THE EFFECTS OF ATTENTIONAL FOCUS ON NOVICE AND EXPERT DYNAMIC INDOOR ROWING PERFORMANCE

by

Nicholas Lee Parker

Dissertation Committee:

Professor Lori Quinn, Sponsor
Professor Richard Magill

Approved by the Committee on
the Degree of Doctor of Eduction

Date____20 May 2020_____

Submitted in partial fulfillment of the
requirements for the Degree of Doctor of Education in
Teachers College, Columbia University

2020

ABSTRACT

THE EFFECTS OF ATTENTIONAL FOCUS ON NOVICE AND EXPERT DYNAMIC INDOOR ROWING PERFORMANCE

Nicholas Lee Parker

Background. Motor skill learning and performance are optimized when individuals direct their attention externally towards the desired effect. Improvements include increased force production and improved coordination, determinants that also significantly influence rowing performance. However, no consensus surrounding an "ideal" rowing technique and these determinants exists. Attentional focus cues may not only improve rowing performance, but also enhance understanding of factors affecting force production. **Aims.** Two studies evaluated the efficacy of attentional focus on 1) distance rowed by novice participants; 2) power and peak force generated by novice participants; 3) distance rowed by novice & expert participants 4) force production measures of power, peak force, peak force max, and joules, as well as force signature measures of stroke length, peak force position, mean to peak force ratio, and variability in novice and expert participants; 5) rowing outcomes while controlling for participant stature; and 6) coordination of the legs and trunk during dynamic indoor rowing. **Methods.** Thirty novice and nineteen experts completed three 45 second long trials on a dynamic indoor rower (RP3), with the goal of rowing as fast as possible between 24 and 26 strokes per minute. Prior to each trial, participants were given attentional focus cues: internal - "As you row, focus on pushing with your legs"; external - "As you row, focus on creating pressure on the handle"; and a baseline condition, where no cue was provided. All three cues were counter-balanced. **Results.** There were no effects of attentional focus on outcomes, with the exception of increased stroke length for expert participants while rowing with an external focus. Significant effects were found for gender, expertise, and stature. Variability distinguished novices from experts. Participants reported difficulty managing their ability to row as fast as possible, maintain a stroke rate of 24 to 26, and focus on the cue. **Conclusion.** As the first study to evaluate the efficacy of attentional focus on force production in rowing, results indicated limited support for an external focus of attention. Individual, task, and environmental factors may have influenced rowing outcomes. Further investigation evaluating attentional focus and rowing that accounts for these factors is suggested.

DEDICATION

For my parents, who taught me that making good choices
requires knowledge, discipline, and empathy.

ACKNOWLEDGEMENTS

Laura Conti — You demanded excellence, but demonstrated compassion. I aspire to that perfection. Danke Frau.

P. J. Barbeau — You crafted my vision of a real hero, and I have never been the same. Thank you for elevating my perception of strength and struggle.

Marcia DeGuire — Although I may be following in your coaching footsteps, no one will ever be able to fill your shoes.

Chris Weait — Through music, you shaped me into a coach of kinesthetic poetry. I am forever in your debt.

Jimmy Joy — You gave me insight to a Beginner's mind, and that has made all the difference.

Mike Zimmer — At Columbia University, I am standing on the shoulders of a giant. Your shoulders. Thank you.

Julie Fineman — With you, we feel safe, we feel a sense of belonging, and we have purpose. You elevate us all while reminding us to stay true to our goals as practitioners and researchers.

Jesse Foglia — As rowers, we remember the boys in the boat. As coaches, we remember our colleagues who help us create that experience for others. Thank you for sharing your perspective and wisdom with me as we keep searching for ways to make the boats go faster.

Peter Steenstra — Some of life's most important lessons can't be taught, only experienced through great leadership. Thank you for leading thousands of rowers through that process. The whole of rowing is better not only because you helped us grow as athletes, but also as individuals.

Lori Quinn — There is no greater compliment than a mentor believing you can solve the problem. The patience you demonstrated in never telling me what you knew I could discover on my own is nearly inconceivable. Although I have many more questions, your guidance has created a path forward. Thank you.

