Original Article

Performance analysis of the flip turn in swimming: The relationship between pressures and performance times

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ABSTRACT

This study examined the effects of pressure and other kinetic variables on freestyle flip turn performance. It was hypothesized that an increase in average and peak pressure, and a decrease in the magnitude difference between left and right foot pressure, would result in an improved performance of a swimmer as they performed a flip turn. Ten University level (varsity) swimmers performed five freestyle flip turns using their competition technique. Data were collected from a pressure pad mounted to the vertical wall of the pool and from an underwater camera in the sagittal plane. A negative correlation of .58 and .67 was seen for average and peak pressures respectively when compared to five-meter performance times. Average contact area throughout the push-off phase compared to average and maximum load was .94 and .88. An increase in average contact area from 40 cm^2 to 50 cm^2 resulted in a 26% increase in maximum load. No difference in performance was seen for varying maximum knee flexion angles. Differences between pressure magnitudes between left and right foot did not impact the five-meter performance time. Therefore, increased average contact area throughout the push-off phase caused higher average and maximum loads, and to a lesser extent average and peak pressures. Increases in pressure and load resulted in an improved five-meter performance time. It is concluded that flip turn performance increases through higher contact area with the feet when pushing off the wall.

Keywords: Biomechanics; Performance analysis; Swimming; Elite athletes; Flip turn.

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INTRODUCTION

At an elite level of swimming, the time difference between achieving a podium finish can come down to tenths of a second, especially in short distance sprint races (Clephas & Wilhelm, 2019). Races consist of the start, the actual swimming component, and for the majority of races, the turns. While the swimming start has been studied, the technical nature of the freestyle flip turn has only been examined to a certain extent. Turns have been analysed kinetically in the form of peak force and impulse, and kinematically in the form of wall contact time, angles of segments and turn path length (Araujo et al., 2010; Blanksby, Skender, Elliott, McElroy, & Landers, n.d.; Chollet, Hogie, & Papparodopoulos, 2002; Lyttle, Blanksby, Elliott, & Lloyd, 1999; Puel et al., 2012).

In a study examining the contribution of each race segment in the 1992 Atlanta Olympics, it was found that with the exception of clean swimming speed, turning is the only race segment speed that is significantly related to end race result in all strokes, in Olympic swimmers, and in almost all functional Paralympic classes (Daly, Malone, Smith, Vanlandewijck, & Steadward, 2001). Furthermore, when the turn is broken down, (Araujo et al., 2010), found that peak force and impulse had the largest contribution to improving turn time. It was stated that while the turn depends on force, the time associated with the force application is important (Araujo et al., 2010). The intricacies of a flip turn is evident by previous literature also studying the effect of hydrodynamic drag in relation to wall-exit velocity and inducing a more stream-lined body position (Lyttle et al., 1999).

Previous research has solely examined the resulting effect of kinetic variables such as peak push-off force and wall-exit velocity when compared to a performance measure. However, not much is known about how a swimmer's push off the wall can affect the corresponding performance of a freestyle flip turn. The short time a swimmer is in contact with the wall, leads to the results seen in previous literature. By examining the effect of pressure, whether it is peak or average pressure, and how the foot is used to contact the wall through the push-off phase, it could provide insight into the most effective technique in performing a flip turn.

Therefore, the aim of this study was to biomechanically examine the effect of pressure on the performance of a freestyle flip turn by using a waterproofed pressure pad and finding the interconnected kinematic and kinetic variables that contribute to improving swimmers' five-meter performance time. It is hypothesized that an increase in average and peak pressure, as well as a decrease in the magnitude difference between the left and right foot pressure, will result in an improved five-meter performance time.

