# APPLICATIONS OF BIOMECHANCIS IN SWIMMING

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Swimming is one of the most popular forms of physical activity and competitive sports around the globe. The purpose of this study was to further understand how people move through the medium of water. To address this issue three projects were conducted on elite swimmers (FINA rankings >900) and quantified the biomechanics of swimming via inertial sensors, towing force devices, and bilateral swim ergometers combined with 3D kinematics. The previously unknown parameters of quantifying kick rate and kick have been established; the influence of breathing on the net drag identified; and scientific basis for the Paralympic swimming classification process quantified. Applications of these biomechanical measures add to the pool of knowledge on swimming technique and form the foundation for an evidence-based International Paralympic swimming classification system.

**KEY WORDS:** swimming, paralympic, inertial sensors, net force.

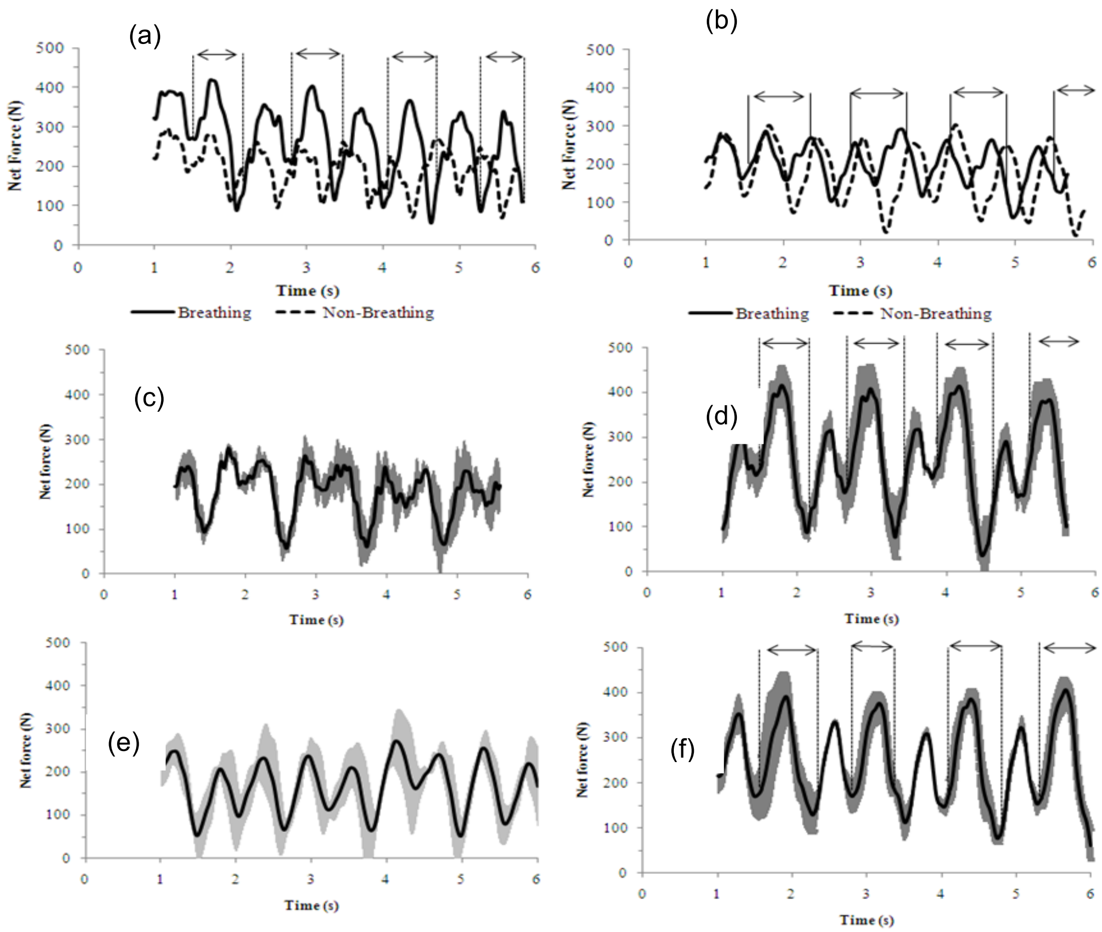
**INTRODUCTION:** Swimming movements involve complex relationships between the propulsive and resistive forces acting on the body, whilst in the challenging measurement environment of water. Measuring a swimmer's kick rate is difficult when observing with just the human eye or above water video, due to the water turbulence and mass of white water associated when kicking. To overcome this issue the unobtrusive, lightweight, wireless, inexpensive and commercially available features of an inertial sensor makes this technology an attractive option for field-based research (Lee, Burkett, Thiel, & James, 2011). Therefore the first application of biomechanics in swimming was to determine the validity of using inertial sensor technology to quantify the kick variables of kick rate and kick count (Fulton, Pyne & Burkett, 2009).
The second project investigated the influence of breathing on the net force production when swimming. Breathing is an essential component of the prone swimming strokes of freestyle, breaststroke or butterfly. Naturally, if a swimmer can integrate the breathing action into the stroke without compromising net force production swimming performance will be enhanced. Using a net force towing device the modifications in swimming efficiency can be identified as the swimmers rotates to breath (Formosa, Mason, & Burkett, 2011).
The third project was related to the Paralympic Games, which are the highest form of competition for an athlete with a disability. The fundamental distinction between the Olympic and Paralympic Games is the Paralympic classification system. Recently the International Paralympic Committee mandated the development of an evidence-based classification system for each sport. These systems were established to provide a 'fair and equitable' playing field for athletes with a complex range of physical disabilities (Tweedy & Vanlandewijck, 2009). To create an objective Paralympic classification system this study evaluated the current classification musculoskeletal protocols with swimming specific equipment.
The three objectives of this study were; (i) to apply and validate inertial sensor technology to quantify kick rate and kick count, (ii) to determine the influence of breathing on swimming net force, (iii) to objectively assess the International Paralympic Committee swimming classification system. The findings from this research can guide future teaching and performance enhancement coaching of elite swimmers.