N. L. P.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Rowing

Rowing is one of the oldest forms of sporting competition, originating in ancient Egypt and continuing to evolve into modern times. As recently as the turn of the 20th Century, rowing was one of the most popular competitive sports globally (Mallory, 2011). For over 150 years, rowers, coaches, and sport scientists have studied the mechanics of rowing in search of the primary discriminant factors that contribute to performance. During that time, rowing outcomes have improved linearly at a rate of 2-3% per decade (Seiler, 2015). In the men's single, that represents an improvement of over a minute. Known factors, such as the change in athlete size, increase in training load, and improvements in materials and design account for less than 70% of the performance gains (Kleshnev, 2019; Seiler, 2015). The remaining source of improvement is generally attributed to technique, however, in spite of decades of research, there is little consensus surrounding an ideal technique (Baudouin & Hawkins, 2002; Soper & Hume, 2004; Warmenhoven, Cobley, Draper, & Smith, 2018). These data suggest that in addition to, or in spite of, the numerous rowing techniques or “styles” (i.e., Adams, DDR, Rosenberg, Grinko, and Fairbairn) that have won world championships, additional factors influence rowers and their ability to improve performance.

Two main obstacles challenge coaches as they confront the relationship between motor learning or motor performance strategies and rowing outcomes. First, practitioners have access to decades of research supporting the efficacy of specific coaching interventions related to athlete size, training method, and equipment. Taller athletes result in faster boats (Mikulic, 2009). Stronger and more fit athletes result in faster boats (Hagerman, Hagerman, & Mickelson, 1979). Improved materials and design result in faster boats (Filter, 2019). Although there is some research identifying components of better rowing technique, the same level of scientific support is not available (Warmenhoven, Cobley, Draper, & Smith, 2018). The second obstacle is that rowing technique outliers, even when successful, are often considered a product of experience over instruction. Ned Hanlan, for example, rowed across the Toronto Harbor daily to attend school, perfecting his bladework on his way to becoming the shortest men’s single scull world champion (Sward, 1983). Similarly, Robbie Manson is from a family of rowers who introduced him to the sport at a young age. In 2017, he set the world record despite being 12 centimeters shorter than the previous record holder (World Rowing, 2020). In each of these cases, the rowers are known for aspects of their technical skill. Coaches, however, have few resources or limited motor performance knowledge to use in identifying salient features of such techniques. Therefore, coaches will rely on the previous three factors they “know” can have a significant impact on performance.

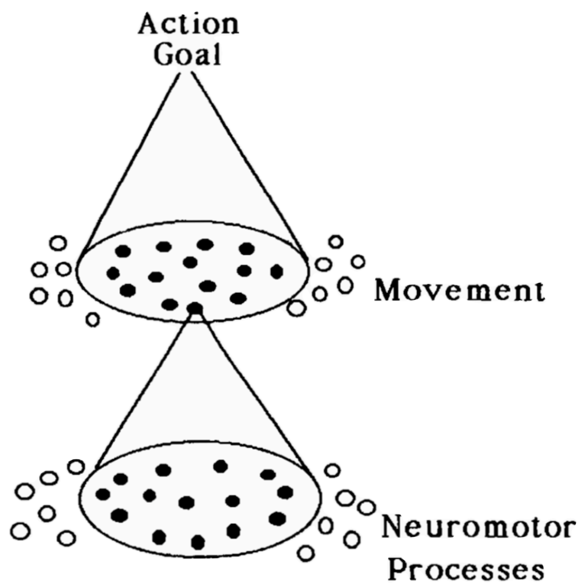
This chapter will provide an overview of rowing literature and discuss research in support of motor learning strategies to enhance rowing performance. Although the current status of rowing knowledge precludes consensus on an ideal technique, discriminant factors consistently associated with improved performance have been identified. Previously demonstrated and emerging constructs in the field of motor learning may explain the relationship between those factors and rowing outcomes. One such strategy, attentional focus, has been widely shown to accelerate one's ability to learn and perform skilled movements. This strategy, along with its supporting constructs, is reviewed, and specific applications for rowing are discussed.

