IMPROVING TUMBLE TURN PERFORMANCE IN SWIMMING – ABOUT THE IMPACT OF WALL CONTACT TIME AND TUCK INDEX

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Race time can be shortened by improving turn performance in competitive swimming, but this requires insight into the optimal turn technique. This study aimed to experimentally investigate the effect of wall contact time (WCT) and Tuck Index on the tumble turn performance. Eighteen Dutch national level swimmers participated and conducted tumble turns with three different WCTs and Tuck Indices. The results showed that a sufficiently long WCT that allows time to generate a high push-off force at the end of the wall contact when the body is in a proper streamlined position. The results also showed that it is possible to recommend an optimal Tuck Index for individual swimmers, which might help to improve their tumble turn and thus their race performance. These results should be verified by an intervention study in which the swimmers are trained to perform the tumble turn with the recommended WCTs and Tuck Indices.

KEYWORDS: free style swimming, manipulation, tuck index prediction.

INTRODUCTION: Between winning a gold or silver medal on the 100m freestyle during the Tokyo Olympic Games 2021 was a margin of 0.06 seconds. With such small differences, every opportunity for improvement should be exploited. In general, performance improvement may be achieved in any of the four components of a swimming race, i.e. starting, free swimming, turning and finishing. With an approximated contribution up to 40% on the short course (25m-pool), the turn can be considered a major determinant of swim performance (Born et al., 2021). The overall turn performance is expressed as the duration covering the approach, rotation, wall contact, glide, underwater propulsion and stroke resumption. However, to identify those parts of the turn which can be improved, it is necessary to dissect the movement and examine the effects of specific performance determining variables. Besides the push-off force (F_{peak}), research has shown that the wall contact time (WCT) and the Tuck Index are associated with turn performance (Blanksby et al., 1996; Cossor et al., 2014; Pereira et al., 2006; Skyriene et al., 2017).

The WCT is defined as the time between the first wall contact of the swimmers' feet and the end of wall contact. Several studies have shown that a shorter WCT is related to a higher F_{peak}, resulting in faster turn times (Araujo et al., 2010; Blanksby et al., 2004; Pereira et al., 2006). A longer WCT allows swimmers to produce an F_{peak} more towards the end of the push-off, resulting in a lower peak drag force and thus a higher acceleration (Lyttle et al., 1999).

The WCT correlates negatively with the Tuck Index (Blanksby et al., 2004), defined as the instant at which the hip is at its minimum distance from the wall expressed as a percentage of the trochanteric height. Also, a positive correlation between the Tuck Index and peak power and a negative correlation between the Tuck Index and the 5mRTT was reported (Blanksby et al., 2004; Cossor et al., 1999). However, the latter finding was contradicted by the results of Skyriene et al. (2017) and Cossor et al. (2014).

Although the performance determining factors of the turn are well investigated, it remains unclear whether a change in WCT or Tuck Index could improve a swimmer's turn performance. Therefore, this study aimed to manipulate WCT and Tuck Index to gain insight into their effects on performance. An additional aim was to identify the optimal Tuck Index for the participating swimmers.

METHODS: This study investigated the effect of WCT and Tuck Index on turn performance by experimentally manipulating the WCT and Tuck Index of the swimmers away from their preferred values. This was done on two independent test days within a 4-week period.
Eighteen Dutch national level swimmers (FINA points for 100m freestyle 552 ± 122, eight male, ten female, age 18.44 ± 1.06 years, mass 68.65 ± 3.01 kg, height 179.8 ± 1.8 cm; mean ± standard deviation) participated in the experiment. The participants or their legal guardians in case they were underage signed an informed consent form before participation.
A 900x600x40mm Kistler force plate (1000 Hz, 9691A, Switzerland) attached to the wall and four digital video cameras (50 Hz, Basler, Germany) were used to record each tumble turn. The cameras were positioned on the lateral side of the pool, at the 2.5-m, 5-m, 10-m and 15-m marks. From each video, the Tuck Index, 5mRTT, approach and exit velocity (V_{in}, V_{exit}) and the adaptation time (T_{adapt}), i.e. the time the swimmer needs to bring the feet to the wall, were determined using the customized TurnAnalyzer software (Escrito Sport, The Netherlands). WCT and peak Force (F_{peak}) were derived from the force plate data. A marker was placed on the trochanter major to calculate the Tuck Index.
On both test days, all swimmers were requested to perform 17 turns, starting at about 15m from the wall. During the sessions, 5 out of the 17 turns had to be executed with the preferred WCT or Tuck Index, respectively, followed by 6 turns with a 25% shorter (Short) and 6 turns with a 25% longer (Long) WCT than preferred. For the investigation of the Tuck Indices, the athletes were asked to perform 6 turns closer (Close) and 6 turns further away (Far) from the wall without using fixed thresholds. During both test sessions, all swimmers started with the preferred reference condition, followed by the two manipulations in counterbalanced order. An additional trial for the experimental conditions was allowed in anticipation of possible invalid trials. Feedback was given if the desired condition was not realized.