MATERIALS AND METHODS

Participants and Measures

The sample was comprised of N = 10 (5 males and 5 females) who compete for a varsity swim team. The subjects had a mean age of 19.1 ± 1.1 years, height of 179.3 ± 12.2 cm, and mass of 75.12 ± 13.7 kg. All participants performed the same style of freestyle flip turn that they use in a competition. Five swimmers used a lateral push-off and five swimmers used a vertical push-off. Five of the ten swimmers were freestyle specialists, while the other five swimmers reported a different discipline. Each participant prior to data collection signed informed written consent, approved by the institution's ethics board.

Procedures

Each participant completed their regular warm-up at the start of varsity practice. Swimmers performed five freestyle turns under competitive conditions with maximal effort. The procedure had the participants start 15 meters from the vertical wall in a still position and swim at their maximal speed to perform a freestyle flip turn. Depending on the swimmer's preference, a vertical or lateral push-off occurred on the underwater pressure pad mounted to the vertical wall in Lane 2 and participants swam back past the 10-meter point. The pressure pad mount was designed to mimic the Omega touch pad that is used in competitions as closely as possible, and swimmers reported the pressure pad to be comparable.

Kinetic and kinematic variables were investigated in this study. The kinematic variables consisted of maximum angle of knee flexion and kinetic variables consisted of average pressure, peak pressure, average load, maximum load, impulse and average contact area.

In the assessment of the kinetic variables, an XSensor X100 Pressure pad (Calgary, Alberta, Canada) with a contact area of 80cm by 80cm and a sampling frequency of 31 frames per second was used. To mount the pressure pad to the vertical wall, the pad was connected to a 1cm thick PVC plastic board that rested along the pool deck and dropped down 90 degrees against the vertical wall. Data were analysed in the accompanying X3 Pro V7 Software from Xsensor Technology Corporation (Calgary, Alberta, Canada).

During the push-off phase, while the swimmer was in contact with the pressure pad, average pressure was determined as the pressure across every active sensor for each frame of contact. For each trial, the frames were averaged to obtain one average pressure for the entire wall contact time. The peak pressure was defined as the maximal pressure occurring on any individual sensor throughout contact with the pressure pad. The sum of the peak pressure for the left foot and peak pressure for the right foot were then summed to create the total maximum peak pressure.

Average and maximum load were exported from the X3 Pro V7 software and were examined in the same way as the pressure variables with average load defined as the average of each frame of data throughout the swimmers contact with the vertical wall. Maximum load was obtained from the maximum load occurring during any time of the contact phase for the summation of the loads produced from the right and left foot. From the determination of the load, the impulse was calculated in the normal direction to the pressure pad for every recorded flip turn trial to account for the combination of load and contact time.

To determine the average contact area throughout the push-off, the area of the active sensors for the left and right foot were summed for each frame of data and the frames were averaged for the time period that the swimmer was in contact with the pressure pad. The difference in average area between right and left foot was calculated to examine if greater symmetry or in other words, a reduced area difference had an effect on turn performance. Furthermore, the areas were compared to the two different turn techniques, lateral and vertical push-off, to note any differences that could be a result of how the push-off is performed.

Analysis

To examine maximum angle of knee flexion, 5-meter time and turn time, a SeaViewer Seadrop 650 underwater video camera measuring at 30 frames per second was positioned on the side-wall of the pool in the sagittal plane, with a field of view containing the pressure pad to the 5-meter distance. Maximum angle of knee flexion was defined as the maximum angle of the knee closest to the underwater camera during contact with the vertical wall. The angle was calculated using Dartfish Video Analysis software (TeamPro 7.0) and was determined by the angle created from the lateral malleolus, lateral epicondyle and greater trochanter.

Five-meter time was defined as the time of first contact with the vertical wall up until the first body segment, in this case the fingers, passed the 5-meter point. A 5-meter reference frame was determined using Dartfish

Video Analysis software and all subsequent distances were based off the initial reference distance. Turn time was defined as the time occurring from the swimmers reaching one-meter prior to touching the wall, until three-meters from the wall after push off. The International Federation of Amateur Swimming (FINA) uses a standard distance of 15m for turn time, however, the distances chosen above were selected to isolate only the turn phase of a freestyle flip turn and attempt to negate the other effects associated with swimming a 15m distance.

