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Project Report

Using Rowers' Perceptions of On-Water Stroke Success to Evaluate Sculling Catch Efficiency Variables via a Boat Instrumentation System

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Abstract: Aim: An effective catch in sculling is a critical determinant of boat velocity. This study used rowers' performance-based judgments to compare three measures of catch slip efficiency. Two questions were addressed: (1) would rower-judged *Yes* strokes be faster than *No* strokes? and (2) which method of quantifying catch slip best reflected these judgements? Methods: Eight single scullers performed two 10-min blocks of sub maximal on-water rowing at 20 strokes per minute. Every 30 s, rowers reported either *Yes* or *No* about the quality of their stroke at the catch. Results: It was found that *Yes* strokes identified by rowers had, on average, a moderate effect advantage over No strokes with a standardised effect size of 0.43. In addition, a quicker *time to positive acceleration* best reflected the change in performance; where the standardised mean difference score of 0.57 for *time to positive acceleration* was larger than the scores of 0.47 for *time to PowerLine force*, and 0.35 for *time to 30% peak pin force* catch slip measures. For all eight rowers, *Yes* strokes corresponded to *time to positive acceleration* occurring earlier than *No* strokes. Conclusion: Rower judgements about successful strokes was linked to achieving a quicker *time to* *positive acceleration*, and may be of the most value in achieving a higher average boat velocity.

Keywords: rowing; biomechanics; performance; judgements and catch

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1. Introduction

Olympic rowing may be seen as an optimization problem where the overarching goal is to maintain the highest average velocity over a 2000 m course [1]. Optimization requires consideration of multiple factors including (but not exclusive to) minimisation of energy loss, application of propulsive force, and decreasing the drag for each stroke [2–4]. A particular point of interest is what rowers refer to as the "catch", where the oar first enters the water as part of the rowing cycle [5]. The catch in rowing can be seen as the prominent point of force application that supports the cyclical movement of sculling (rowing). In common with other cyclical, athletic movements, small variations in force application during the catch can have meaningful effects on performance due to the repetitive nature of the skill [6]. This problem is perhaps best contextualised when set against the smallest worthwhile difference of 0.3% separating medal prospects in international racing, which equates to a distance of 6 m over a 2000 m course [7]. Consequently the relative efficiency of the catch and how it is modelled is of interest to coaches and rowers.

An explanation of the catch is the oar first enters the water, until it is fully covered or "locked" into the water and does not "slip" [5]. The period of time between entry and lock is termed "catch slip". This explanation however, fails to adequately capture, in detail, determinants of an ideal and proficient catch. There is little disagreement that good timing of the catch can minimise boat velocity losses on the recovery of the rowing stroke [5]. Trying to determine a successful and well-timed catch can be problematic, as it can be measured in several ways; a problem that in part rests with disagreement amongst rowing coaches about how a successful catch is achieved [8]. There are three main catch measures in the literature, which attempt to define catch slip and how this impacts boat performance. These are time taken to achieve 30% of peak pin force [4], time to positive acceleration in the direction of the race [9], and a catch slip value automatically generated by a biomechanical feedback instrument for rowing such as PowerLine™.

Time to 30% of peak pin force was a catch measure designed and tested by Kleshnev in 1999 to evaluate oar entry efficiency or catch slip. The aforementioned study showed that a faster time to 30% of peak pin force was achieved, the earlier the rower and boat system started to accelerate, and this was claimed to have potential performance gains of up to 5% [4]. However, there are some limitations with this method, as the rower could start applying force to the oar while it is changing direction, and this can give a quicker time to 30% peak pin force production without achieving a quicker time to positive boat acceleration [10].