The data was analysed using SPSS (IBM SPSS Statistics, Version, 27.0) and Matlab R2020b. To examine whether the swimmers achieved significantly different WCTs and Tuck Indices during the test conditions, 3x2 ANOVAs with repeated measures were performed with the experimental condition as within-participant factor (3 levels) and sex as between-subject factor (2 levels). It was also verified if the manipulations resulted in differences for the 5mRTT and the F_{peak} using the same method. Bonferroni post-hoc tests were performed if significant main or interaction effects were found.
Pearson correlation coefficients were calculated to see how the different variables were related to each other. In addition, a linear mixed effect model analysis was performed to examine the extent to which the WCT, F_{peak}, V_{in}, T_{adapt} and V_{exit} accounted for the 5mRTT.
To estimate the optimal Tuck Index a quadratic estimation function was used on both the entire group and the individual swimmers. The significance level for all statistical tests was set at a p-value smaller than 0.05.

RESULTS: The WCT's were significantly different across the experimental conditions ($p<0.001$, $\eta_p^2=0.858$, table 1), indicating that the manipulation was successful. There was a significant main effect of the WCT manipulation on the 5mRTT ($p<0.001$, $\eta_p^2=0.442$) with the 5mRTT being shortest for the reference condition. F_{peak} was the highest in the short contact trials and differed significantly from the reference trials and long contact trials ($p<0.001$, $\eta_p^2=0.631$). The results for the other variables are displayed in table 1.
The linear mixed effect model resulted in negative significant effects of WCT ($p<0.001$), F_{peak} ($p=0.04$), V_{in} ($p=0.02$), T_{adapt} ($p=0.002$) and V_{exit} ($p<0.001$) on the 5mRTT.

The achieved Tuck Indices were different across the experimental conditions ($p<0.001$, ηp2=0.890), indicating that also this manipulation was successful (table 1). The 5mRTT was shortest in the reference trials ($p<0.001$, $\eta_p^2=0.829$). Post-hoc tests revealed that performance was significantly higher in the reference condition than in the far and close condition.
A significant main effect of the experimental manipulation was found for the WCT ($p<0.001$, $\eta_p^2=0.781$). Post-hoc tests revealed that the WCT was shortest during the Far condition. A

significant main effect of condition was also found for F_{max} ($p<0.001$, $\eta_p^2=0.781$). Post-hoc tests showed that F_{peak} was highest in the Far condition and lowest in the Close condition.

Table 1: Descriptive and statistical results

Manipulating WCT	Short	Reference	Long	F-Statistics
WCT (s)	0.27 ± 0.06	0.33 ± 0.05	0.43 ± 0.08	p<.001
5mRTT (s)	5.78 ± 0.49	5.65 ± 0.47	5.93 ± 0.47	p<.001
F_{peak} (N)	1223 ± 334	1052 ± 282	1006 ± 279	p<.001
V_{in} (m/s)	1.56 ± 0.14	1.61 ± 0.12	1.55 ± 0.13	p=.021
Manipulating Tuck Index	Close	Reference	Far	
Tuck Index	0.44 ± 0.09	0.65 ± 0.06	0.82 ± 0.07	p<.001
5mRTT (s)	6.23 ± 0.56	5.67 ± 0.47	6.01 ± 0.51	p<.001
WCT (s)	0.58 ± 0.18	0.33 ± 0.05	0.22 ± 0.05	p<.001
F_{peak} (N)	887 ± 259	1046 ± 278	1270 ± 384	p<.001

A negative correlation between Tuck Index and WCT ($r = -0.830$, $p<0.001$), and a positive correlation between Tuck Index and F_{peak} were found ($r = 0.473$, $p<0.001$), in the absence of a significant correlation between Tuck Index and 5mRTT ($r = -0.102$, $p=0.100$).
The quadratic estimation function resulted in a predicted Tuck Index of 0.70 ± 0.04 across all swimmers with an average measured Tuck Index of 0.65 ± 0.06.