RESULTS

The kinematic and kinetic variables analysed for freestyle flip turn performance are displayed in Table 1, with the means and standard deviations for all swimmers across all trials.

Table 1. Trials (n), mean, minimum, maximum and standard deviation (SD) for measured kinetic and kinematic variables.

Variable	n	Mean	Min	Max	SD
Average Pressure (kPa)	49	247.35	172.31	341.24	34.196
Peak Pressure (kPa)	49	570.93	305.88	798.18	110.608
Average Load (N)	49	598.67	170.94	1171.67	295.957
Maximum Load (N)	49	836.67	140.54	1624.36	390.06
Impulse (Ns)	49	170.74	57.75	352.01	81.024
Average Area (cm^2)	49	45.80	16.13	80.64	19.024
Maximum Angle of Knee Flexion (°)	25	69.64	50.2	84.8	9.877
5-Meter Time (s)	49	1.263	0.887	1.804	0.208
Contact Time (s)	49	0.319	0.17	0.44	0.064
Turn Time (s)	49	1.452	1.134	1.768	0.187

For peak pressure, there was a maximum peak pressure of 798.18 kPa exhibited by Swimmer 5, a male with a specialty swimming discipline of short distance freestyle races. Comparatively, Swimmer 7, a female who is a butterfly stroke specialist, exhibited a minimum peak pressure of 305.88 kPa (Table 1). A similar outcome was shown in average pressure as the same two swimmers also obtained the maximum and minimum average pressures. However, the maximum and minimum average pressures occurred during a different turn trial then was found for peak pressures. The correlation found between average pressure and peak pressure was .57 with peak pressures displaying a stronger correlation to the 5m-performance time (Figure 1, Table 2). The difference in magnitude between the left and right foot pressures, or in other words the symmetry between the swimmer's two feet, did not have an impact on performance times or in relation to any other kinetic variables.

The maximum load exerted by the swimmer at any point while in contact with the pressure pad led to a correlation with the 5-metre time of .62. Comparatively, taking the average load applied by the swimmer throughout the push-off found a slightly higher correlation to the 5-metre time at .67 (Figure 1, Table 2). These results were supported by the findings of Lyttle et al. (2009), who found that higher peak forces produced a faster wall-exit velocity, leading to an improved time performance. Contrary to that study, no strong correlation existed between contact time with the wall and average or maximum load. Due to the effect of this load on the 5-metre performance time, the impulse was examined and was found to have no impact on five-meter or turn time performance. However, impulse was strongly correlated to the average contact area with the vertical wall.

Table 2. Correlations between kinetic and kinematic variables analysed for all swimmers.

	r^2 Correlation
5m Time x Average Pressure	.58
5m Time x Peak Pressure	.67
5m Time x Average Load	.67
5m Time x Maximum Load	.62
5m Time x Average Area	.59
5m Time x Maximum Knee Flexion	.01
Turn Time x Average Pressure	.37
Turn Time x Peak Pressure	.43
Turn Time x Average Load	.39
Turn Time x Maximum Load	.41
Average Area x Average Pressure	.34
Average Area x Peak Pressure	.64
Average Area x Average Load	.94
Average Area x Maximum Load	.88
Average Area x Impulse	.86