A rowing boat moves through phases of positive and negative acceleration during the stroke cycle [11]. Better rowers achieve at the same stroke rate positive boat acceleration after the highest negative values (world champions -10.1 m/s^2 *versus* national championship finalists -6.9 m/s^2) in shorter time [12]. Therefore, achieving positive boat acceleration quickly, is understood to be related to a rowers' ability to accelerate their body more rapidly at the catch [9]. Measuring the time to positive acceleration can be performed in the same way as calculating 30% of peak pin force; *i.e.*, measure the time taken from the catch to when positive boat acceleration occurs [13]. Rowers who have a good technical ability are able to reach positive boat acceleration in a shorter time and, thus, able to minimise the effect of the negative boat acceleration that occurs at the start of the drive. This technical ability is thought to be associated with minimising the "slip" of the rowing oar as it enters the water. The oar inevitably slips a little as it enters the water before it grips in order to propel the boat, but what is to be avoided is a long slip period [5]. As with 30% of peak pin methods, time to positive acceleration can only be calculated with post-event analysis, and so this delays when feedback can be given to the rowers.

PowerLine™ is a biomechanical instrumentation system that is commonly used by international rowing programs around the world. It can automatically generate data on key biomechanical variables in real-time or to be used *post hoc*. Amongst the default variables generated is catch slip. PowerLine™ generates a catch slip value, which is the angle travelled by the oar until it reaches a pre-set threshold force applied to the pin along the longitudinal axis of the boat. In addition, PowerLine™ calculates the time taken from the catch to reaching a pre-set catch slip threshold, which for sculling is 196 N. Similar to the 30% peak pin force, PowerLine slip can provide inaccurate readings if force is applied to the pin before the blade has entered the water. Therefore, this could make PowerLine slip an inaccurate measure for catch efficiency.

One way to assist coaches and rowers in the decision regarding which measure of catch performance is most effective is to ask rowers to judge strokes as either successful or not. Once performance judgments are made, it is possible to compare the standardised mean differences [14] of the three catch measures with respect to velocity. Performance-based judgements is not a new concept; it is a fundamental skill of coaching [15,16]. However, using athlete's judgments to evaluate performance measures compared to boat instrumentation is novel.

Individuals have the ability to accurately distinguish between different stimuli and then respond appropriately to what they perceive. Fajen, Diaz, and Cramer [17] demonstrated that athletes are knowledgeable with respect to their own locomotor capabilities and are able to make simple judgements that capture differences between multiple integrated variables at once. This presents high-level performers as expert systems adept at detecting and evaluating change focussed on performance. In contrast, instrumentation is currently built to measure a set of single variables, while people can integrate the variables automatically. Even "accurate" instrumentation is problematic; for example, boat velocity impellers do not integrate information on wind speed and direction, water current speed, and direction, nor what occurred on previous strokes. Consequently optimal performance cannot always be reconciled to basic dimensions such a velocity. Success may be the ability to solve movement problems in context and therefore the quality of the solution is most germane to performance. Recent shifts in thinking with respect to biomechanics and skill theory reflects this when describing concepts such as functional variability [18,19]. When measuring performance *in situ* it seems reasonable to suggest that expert performance judgements (not novice judgements) constitute a sufficient independent variable for studies of performance.

In a recent qualitative study [20] Olympic rowers were confident in their ability to predict performance. In particular, Olympic rowers stated that when they were rowing, they could identify success using their perception of the catch and the passage of water past the boat for any given stroke. For example, one of our rowers stated: "You know straight away if you are out of time, you can just feel it. It is not something that you think about, it is just something that you know". A method for understanding this perception of performance could be through a simple Yes or No scale, where rowers make a decision as they perform. It would be expected that individual strokes, which rowers perceive are successful, would be faster than perceived non-successful strokes.

The aim of this study was to document rower's perceptions of on-water stroke success and use this to evaluate three measures of catch efficiency in order to determine which had the greatest effect on performance; therefore, two questions have been addressed: (1) Would Yes strokes be faster than No rower-judged strokes? (2) Which measure of catch efficiency had the largest standardised mean difference?