Motor Performance and Skill Attainment

The structure of motor performance consist of three primary components — action-goals (referred to as outcomes in this research), movements, and neuromotor processes (Gentile, 1987). Outcomes are the observable changes caused by movement. They are the end result of a task or activity, such as the time taken to complete a race. Movement is the means through which an outcome occurs. Where outcomes describe *what* happened, movement describes *how* it happened. Movements are the components of outcomes (Gentile, 1987). They are also the result of one or more neuromotor processes. Neuromotor processes are one of the less understood aspects of outcomes and movements. In spite of this, they are accepted as plans for movement based in multiple locations throughout the central nervous system (Enoka, 2008; Rosenbaum, 2009). When performance is discussed or evaluated, all three of these components must be considered (Gentile, 1987). The relationship between each of these constructs can be seen in Figure 1 (Gentile, 1987). The small unfilled circles outside the larger circles represent plans that will not achieve the desired outcome. The small filled-in circles represent neuromotor processes or movement plans that will achieve the desired outcome In those cases, many different solutions for achieving the desired outcome are possible, a concept known as motor equivalence (Kelso et al., 1998). Determining which filled-in circle best achieves the task goal, however, requires further inquiry into what they represent.

Figure 1

Outcomes (Action-Goal), Movement, and Neuromotor Processes



Note. Outcomes (Action-Goal), Movement, and Neuromotor Processes. Diagrammatic representation of the relationship between levels of analysis. At the "Movement" level, filled circles represent the many movement patterns that can be used to successfully achieve the "Action-Goal"; unfilled circles are unsuccessful patterns. At the level of "Neuromotor Processes," filled circles represent the many ways neural processes can be organized to produce a specific movement; unfilled circles are unsuccessful modes of organization. Reprinted from "Skill Acquisition: Action, Movement, and Neuromotor Processes," by A. M. Gentile, 1987, *Movement Science: Foundations for Physical Therapy in Rehabilitation* (p. 117).

Changes in the environment, task, or the individual require the performer to adjust from one filled-in circle to another, in order to achieve the desired outcome (Newell, 1986). Motor learning is the process through which an individual first develops an understanding of those requirements, and applies them to subsequently refine the movement (Gentile, 1987). In motor learning literature, the frequency, intensity, and quality of practice during the early (getting an idea of the movement) and later (refining the movement) stages are associated with improved performance outcomes (Gentile, 1987; Magill, 2016). These are strategies that enhance the learning process, increasing the skill level of the performer. That is, they help individuals learn how to select the filled-in circle from Figure 1 that will *best* achieve the desired outcome after controlling for the remaining parameters. Those remaining parameters include athlete size, training method, and equipment previously discussed. Coaches must evaluate the "known" effects of such interventions against the "potential" effects of motor performance strategies, complicating an already challenging situation with respect to performance.

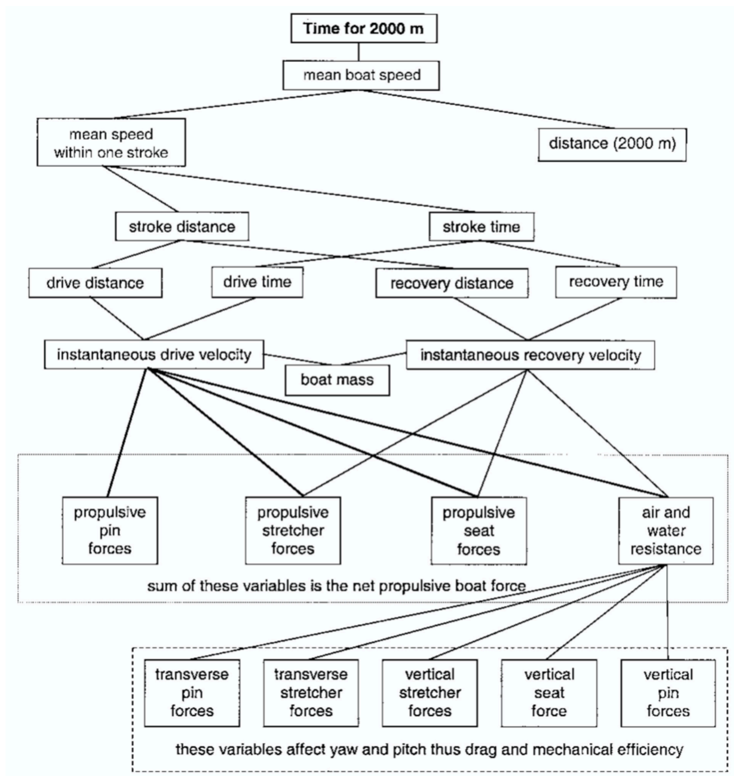
Skilled movement has been defined as the ability to achieve an outcome with consistency, reliability, and some economy of effort (Guthrie, 1952). A movements general framework is determined by the interaction between the performer and the environment. First, the performer develops an internal representation of the movement (Gentile, 1987). Next, consistency is achieved through practice as the individual refines that internal representation until they regularly achieve the desired outcome. After initial success, the performer learns how to adjust the movement so that it remains reliable when conditions change, such as compensating for wind during a tennis serve or accounting for fatigue. Finally, the performer continues to refine elements of the movement to increase efficiency. This third and final component defining skilled movement, efficiency, is of particular interest in rowing. Improved coordination, and the resulting efficiency associated with it, is often cited as the primary means through which rowing technique contributes to the performance gains seen over the last century (Hill, 2002; Kleshnev & Kleshnev, 1998; R. M. Smith & Spinks, 1995). Similarly, Hanlan's bladework and skill with the sliding seat mechanism have been described as primary mechanisms by which he increased efficiency to overcome his larger opponents (Joy, 2013).