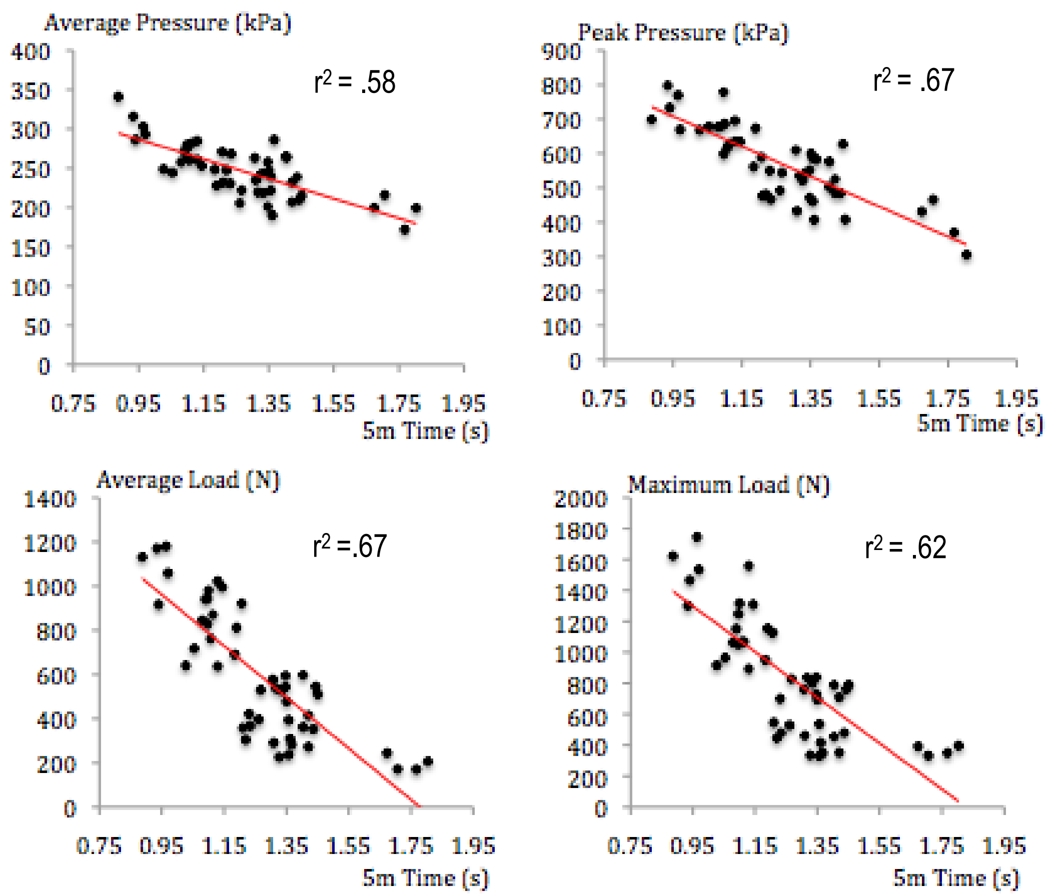

Figure 1. Average Pressure, Peak Pressure, Average Load and Maximum Load compared to 5m Performance Time for all swimmers performing freestyle flip turns.

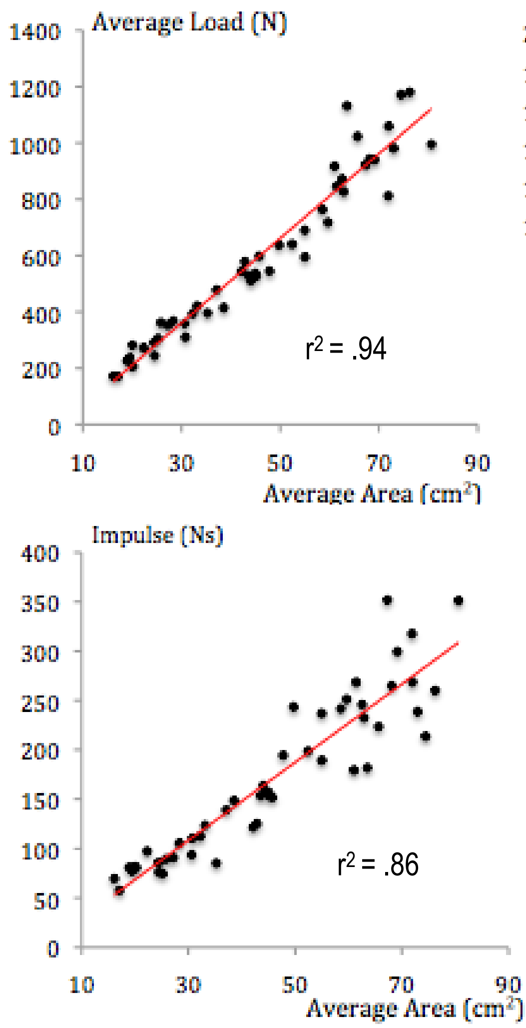

Figure 2. Average Load, Maximum Load and Impulse compared to Average Area for all swimmers performing freestyle flip turns.