2. Method

2.1. Participants

Eight single scull rowers aged 19 to 24 years with four to nine years of experience participated in this study. The gender and weight division of the rowers were four lightweight men (below 72 kg), three heavyweight woman (above 59 kg), and one lightweight woman (below 59 kg). Rowers were all current members of Rowing New Zealand's talent development program and had represented New Zealand at age-level world-championships. The principal researcher's University Ethics Committee provided ethical clearance (AUTEC number 11/161). All rowers were informed of the procedures and gave their written consent.

2.2. Procedure

The rowers performed two ten-minute blocks of sub maximal on-water rowing at 20 strokes per min (spm). Sub-maximal is the level at which over 80% of rowing training is performed at [21]. Before the rowers went on the water to perform, they were told that approximately every 30 s during the two ten-minute pieces they would be asked to state if that stroke was a *Yes* or *No* stroke. While performing on the water, the lead researcher said "Now" late in the drive phase, enabling the rower to say either "*Yes*" the boat was travelling fast because they had timed the catch well or "*No*" the boat was not travelling fast because they had not timed the catch well. The lead researcher was travelling beside the rower in a speedboat and the rower wore a wireless microphone and earpiece that enabled the researcher to say "now" and record responses. Responses for 40 strokes in total were collected.

In order to record what was happening on the boat during the rowers' performance and, specifically, during the *Yes* and *No* strokes; boat acceleration, pin force, gate oar angle, and angular velocity were recorded. Rowers performed the two ten-minutes of rowing in an instrumented and calibrated boat, equipped with a boat sensor that included an impeller and accelerometer. The PowerLine^{TM} software automatically collected data at 50 Hz for boat acceleration, pin force, gate oar angle, and angular velocity, which were measured in the X longitudinal direction of boat movement. Catch initiation was defined by the point at which angular velocity of the oar was closest to zero and a negative value. Negative oar angular velocity decreases during the recovery section of the stroke and becomes positive at the start of the drive phase. This was preferred to using the minimum gate angle reached [9], as pilot testing revealed instances where rowers appeared to stay at minimum gate angle for a period of time (e.g., for 20–60 ms), which presented difficulties obtaining a reliable time stamp for the initial catch point. Laboratory testing has demonstrated that PowerLine™ force gates have acceptable levels of validity, which was represented by a standard error of the estimate of 8.9 N or less for force, 0.9° for the oar angle measure [22]. On-water testing of PowerLine™ force gates with elite scullers has shown high with-in and between subject reliability, with typical error less than 1.0% [23]. The PowerLine™ force gates and boat sensor were calibrated to within the manufacturer's specifications (Peach Innovations) prior testing for each subject.

Based on the established three measures of catch slip, each rower's *Yes* and *No* strokes were extracted and three catch slip measures were computed using the bilateral average from the two oar gates for:

- Time to 30% peak pin force (pkFT)—The time taken from the minimum negative angular velocity value to the point at which the force exceeded 30% of the peak pin force in the direction of the longitudinal axis of the boat in that stroke.
- Time to positive boat acceleration (AccelT)—The time taken from the minimum negative angular velocity value to the point where positive boat acceleration is first achieved in the direction of travel. See Figure 1 for an example of one stroke showing time to positive boat acceleration.
- Time to PowerLine™ force (PLFT)—The time taken from the minimum negative angular velocity value to the point at which the force exceeded 196 N in the direction of the longitudinal axis of the boat in that stroke.