**METHODS:** To determine kick count and kick rate, 12 elite (Paralympic) swimmers performed a maximal effort 100m freestyle swimming and 100m freestyle kicking-only time trial. A total of 226 swimming trials and 217 kicking-only trials were included in the analysis for validity and reliability. The inertial sensors (MiniTraqua, Australian Institute of Sport), with external dimensions 5.2 x 3.3 x 1.1cm, included a ±2G tri-axial accelerometer, (Kionix; Model KMXM52, New York, USA); a single > 600rad·s-1 angular-rate sensor (gyroscope); a data storage card and USB interface. A complete kick was defined when the gyroscope signal started at zero rad·s-1, (beginning of the down phase), crossed a subsequent zero rad·s-1 and returned to zero rad·s-1 (end of an up phase).

To investigate the influence of breathing 20 elite swimmers (FINA point ranking 909 ± 59) completed six randomised net force free swimming trials, three breathing and three non-breathing breathing. Each trial was videoed using three genlocked 50Hz cameras that were synchronised to an assisted towing device positioned on a 900x600mm Kistler Force-Platform (Type Z12697, Kistler instruments, Switzerland).

For the third study, data was collected via three procedures: (i) The musculoskeletal range of motion, as per the swimming classification protocol; (ii) The 3D kinematic range of movement (120Hz) when simulating swimming; and (iii) The performance output of generated bilateral hand force. The range of motion of the upper body was made with a calibrated goniometer by a qualified physical therapist. Each participant completed three simulated freestyle swimming trials, each of 60s as this reflected a 100m swim. Using a custom-built swim bench the bilateral force was measured using a WEBA Swimming Ergometer (Weba Sport, Vienna, Austria), and the 3D kinematics (Motion Monitor, Version 6.50.0.1 Innovative Sports Training, USA). To mitigate against the numerous physical variations in people with a disability, 32 elite able-bodied swimmers were assessed. The kinematics and hand force were compared to current classification protocols.

**RESULTS:** For the kick analysis project the standard error of the estimate (validity) for kick count, expressed as a coefficient of variation, was 5.9% (90% CI 5.5-6.4) for swimming, and 0.6% (0.5-0.6) for kicking-only trials. The mean bias for kick count was -1.7% (-2.4 - -1.1) for swimming, and -0.1% (-0.2 - -0.1) for kicking-only trials. Correlations between the sensor and video for kick count were 0.96 (0.95-0.97) for swimming, and 1.00 (1.00-1.00) for kicking only trials. The typical error of the measurement (reliability) between trials was approximately 4% for kick count and rate. The inertial sensors generated sufficient validity and reliability estimates to quantify moderate to large changes in kick count and rate. Swimmers took 145 ± 39 kicks (mean ± *s*) for swimming trials and 254 ± 74 kicks for kicking-only trials. Kick rate was 124.9 ± 20.3 kicks·min$^{-1}$ for swimming trials and 129.6 ± 14.0 kicks·min$^{-1}$ for kicking-only trials. There were no substantial changes among 25m segments in kick count in the swimming trials. There was a substantial increase of 10.6% (7.3-14.0%) in the number of kicks in the kicking-only trials by the 4$^{th}$ 25m segment. There was a substantial decrease in kick rate by the 3$^{rd}$ 25m segment for swimming (-12.0%, -12.8- -11.1%) and kicking-only (-7.3%, -8.6 - -5.9%) trials. The relationship between swimming and kicking-only kick rates was $r$ = 0.67 (0.55-0.76 $p$ < 0.001).
When comparing the breathing and non-breathing swimming criteria there was no significant difference in the mean velocity or stroke rate for either condition, indicating a similar swimming style. For the overall mean velocity of 1.80m.s$^{-1}$ the mean net force increased by 22%, when comparing breathing to non-breathing swimming. There was a significant difference (p = 0.006) in mean net force between breathing and non-breathing conditions. Furthermore, there was a significant difference (p = 0.003) in minimum force for preferred breathing, however no significant difference (p = 0.159) in minimum force for non-preferred breathing. The maximum net force revealed a significant difference in the preferred (p = 0.003) and non-preferred (p = 0.032) when comparing breathing and non-breathing data.
In comparing the current International Classification screening protocol and the biomechanical output measures there were inconsistent, and generally weak, correlations between the current classification system range of motion scores, and the actual 3D kinematic range of motion, with similar weak correlations to hand force.