Average area of the feet while in contact with the wall, compared to impulse was found to have a correlation of .86. Furthermore, average area compared to the average load and max load led to correlations of .94 and .88 respectively (Figure 2, Table 2). That is, as the average area throughout the push-off increases, the average and max load also increase. Compared to load, average and peak pressures compared to average area did not produce as strong of correlations but still resulted in positive correlations of .34 and .64 (Table 2).

In comparison across all kinetic variables, it was found that 5-metre performance time led to stronger correlations than our defined turn time. Also, contact time with the vertical wall alone displayed no difference in outcome when compared to any of the kinetic variables measured. Kinematically, maximum knee flexion was examined in the five swimmers that performed vertical push-offs rather than lateral push-offs and was found to have no correlation with any time performance.

DISCUSSION

The purpose of this investigation was to identify possible kinetic and kinematic variables associated with an improved performance of a freestyle flip turn as indicated by a five-meter performance time. The kinetic variables found to be most correlated with the five-meter time were average and peak pressures as well as average and maximum loads. Furthermore, the variable found to have the greatest impact in the resulting pressures and loads was average contact area while in contact with the vertical wall.

A negative correlation existed between pressure and performance time as an increase in average or peak pressure contributed to a decrease in five-meter time. Average pressure was generally found to be higher with a shorter contact time as this could indicate that the longer a swimmer is in contact with the wall, the more difficult it is to maintain a higher average pressure across the contact area. The mass of the swimmer may also impact the results seen as all males exhibited higher average pressures than females, with the heaviest male, Swimmer 1, providing the second highest average pressures behind Swimmer 5, the second heaviest male. However, the relationship did not hold true for the female swimmers as the highest average pressure among females was found in Swimmer 9, the second lightest swimmer.

Similar correlations were seen in average and maximum load in comparison to the five-meter performance time. A negative correlation of .67 and .62 for average and maximum load respectively, indicate that an increase in load throughout the push-off is beneficial for improving flip turn performance. The mass of the swimmer impacts the load a swimmer can produce. However, in a similar manner to pressure, the highest load values were not seen from the heaviest swimmer. While mass contributes to the average and maximum load, a large contribution comes from the average area the swimmer has with the vertical wall throughout the push off. A correlation of .94 for average load and .88 for maximum load when compared to average area was found. As mentioned previously, the larger contact area the foot has with the wall leads to a potential for greater force production. With an increase in average area from 40 cm^2 to 50 $cm^{2,}$ a 26% increase was seen in the maximum load. However, the varying foot sizes of the swimmers could explain some of the results. Looking at each swimmer individually to discount the effect of foot size, seven of the ten swimmers measured displayed consistent results for all five of the flip turn trials, showing that a greater average area throughout the push-off led to higher average and maximum loads.

In elite swimming, turns and the underwater kicking period have become more and more importance over the last decade. In contrast to the start, turns are more important in longer distances because there are more turns during longer races but only one start for all races. In the analysis of the freestyle event at the 1992 Olympics Arellano et al. (1994) showed in 100m and 200m races, a similar correlation existed in the turns, whereas the importance of the start decreased in male as well as in female athletes. These findings were supported by Mason and Cossor in their analysis of the 1999 Pan Pacific Games. Furthermore, they found that the turn time correlated in all freestyle events up to 800m in female and m in male athletes. From 200m to 1500m in male athletes they observed a correlation greater than an $r^2 = .9$.