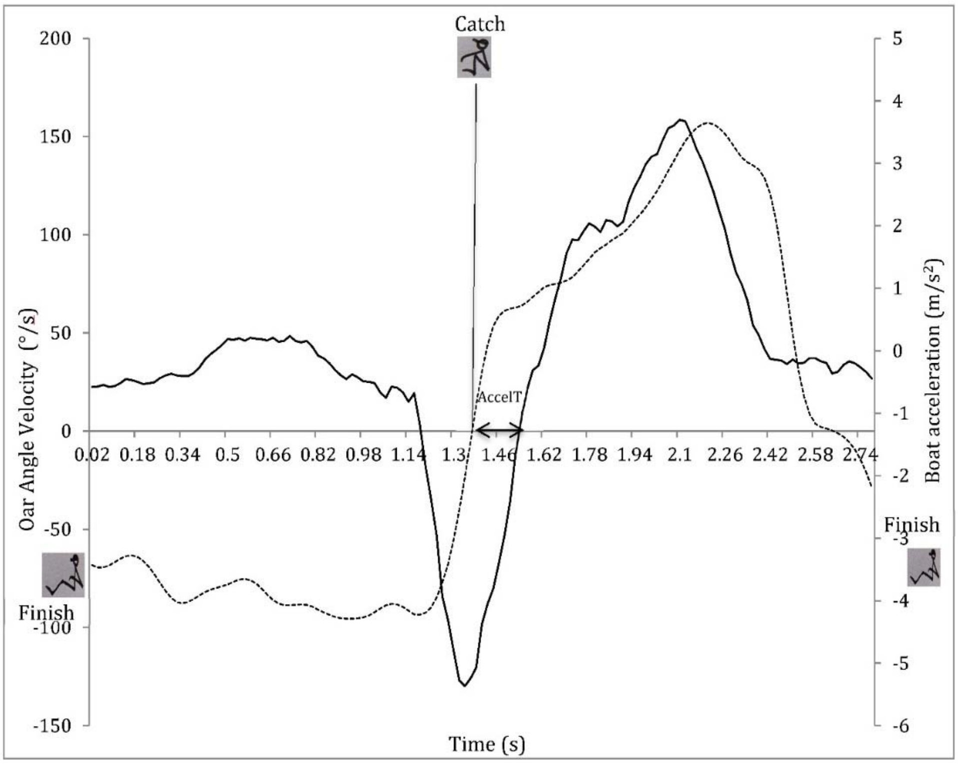

Figure 1. Example of one stoke, showing time to positive boat acceleration (AccelT), the time displacement between the initiation of the catch, and the point at which boat acceleration reaches zero (m/s^2).

2.3. Analysis

The standardised mean difference between each rower's boat velocity (m/s) was calculated between individual rowers judged Yes *versus* No strokes. This was achieved by dividing the difference between the *Yes* and *No* stroke boat velocity means by the average of the perceived *Yes* and *No* stroke standard deviations. This calculation gave a between subject standardised mean difference score. Within subject mean, standard deviation, and ±95% confidence limits were calculated to give a standardised mean difference between all eight rowers. Between and within subject standardised mean differences were calculated between each rower's three catch slip measures in time (ms). Magnitudes of standardised effects were calculated and described using a modified Cohen scale with 0.2 as the smallest worthwhile effect size [24,25].

3. Results

3.1. Boat Velocity

Of the total 273 strokes, 148 *Yes* strokes and 125 *No* strokes were analysed. There was an average of 18.5 ±5.8 *Yes* strokes per rower and 15.6 ± 4.0 *No* strokes per rower. The individual standardised mean differences between the boat velocity of Yes and No strokes for each rower are presented below in Table 1. Overall rowers made correct performance judgments with respect to boat velocity; with yes strokes revealing a small (0.2) to moderate (0.68) positive advantage than the slower no strokes.

Table 1. Standardised Mean Differences between boat velocity of Yes and No strokes for all eight rowers.

Rowers							
1	2	3	4	5	6	7	8
Standardised Mean Differences							
0.37 *	0.48 *	0.52 *	0.55 *	0.26 *	0.68 **	0.38 *	0.20 *

Notes: Magnitude of effect size of standardised mean differences [24,25]. * = Small to moderate effect size, and ** = moderate to large effect size.

The between subject standardised mean difference score for yes and no strokes was 0.43 (SD 0.28) with a ±95% confidence limit of 0.19.

3.2. Catch Measures

The within subject mean, standard deviation and 95% confidence limits of the standardised mean differences between the three catch measures are illustrated in Table 2.