DISCUSSION: In this study, the effects of changes in the WCT and the Tuck Index on the 5mRTT and other performance-related variables was investigated experimentally. The results show that swimmers are able to change the two experimental variables of interest and that these changes affect their performance. The main findings indicate that shortening the WCT and adopting a Tuck Index of approximately 0.7 might improve the tumble turn performance.
The WCT and F_{peak} results of the reference trials of this study were comparable with those of previous tumble turn studies (Cossor et al., 2014; Lyttle et al., 1999; Puel et al., 2012; Skyriene et al., 2017). Manipulating the WCT affected the F_{peak} and V_{exit} with shorter WCT resulting in a higher F_{peak}, and a longer WCT accompanying a higher V_{exit}, which is consistent with other studies (Klauck, 2005; Lyttle et al., 1999). The high F_{peak} during short WCT is possibly caused by a high impact force, resulting in a less efficient push-off resulting in a lower V_{exit} (Lyttle et al., 1998). The higher V_{exit} during the longer WCT is likely related to the later occurrence of F_{peak} (Lyttle et al., 1999; Puel et al., 2012), which increases the acceleration during push-off due to the more streamlined position at the end of the WCT (Klauck, 2005; Lyttle et al., 1999). However, to have a beneficial effect on the turn performance, the higher V_{exit} has to compensate for the time lost during a longer WCT.
It is clear that these results are mediated by other variables, since the measured 5mRTT was longest for the long WCT, while the mixed effect model discussed below showed a positive effect of a longer WCT. Important mediating variables are likely the glide depth and the initiation time of the dolphin kicks (Cossor et al., 2014).
The presented Tuck Index results are in line with previous studies that reported tuck indices ranging between 0.56 ± 0.1 and 70.71 ± 0.09 (Blanksby et al., 1996; Skyriene et al., 2017).
Prins and Patz (2006) also estimated the optimal Tuck Index. For an optimal take-off during the tumble turn, the Tuck Index was 0.46. However, the Tuck Index that resulted in an optimal 5RTT was 0.57 ± 0.14, but this did not result in an optimal take-off power. Ultimately, the swimmer wants to swim as fast as possible; we therefore based the calculations on the 5mRTT, which resulted in a Tuck Index of 0.70 ± 0.04. For some swimmers, this meant that their optimal Tuck Index fell within their reference values, while the prediction of the Tuck Index was higher than the reference values for others, indicating that they might achieve a faster turn when turning slightly further from the wall.
The Tuck Index was negatively correlated with the WCT because it takes more time to extend the legs. This finding confirms the results from previous studies (Blanksby et al., 2004; Cossor et al., 1999). In addition, the Tuck Index correlated positively with the F_{peak}, which is supported by the results of Blanksby et al. (2004). This can be explained by the small knee flexion angle

during close turns which forces the extensor muscles to work at an inefficient length, thus producing less force compared to a larger knee flexion angle. Pereira et al. (2006) advised a knee angle between 110 and 120 degrees for better turn performances. Although it is difficult to compare knee angles with the Tuck Index, a knee angle of 90 ° is related to a Tuck Index of around 0.70.

Here, no significant relationship was found between the Tuck Index and 5mRTT, while in previous studies both positive (Cossor et al., 2014; Skyriene et al., 2017) and negative relationships (Blanksby et al., 2004) were reported. This might be the result of differences in the study designs used and the reported ranges of Tuck Indices.

During the manipulation of the WCT and the Tuck Index, the swimmers were instructed to keep the approach of the wall and underwater phase as constant as possible. However, this was not the case for V_{in} and T_{adapt}. The slower V_{in} in the manipulated conditions was possibly caused by the fact that the participating swimmers were less familiar with the experimental conditions other than the reference conditions. Fatigue might have also played a role, although sufficient recovery time was given.

CONCLUSION: To increase turn performance for all swimmers it is recommended to focus on generating a high F_{peak} at the end of the WCT when the body is in a proper streamlined position. To this end, a sufficiently long WCT is required. The present results further suggest that it is possible to recommend an optimal Tuck Index for individual swimmers, which might help to improve their tumble turn and thus their race performance. These results need to be confirmed by an intervention study in which the swimmers are trained to perform the tumble turn with the recommended WCTs and Tuck Indices.

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