Future research should take a deeper look into additional aspects of turns. One option is the variation in test performance during turn. Clephas et al. (2019) has shown that the variation in start performance analysis is correlated to the variation in overall performance. Compared with the knowledge that variation in performance is an important indicator for future success, this information can help coaches assess athlete progression.

CONCLUSIONS

The findings of this study indicate that pressure has an effect on the performance of a freestyle flip turn. With higher average and peak pressures, it was found that a five-meter performance time subsequently decreases, resulting in improved performance. Average contact area with the vertical wall was the primary mechanism studied that was found to have an effect. With a higher average contact area, higher pressures and loads could be obtained. Further research is required in comparing different turning styles, namely vertical and lateral push-off as well as further examination into a possible relationship between maximum knee flexion and pressure. From our initial findings, the recommendation for improving turn performance lies in increasing the average contact area with the foot throughout the push-off phase.

AUTHOR CONTRIBUTIONS

All authors did substantial contributions to the paper. Stergiou and Katz did conception and design in close collaboration with Clephas. They also tested the force plate in a pilot. Data analysis and data interpretation where done by Forster, who also did a first manuscript. Afterwards, Katz and Clephas did revisions to improve important intellectual content. Finally, Clephas did some formatting for the publication.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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REFERENCES

Arellano, R., Brown, P., Cappaert, J. & Nelson, R. C. (1994). Analysis of 50-, 100-, and 200-m freestyle swimmers at the 1992 Olympic Games. Journal of Applied Biomechanics, 10, 189-199. https://doi.org/10.1123/jab.10.2.189

Araujo, L., Pereira, S., Gatti, R., Freitas, E., Jacomel, G., Roesler, H., & Villas-Boas, J. (2010). Analysis of the lateral push-off in the freestyle flip turn. Journal of sports sciences, 28(11), 1175–81. https://doi.org/10.1080/02640414.2010.485207

Blanksby, B. A., Skender, S., Elliott, B. C., McElroy, K., & Landers, G. (n.d.). An Analysis of the Rollover Backstroke Turn by Age-Group Swimmers. Sports Biomechanics. https://doi.org/10.1080/14763140408522826

Clephas, C. & Wilhelm, A. (2019). Variability of competitive results during one season in swimming. German Journal of Exercise and Sport Research. https://doi.org/10.1007/s12662-018-0563-7

Clephas, C., Stergiou, P., & Katz, L. (2018). Start performance and its relation to competition times in Paralympic swimmers. Journal of Human Sport and Exercise, 14(3), 645-655. https://doi.org/10.14198/jhse.2019.143.14

Chollet, D., Hogie, S., & Papparodopoulos, C. (2002). Kinematic analysis of butterfly turns of international and national swimmers. Journal of Sports Sciences, (20), 383–390. https://doi.org/10.1080/026404102317366636

Daly, D. J., Malone, L. A., Smith, D. J., Vanlandewijck, Y., & Steadward, R. D. (2001). The Contribution of Starting, Turning, and Finishing to Total Race Performance in Male Paralympic Swimmers. Adapted Physical Activity Quarterly, (18), 316–333. https://doi.org/10.1123/apaq.18.3.316

Lyttle, A. D., Blanksby, B. A., Elliott, B. C., & Lloyd, D. G. (1999). Investigating Kinetics in the Freestyle Flip Turn Push-Off. Journal of applied biomechanics, 15, 242–252. https://doi.org/10.1123/jab.15.3.242

Mason, B. & Cossor, J. (2000). What can we learn from competitions analysis at the 1999 Pan Pacific swimming championships? Conference: 18. International Symposium on Biomechanics in Sports. Hong Kong, China.

Puel, F., Morlier, J., Avalos, M., Mesnard, M., Cid, M., & Hellard, P. (2012). 3D kinematic and dynamic analysis of the front crawl tumble turn in elite male swimmers. Journal of biomechanics, 45(3), 510–5. https://doi.org/10.1016/j.jbiomech.2011.11.043