Of the three catch slip measures; time to positive acceleration corresponded with the greatest difference between yes and no strokes, the other measures though greater than criterion (0.2) were not of the same magnitude. Despite some individual differences all rowers reached the *AccelT* earlier on *Yes* than *No* strokes values (see Table 3), the differences were in part due to the range of male/female and heavy and lightweight rowers in this subject group. Table 3 shows the individual standardised mean differences for each catch clip measure.

Table 2. Within-subject Mean, Standard Deviation (SD), and ±95% Confidence Limits of the Standardised Mean Differences between Yes and No Strokes for the three catch slip measures.

Catch Measure	Mean (SD)	Confidence Limits ±95%
pkFT	0.35 (0.20)	±0.24
PLFT	0.47 (0.40)	±0.33
AccelT	0.59 (0.42)	±0.41

Table 3. Individual standardised mean differences for each of the three catch slip measures.

Catch Slip	**Rowers**							
Measure	1	2	3	4	5	6	7	8
pkFT	0.38 *	0.07	0.15	0.13	0.61 **	0.62 **	0.46 *	0.44 *
PLFT	0.32 *	0.35 *	0.22 *	0.05	1.11 **	0.59 *	0.97 **	0.07
AccelT	0.71 **	0.29 *	0.21 *	0.39 *	1.50 ***	0.86 **	0.57 *	0.21 *

Notes: Magnitude of effect size of standardised mean differences [24,25]. * = Small to moderate ** = moderate to large and **** = large to very large effect size.

For all eight rowers, *AccelT* had a larger than 0.2 effect size in the *Yes* strokes compared to the *No* strokes. Whereas the other two catch slip measures had a mixture of effect sizes from small to large depending on the catch measure and rower.

4. Discussion

While there remains disagreement between rowing coaches about how the catch is best achieved [8], there is little dissent regarding the need for good catch technique in order to minimise boat velocity losses [26]. In a recent qualitative study, expert-level rowers and coaches stressed the importance placed on the catch declaring it the point in the stroke that had the greatest influence on performance [20]. This point is supported by the literature, arguing that proficiency of technique at the catch is a determinant of performance [5,8,27]. Therefore, this current study looked at the catch section of the rowing stroke in detail and utilised rowers' subjective performance-based judgments to help evaluate catch measures. Results in this study showed that there did appear to be differences between the three biomechanical measures of "catch slip" when compared with respect to velocity. This result supports the use of expert performance judgments as a way of further determining the effectiveness of performance measures.

4.1. Links to Boat Velocity

In rowing, having the highest average boat velocity over a set distance is crucial for performance. This is not only an issue of force production, but also how it may be optimally applied across repeated attempts. Thus, it is important to consider success with regard to boat velocity in the context of concurrent strokes within the immediate performance setting (*i.e.*, the strokes close or before the current ones). Rowers' perceptions of success in this situation may be seen as a useful index of performance. In this study, rowers demonstrated that the strokes they considered to be successful were faster than strokes they judged as unsuccessful. Specifically, *yes* strokes, when averaged, provided a small to moderate positive performance difference. For all eight rowers the standardised mean differences were greater than the smallest effect size of 0.2.

In this study rowers made performance judgements about boat success differences between strokes while rowing in the absence of boat velocity instrumentation. The ability to do this may be argued to be the product of unique and developing knowledge which emerges from extended practice [28,29]. These results invite an interesting perspective on the cost and time required for extra feedback from boat instrumentation given expert rowers' accuracy as informants regarding performance. The accuracy of their perceptions of performance may be partially due to the cyclical nature of the rowing task and in some part related to the use of instrumentation in earlier phases of their career. This increased understanding about the accuracy of rower-based performance judgements might provide coaches with alternative methods for assisting the development of their rowers; for example getting the rowers to self-evaluate performance.