The Rowing Stroke

Rowing is a cyclical or continuous movement, meaning that it has defined phases that repeat over time (for a review, see Dal Monte & Komor, 1989). A standard representation of rowing includes four distinct periods of movement. At the catch, the blade enters the water when it is located closest to the bow or front of the shell. Next, during the drive phase, the rower initiates a pre-determined sequence that coordinates the ankle, knee, hip, and lumbar region from flexion to extension while the shoulder, elbow and wrist joints move from extension to flexion. The result of this movement is to pry the shell through the water using the oar as a lever, positioned against an outrigger. The drive phase concludes when the handle reaches the body, at which time the rower must extract the blade from the water. The final phase is the recovery. In this phase, the rower returns to the catch position through another predetermined sequence of arms, trunk and legs. This final phase of the stroke positions the body segments for their next propulsive effort. These movements are learned and then refined to increase force production, efficiency, and improve the overall stability of the rowing shell.

Figure 2

Biomechanical Determinants of 2,000m Rowing Performance

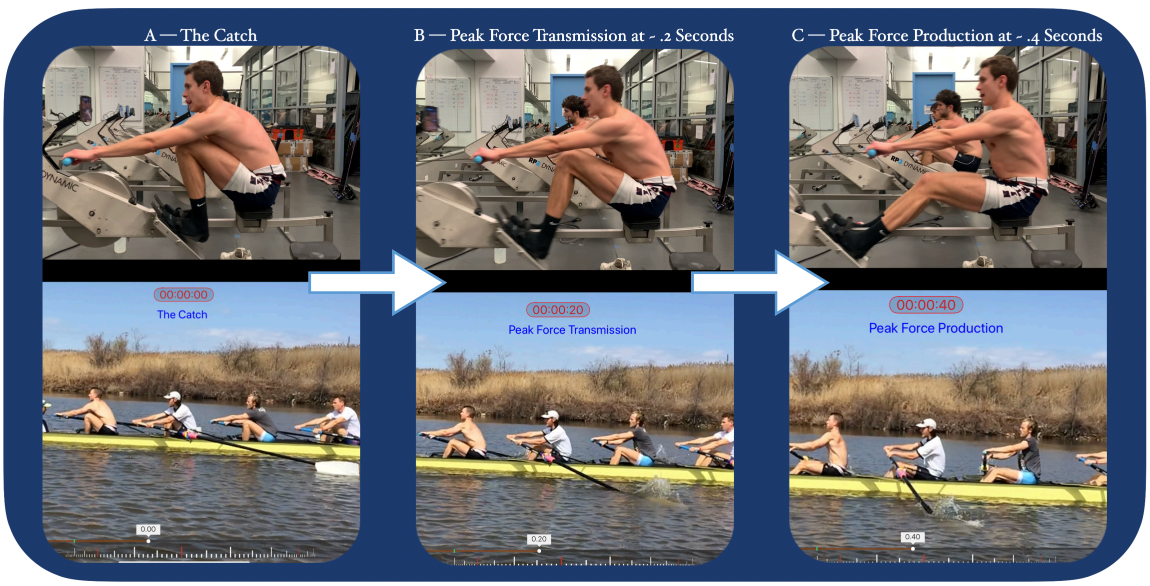


Note. Biomechanical determinants of 2,000m rowing performance are grouped according to categories of known influences on force production, drag factors, and their relationship to mean boat speed. Increases in mean boat speed require increases in propulsive forces, decreases in drag forces, or both. Reprinted from "Biomechanics feedback for rowing," by Smith & Loschner, 2002, *Journal of Sports Sciences*, p. 783.

Biomechanical determinants represent the salient features known to impact rowing performance, independent of technical style. The use of performance measures over the last 150 years has allowed researchers to create a map of these determinants, as well as the feedback systems individuals use to guide movement. Examples of such performance measures include limb kinematics, force production intensity, and muscle activation patterns. Researchers quantify components of movement using these measures to determine their relationship to the outcome. The components that are significant effectors of rowing outcomes are shown in Figure 2 (R. M. Smith & Loschner, 2002). The map of determinants serves as a guide to understand which aspects of the rowing movement have significant effects on the final outcome — in this case, the time needed to row 2,000m.

Figure 3

The Critical Drive Phase of The Rowing Stroke



Note. The critical drive phase of the rowing stroke. *Top*. A rower moving from onset to offset time points of the critical drive on an RP3 dynamic indoor rower. *Bottom*. Rowers moving from onset (blade half buried) to offset time points of the critical drive in an eight-oared racing shell.