a) Male participant 1.89m.s$^{-1}$ comparison between breathing and non-breathing condition
b) Female participant 1.69m.s$^{-1}$ comparison between breathing and non-breathing
c) Male participant 1.85m.s$^{-1}$ non-breathing with standard deviation
d) Male participant 1.85m.s$^{-1}$ breathing with standard deviation
e) Female participant 1.77m.s$^{-1}$ non-breathing with standard deviation
f) Female participant 1.77m.s$^{-1}$ breathing with standard deviation

**Figure 1: The net force profile (force-time) for male and female participants at their maximum speed, arrows indicate the breathing stroke.**

From the musculoskeletal screening protocols the only variable with a significant difference between side was shoulder external rotation, mean (95% CI); left 98.4 (93.9-102.9) degrees compared to right 109.9 (101.5-118.3) degrees. Although not identified in the bench-test screening process, when the participants were dynamically moving on the swim-bench with 3D technology, significant ($p<0.05$) differences were also found between side. As expected the 3D kinematic movements were all within the bench-test musculoskeletal range of motion movements. The force profiles from the bilateral ergometer indicated similar force output for side, but differences between genders. Peak force was measured for females as: left 38.4N (35.2-41.7) and right 35.4N (32.4-38.3); males, left 52.0N (47.1-56.8) and right 52.0N (47.7-56.4).

**DISCUSSION:** The new method of assessing kick count and kick rate in freestyle swimming using inertial sensor technology was found to be valid and reliable. Kicking movements that are otherwise difficult to detect, can now be identified with this technology. The evaluation of semi-automated kick count and kick-rate detection yielded small differences between swimming and kicking-only trials. Coaches and scientists can use this technology to identify changes in kick count and rate patterns between training sessions and for seasonal changes between major competitions.

The breathing action resulted in a substantial increase in mean net force, regardless of gender. This study demonstrated that integrating the breathing action into front crawl caused a large increase in net force, which may be detrimental to swimming performance. This unique objective information provides coaches and swimmers with a practical tool to identify how much additional net force the swimmer must overcome during the breathing action.

Although not evident in the relatively static musculoskeletal protocols, important swimming specific asymmetry differences were identified in shoulder abduction/adduction along with external rotation. These findings highlight firstly the deficiencies in the current classification system, followed by the advantages of implementing sport-specific technology to objectively address this international issue. There were inconsistent and generally (approximately three-quarter of all measures) weak correlations between the current Paralympic classification screening scores and the measured 3D kinematic range of motion and the generated hand-force outputs. In terms of direct relationships between the range of movement measures and the eventual force output, the dynamic sports 3D technology measures fared higher than the current bench-test screening scores, where approximately 31% of dynamic 3D and force relationships established correlations scoring better than moderate, compared to approximately 21% moderate or better correlations for the bench-test measures. The fundamental principle of the 'functional' classification system is to determine how an athlete's impairment impacts on sports performance, however the technology-derived measures within this current study suggest the existing subjective screening measures that form the backbone of the classification system weakly correlate with function. Since the development of the current Functional Classification System in 1990 there have been many technological advances that allow the sports scientist to objectively measure force, strength, movement and movement quality. The key now is to develop a process that utilizes valid, objective and reliable sports technology tools to measure both impairment and activity limitation. It should be acknowledged that the classification system was developed almost 20 years ago, being implemented at the 1990 World Championships, and the level of scientific understanding and sports technology in swimming has dramatically increased over the past two decades.

**CONCLUSION:** The collection of the studies presented highlights some applications of biomechanics technology, with respect to further understanding swimming. Of most importance is the development of objective measures to allow scientific guidance to any intervention process. A key aim for future studies is to increase the local and global collaboration of research teams to further advance this sport.

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*Acknowledgement:* We would like to thank the swimmers for their commitment and time to these research projects.