4.2. Which Catch Measure to Use?

This study has endeavoured to provide answers for coaches, rowers, and biomechanists regarding which of the three catch slip measures is most useful, based on performance effect sizes. The results indicate that the time to positive acceleration is the better measure to use (see Table 2). This result supports other research (*i.e.*, [11,30]) finding that achieving a quicker time to positive boat acceleration was associated with more successful performances. This would indicate that technical aspects of the catch are influential in overcoming the deceleration of the boat as well as returning the boat to positive acceleration.

The poorer result for the two other catch slip measures in Table 2 (*i.e.*, PLF and pkF) are consistent with findings of elite scullers [9]. Coker [9] found inconsistent results when comparing time to 30% peak pin force and time to PowerLine™ force to boat velocity. The poorer results associated with reaching 30% of peak pin force and PowerLine™ catch slip may be attributed to rowers applying force to the oar while it is changing direction and this can give a better score in the criterion, without achieving a quicker acceleration time [10]. It is worth highlighting that all three-catch measures had varying positive effect sizes and, for a couple of rowers, these effects were large to very large (see Table 3). The variation between results speak to individual characteristics of technique and, probably, levels of expertise. Consequently more research is needed to capture other variables of importance at different parts of the stroke and for different performers at different levels of expertise.

4.3. Recommendations

While detailed biomechanical measures like positive acceleration and PowerLine™ angle are available in some high-performance environments, it might be that these are better suited for post-collection analysis. A possible solution for, coaches could be to ask more experienced rowers to self-judge their catch and count the frequency of *Yes* to *No* ratings to see what improvement in the ratio may occur over time. With less experienced rowers, the rower could identify a perceived successful catch and confirm this with their coach, before continuing on with counting the frequency of Yes- and No-rated strokes. Alternatively, if the coach has access to a boat instrumentation system, then periodic measurements of time to positive acceleration could help determine changes in performance improvement.

Training rowers to take notice of boat movements, and the velocity of the movement, could help to improve performance of the catch efficiency.

Data on expertise indicate that experts acquired knowledge specific to their own performance [15,31]. The present study made use of rowers' subjective judgements about successful rowing performance relative to boat speed; where it was confirmed that experienced rowers were able to make judgments about their own performance that was reflected in the speed of the boat. From a practical point of view, coaches need to consider integrating the specific knowledge rowers have about their performance into their coaching pedagogy. The application of unique athlete-environment knowledge, [28,32] supports contemporary approaches to coaching high-level performers, where the coach should consider athlete knowledge about performance first, and then use his or her own coaching knowledge as a supplement.

4.4. Limitations

Potential limitations in our study relate to data capture, analysis, and the question asked of the rowers. In our study, analysis emphasised individual strokes drawn from a set without fully exploring other determinants within that stroke and the previous stroke. A more evolved analysis would examine the relationships within multiple successive strokes. With this in mind, antecedents of catch behaviour such as the approach also warrant inclusion in future models. The question posed to the rowers for identifying successful strokes may have been interpreted as a judgment of velocity or stroke quality. Ideally, one or the other should be considered but not both at the same time. Nevertheless, the current approach was sufficient to determine differences between efficiency estimators and was supported by boat velocity data. A concluding limitation is the small sample of a rather homogeneous set of advanced rowers and that the results should be confirmed in other samples of rowers.

5. Conclusions

Rowers' subjective judgment about their catch may be useful for performance monitoring. With the increase of on-water boat instrumentation, consideration needs given to its use for the benefit of rowers. This study tested three catch slip measures and found that achieving a quicker time to positive acceleration had the largest effect on performance. In addition, all eight rowers were correct in that the Yes strokes they judged as more successful were faster on average than the No strokes.

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Author Contributions

Sarah-Kate Millar had the idea for the paper, reviewed literature and conducted the initial analysis of data, and drafted the first version of the paper. Anthony Oldham provided additional data analysis, literature searching and edited the paper. Patria Hume provided advice on the methods, reviewed the data analysis and edited the paper. Ian Renshaw provided advice on the methods and edited the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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