Determinants are grouped according to their status as propulsive forces or drag forces. The net difference between propulsive forces and drag forces is relatively small (Draper, 2020). As a result, researchers have found that even small changes in force production or movement coordination can have significant impacts on the speed of an individual or a crew (Hill, 1995). To increase mean boat speed, the rower must amplify net propulsive forces on the blade (Baudouin & Hawkins, 2002). For practitioners, identifying those small changes responsible for increases in speed may require investigation beyond visual inspection. Francis (2013) reported that the period of the rowing stroke most sensitive to increases in force production as the first .4 seconds of the drive. Changes in coordination patterns during this phase typically result in a speed decrease. Although Francis was able to visually recognize that relationship and empirically demonstrate it in this instance, it is unlikely that coaches will be able to do the same with all factors contributing to rowing technique.

The largest effectors for rowing performance are increases in force production, improvements in prolonged force production (largely a physiological determinant), and improved coordination (Baca, Kornfeind, & Heller, 2006; Korner & Schwanitz, 1987; R. M. Smith & Loschner, 2002). However, increased power output with poor coordination may decrease mean velocity (Hill, 1995, 2002; Nolte, 2011). As with Figure 1, all factors must be considered. Support for the important of an increase in force production grew when Bourdin et al. (2004) reported peak power or maximal force production to be the best predictor of rowing performance. As for prolonged force production and coordination, the two are highly correlated outcomes within rowing literature (Nolte, 1981, 2011). In the last four decades, researchers confirmed that better force production coordination within multi-person crews improves performance (Hänyes, 1983). Hill (1995, 2002) replicated those findings, adding to them a relationship between better coordination and prolonged force production. Additionally, Hill suggested that within individual adaptations of the trunk and leg segments also significantly contributed to performance improvements.

The implications of these studies were subsequently connected to rowing technique. Kleshnev V. and Kleshnev I (1998) reported that increased concurrent use or coordination of principle segments led to improved efficiency, however, the same study also reported that such use led to a decrease in peak force production when measured per stroke. Coaches evaluating rowers have few datapoint upon which they can rely to determine if one particular style is better than the other. Additionally, the relationship between the inherent characteristics of the rower and these technical considerations have not been investigated. As such, despite the gains in understanding many determinants of rowing performance, advances have not led to a consensus on rowing technique.

