

In the first sub-study, wall-contact-times from a single participant (participant A) were recorded using a different Omega OCP5 touchpad per session. As three separate Omega OCP5 touchpads were used, separate analyses were performed on the results generated per touchpad (A_1, A_2 and A_3). The mean differences between the *Pool Pad* and the 2D video wall-contact times were 0.07 ± 0.02 s, 0.20 ± 0.03 s and 0.07 ± 0.01 s for A_1, A_2 and A_3 turn trial sets, respectively. A review by Slawson et al. (2010a) documented the typical foot contact time (wall-contact-time) measurement values to vary between 0.28 – 0.60 s (Cossor et al., 1999, Lyttle, Blanksby, Elliot, & Lloyd, 1999, Tourny-Chollet et al., 2002, Blanksby et al., 2004, Prins & Platz, 2006). Similarly, research by Cossor et al. (1999) stated that the average time spent on the wall during the turn phase (wall-contact-time) is approximately 0.30 – 0.50 s. The average wall-contact-time recorded by the *Pool Pad* for A_2 was 0.55 ± 0.05 s. This was above the average wall-contact-time stated in the research by Cossor et al. (1999) and was higher than that particular participant's average which was 0.50 s. Nonetheless, the corresponding wall-contact-times identified from the

2D video times were within the average range at 0.35 ± 0.02 s. Furthermore, the R^2 value of 0.04 for the participant A_2 trials illustrated close to a zero relationship between the 2D video wall-contact times and the *Pool Pad*. A potential explanation was directed at the sensors within the Omega OCP5 touchpad as assessing these sensors post testing illustrated that they had ceased to function as a switch and where acting as a battery. This would result in the sensors storing voltage, meaning that at the instant the foot leaves the Omega OCP5 touchpad the signal is delayed before returning to the zero datum.

The average wall-contact-time from A_1 and A_3 trial sets were within the average range at 0.44 ± 0.05 s and 0.39 ± 0.04 s, respectively (Cossor et al., 1999). Larger differences between the 2D video wall-contact times and the *Pool Pad* for A_1 and A_3 could be potentially due to the accuracy of the Omega OCP5 touchpad. The results from the A_3 trial set produced the most consistent wall-contact-times with an R^2 value of 0.66 and the standardised typical error estimate of 0.60. This indicated that the difference between the digitised 2D video wall-contact times and the *Pool Pad* will have moderate practical significance (Hopkins, 2015).

Individual Participant Analysis Using a Single Touchpad

Assessing each individual participant trial set unfolded further findings related to the concurrent validity of the *Pool Pad* and provided an additional measure. Reviewing the average wall-contact-times among the participants B to I in the second sub study revealed times that were within the 0.30 – 0.50 s range stated in the research by Cossor et al. (1999). The absolute mean differences between 2D video wall-contact times and the *Pool Pad* varied by less than 0.02 s for seven out of the eight participants. The R^2 value were 0.85, 0.68, 0.94, 0.68, 0.59, 0.96, 0.78 and 0.83 where the standardised typical error estimates were 0.41, 0.77, 0.27, 0.60, 0.68, 0.17, 0.50 and 0.44, participants B to I, respectively. The R^2 value indicated a very high correlation between the wall-contact times identified from the 2D video footage and the *Pool Pad*; however participant C, E and F presented the highest standardised typical error estimates. These three participants were considered sub elite and hence their performance was more variable compared to the remaining six participants. Furthermore, these errors were still considered small to moderate according to Hopkins (2015) and did not affect the overall validity of the *Pool Pad*.

Pool Pad Reliability

The reliability analyses were performed using the wall-contact-times recorded from the second sub-study using the same Omega OCP5 touchpad from eight of the nine trialled participants (B to I). The overall ICC between the *Pool Pad* (practical) and the 2D video wall-contact times (criterion) was very strong (ICC = 0.89 with limits of agreement = 95% n = 74) indicating that the *Pool Pad* was suitable for practical application over a range of participants when the same Omega OCP5 touchpad was used.

The sample size used in this study was small but elite as a consequence. Among the nine participants in the study there was a mix of male and females with varying swimming turn styles, incoming speed before the turn, foot placement of the touchpad and force generation off the Omega OCP5 touchpad during the turn phase. These variances created uncertainties in the recorded wall-contact-times, yet testing the *Pool Pad* over a range of turn techniques was considered beneficial as the aim of this study was to determine the reliability and concurrent validity of the *Pool Pad* in a practical training setting. The use of freestyle and backstroke did not affect the results as these strokes both adopt the same tumble turn technique. Furthermore, testing the *Pool Pad* during training sessions was considered a natural environment in which this system was designed for and gives coaches confidence in using it as a training tool to measure wall-contact-time during the swimming turn phase.

Conclusion

This study aimed to assess tumble turn wall-contact-time data measured from the *Pool Pad* App. The results from the concurrent validity and reliability analyses indicated that the system is suitable for practical application using one particular Omega OCP5 touchpad. The statistical results from the individual participant, which used a different Omega OCP5 touchpad across the three training sessions, presented findings which further indicated that the *Pool Pad* is dependent on the adequate functionality of the sensors within the Omega OCP5 touchpad. This dependence is due to the *Pool Pad*'s direct connection into the Omega OCP5 touchpad and thus, it relies on its integrity.

Finally, although the findings from the concurrent validity and reliability analyses of the *Pool Pad* were not as strong when using multiple Omega OCP5 touchpads, it gives coaches and sports practitioners an indication of the reproducibility of the *Pool Pad* to measure wall-contact-time. This can lead to future research and development opportunities. Consequently, recommendations have been made to Superinteractive to improve the functionality of the *Pool Pad* (algorithm within App and Stomp Pad interface cable) to account for the differences among the Omega OCP5 touchpads and varying swimming techniques.

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