The positive effects of motor learning research on feedback type, feedback timing, and contextual interference have been applied in various settings (Adams, Gopher, & Lintern, 1975; Magill & Hall, 1990; Newell, 1974). Rowing practitioners use a range of related techniques to enhance rowing performance. Common examples include pause drills focusing on a specific time point in the rowing stroke, or fractional rowing to increase repetitions of a specific segment within the rowing stroke. There has been limited research, however, on the use of motor learning strategies to enhance performance, despite its implementation in other sports such as soccer (Wulf, McConnel, Gärtner, & Schwarz, 2002) and weight-lifting (Marchant, 2011). In particular, the application of external focus of attention, a successfully demonstrated concept that accelerates skill acquisition and performance in other activities, may provide insight on how rowers improve with respect to known determinants.

Attentional Focus

Attention represents the ability of an individual to concentrate on a discrete component of behavior or on a cognitive task (for more on attention, see Kahneman, 2011). Attention is a limited capacity resource, meaning that it has finite limits for the individual. Broadly explored, attention has three main constructs. First, attention may be described as associative or dissociative (Magill, 2016). An associative focus of attention is one which directs performers to focus on an aspect of the task. In a rowing race, this would emerge as stroke rate, feeling of the boat, position in the race, breathing, etc. A dissociative focus directs the performer towards unrelated items, such as watching television while walking on the treadmill at the gym. Second, attention can be narrow or wide. A narrow focus of attention is necessary for threading a needle, while a wide focus of attention is necessary for navigating a crowded subway (Nideffer, 1989, 1993). The third representation of attention is internal versus external (Wulf, 2013; Wulf & Lewthwaite, 2016). An internal focus relates to the body, i.e., a rower thinking about pushing with their legs. An external focus specifically directs the performer towards an effect of the movement, such as pressure on the face of the blade or the run of the racing shell across the water.

External focus has been shown to enhance learning and performance in a wide range of activities, including some with similar determinants to rowing (Marchant, 2011; Wulf, 2013; Wulf, McNevin, & Shea, 2001). Although researchers hypothesized as early as 1890 that directing attention to the “remote effects” of simple movements would lead to better performance, new developments indicate that attentional focus is in fact a critical feature in the acquisition and refinement of complex motor skills (James, 1890; Prinz, 1997; Wulf & Lewthwaite, 2016). More specifically, external focus leads to improved accuracy, efficiency, and learning (Wulf, 2013). The motor skills and activities reviewed have included golf (Wulf, Lauterbach, & Toole, 1999), basketball (Zachry, Wulf, Mercer, & Bezodis, 2005), dart throwing (Lohse, Sherwood, & Healy, 2010), weight-lifting (Marchant, Greig, & Scott, 2009; Vance, Wulf, Töllner, McNevin, & Mercer, 2004), running (Schücker, Hagemann, Strauss, & Völker, 2009), swimming (Stoate & Wulf, 2011), and rowing (Parr & Button, 2009), among others.

Accuracy is the first level by which the effects of attentional focus have been evaluated. In darts, throwers were more accurate when instructed to “visually focus on the bulls-eye” as opposed to the movements of their arm (Lohse et al., 2010, p. 548). Porter, Ostrowski, Nolan, and Wu (2010) investigated the effects of attentional focus during a standing long jump. They reported a significant increase in jump distance during external focus trials. Increased jump distance describes the outcome, or *what* happened. *How* the individual achieved that improvement is equally important (*how* describes the movement component of Figure 1). As such, a follow-up study by Wu, Porter, and Brown (2012) repeated the experiment, but added a force plate to measure ground reaction forces. The researchers believed that an increase in force production would explain the increase in distance jumped. Despite confirming increased jump distance under external focus conditions, there were no significant differences in ground forces between conditions. Similar to Klesnev's (1998) finding that higher levels of coordination improve efficiency in rowing, the authors suggested that improved whole-body coordination under external conditions provided an advantage. That is, it allowed the individual to jump farther even though there was no increase in force production. That aspect of jumping has yet to be evaluated, but additional research on coordination does support the hypothesis (Marchant, Greig, Bullough, & Hitchen, 2011; Preatoni et al., 2013).

Performance improvements in the aforementioned studies could have come at a cost or benefit to the performer's efficiency, similar to comparisons of sequential (increased peak force) versus concurrent rowing technique (increased efficiency). Vance et al. (2004) used a two-part bicep curl study to evaluate this possibility. Participants were asked to bicep curl a weight 10 times under counter-balanced conditions of control, internal, and external focus conditions. The time to complete the movement was recorded, as well as the electromyography (EMG) activity of the bicep. Analysis revealed that under external control conditions, not only did the participants complete the 10 repetitions in less time, but they also showed less muscle activation of the involved muscle groups. To test if the lower EMG scores were a reflection of the shorter duration of the trial, a second experiment was done with the bicep curls being set to a metronome. This controlled for the time duration of each trial. Again, EMG activity during the external focus trial was lower. Participants also reported lower rates of perceived exertion, a critical factor for performance when force production over time is a primary consideration (Noakes, St Clair Gibson, & Lambert, 2004). The findings suggest that performance under external focus conditions not only improves force production dependent outcomes (accuracy), but also improves coordination (efficiency).

Wulf, McNevin, and Shea (2001) proposed the "constrained action" hypothesis as the mechanism by which external focus improves performance. It posits that an internal focus "interferes with the automatic control processes that would normally regulate movement" (Wulf et al., 2001, p. 1144). In contrast, an external focus of attention promotes automaticity, allowing body segments to move with improved levels of coordination (Kal, van der Kamp, & Houdijk, 2013). That improved coordination has a functional role, guiding the inherent variability in movement to serve as a factor that increases accuracy, reliability, and efficiency.

Variability has generally been viewed as noise that detracts from a "perfect" performance (N. Bernstein, 1967; Schmidt, 1975). New research, however, suggests that variability serves a functional role in refining and executing movement (or selecting the best filled-in circle). Functional variability, an optimal level of variability for a specific movement, improves not only outcomes, but also efficiency (Glazier, Davids, & Bartlett, 2003; Loosch & Müller, 1999). Movements that are too rigid are unable to adapt to changing conditions. Movements that are too random are unpredictable and difficult to control. Skilled movements must be consistent, reliable, and economical. The optimal amount of variability allows performers to meet Guthrie's (1952) second criterion for a successful highly skilled movement — remaining reliable for the performer under varied parameters. Research from darts

(Loosch & Müller, 1999) to diving (Barris, Farrow, & Davids, 2014) indicates that external focus increases functional variability associated with improved outcomes in those activities.

The application of external focus to rowing is further supported by the results from research on swimming. Swimming, like rowing, is an activity that is sensitive to force production, coordination, and efficiency (Maglischo, 2003). Stoate and Wulf (2011) compared the results of novice and expert swimmers under internal, external, and control conditions. The use of novice and expert participants allowed the researchers to examine the effects of attentional focus on separate levels of expertise. The authors reported that novices swam faster using external focus compared to internal or control conditions. Similarly, expert swimmers were faster under external (push the water back) and control focus compared to internal (pull your hand back) conditions (Stoate & Wulf, 2011). Wulf and Lewthwaite (2016) suggested that an external focus of attention "propels" the performer towards improved performance states. In this particular study, the authors hypothesized that expertise in swimmers automatically induces a state of external focus. The difference between these two categories of experience suggests that motor performance strategies create affordances that are inherently constrained by the population to which they are applied. Evaluating novice and more experienced performers is a requisite for understanding potential effects.

Of particular importance for rowing is the proposal from Zachry et al. (2005) that an external focus on the desired movement outcome improves force production. Increased force production is the primary means through which rowers can improve boat speed (Korner & Schwanitz, 1987; R. M. Smith & Loschner, 2002). As noted above, increased force production with reduced coordination may decrease performance (Hill, 1995). The underlying relationship between these two factors was first described in Fitts' Law, also known as the speed-accuracy tradeoff (1954). Schmidt et al. (1979) provided further evidence supporting Fitt's Law with a series of mathematical proofs demonstrating its broad application to movements of multiple types. The authors suggested that individuals engaged in programmed movements of short or long duration may learn how to assign levels of amplitude and speed that allow them to consistently and efficiency achieve the desired outcome. Schmidt et al.'s (1979) suggestion offers an explanation for Hill's (1995) conclusion that increased force production does not always contribute to improved outcomes. The role of an external focus of attention in "propelling" individuals towards optimal states of force production and coordination in rowing is unknown.

Study Purpose and Aims

Two studies evaluated the effects of attentional focus on dynamic indoor rowing performance as measured by the primary outcome, distance (D) rowed in 45 seconds. Dynamic indoor rowing was chosen over on-water rowing because it captures validated force production measures, takes place in a controlled environment, closely approximates the physics of on-water rowing, and has a high correlation to on-water rowing outcomes (Kleshnev, 2008; Panjkota, Šupuk, & Zanchi, 2006; Schabort, Hawley, Hopkins, & Blum, 1999). Validated on-water measurements systems cost as much as $50,000 US and are highly complex. The dynamic indoor rower is the most recent advancement in indoor rowing (for a review, see Appendix B). Although it does not capture the efficiency of bladework or the interaction of rower mass and shell mass on the recovery, it does closely replicate the physics of the drive. As the drive is responsible for the first determinant of improved outcomes, force production, measuring the effects of motor learning strategies on it offers an approach that increases specificity. To fully evaluate the potential effects of attentional focus, multiple performance measures describing force production, coordination, and rowing kinematics were recorded. These included peak force in Newtons, power in watts, and energy in joules. Participant force signatures, a performance measure illustrating the interaction of force production over time, were also recorded.

Study one examined the effect of attentional focus on the performance outcomes of distance (D), peak force (PF), and energy (J) in novice rowers. Study two examined the effect of attentional focus on the outcomes in two primary groups. In the first, measures associated with force production including distance (D), power (P), peak force (PF), peak force max (PFM), and energy (J) were evaluated. The next group focused on measures describing the force profile produced by participants during trials, also known as the force signature. These measures included stroke length (SL), peak force position (PFP), mean to peak force ratio (MPFR), and a measure of variability called dispersion factor (DF). The final component of study two examined kinematics, comparing the amount of coordination between body segments under different focus conditions.

The research aims for study one were:

Aim 1

To evaluate the efficacy, in terms of distance rowed in 45 seconds on a dynamic ergometer, of an external focus of attention on rowing outcomes in novice participants.

Hypothesis:

1.1 — Participants will row a significantly farther distance under external focus conditions.

Aim 2

To investigate the efficacy of attentional focus on rowing performance measures of peak force and power in novice participants using a dynamic ergometer.

Hypothesis:

2.1 — Participants will produce more power and increase peak force under external focus conditions.

The research aims for study two were:

Aim 1

To evaluate the efficacy, in terms of distance rowed in 45 seconds on a dynamic ergometer, of an external focus of attention on rowing outcomes in novice and expert participants.

Hypothesis:

1.1 — Participants will row a significantly farther distance under external focus conditions.

Aim 2

To evaluate the efficacy of attentional focus on rowing force production performance measures of power, peak force, peak force max, and joules as well as force signature measures of peak force position, stroke length, mean to peak force ratio, and dispersion factor in novice and expert participants.

Hypothesis:

2.1 — External focus conditions will result in increased force production measures of power, peak force, peak force max, and joules for novice and expert participants.

2.2 — External focus conditions will result in increased stroke length, earlier peak force position, increased mean to peak force ratio, and decreased dispersion factor scores for novice and expert participants.

Aim 3

To determine the relationship between outcomes and attentional focus when controlling for height and weight.

Hypothesis:

3.1 — The inclusion of height and weight as covariates in two-way repeated measure ANCOVA models will add significant controls to assess the impact of attentional focus on outcomes.

Aim 4

To assess body segment usage under control, internal, and external attentional focus conditions for a subgroup of novice and expert participants during dynamic indoor rowing.

Hypothesis:

4.1 Rowers completing trials under an external focus of attention will adopt a more concurrent use of the legs and trunk during the critical drive phase of the rowing stroke.

Chapter II

STUDY ONE METHODS

Design

A counter-balanced within-subject design was used to evaluate the efficacy of attentional focus on novice rower's performance. Distance covered in 45 seconds was the primary outcome measure. Additional performance measures describing components of force production for each rower were also captured. These included peak force (PF) in newtons and power (P) in watts. The within-subject design was selected to evaluate a motor-performance effect, allowing the study to determine the presence of an effect of a motor control strategy as research comparing motor learning or performance strategies in rowing is limited. Participants completed a single 30-minute session during which they performed trials in control, internal, and external focus conditions.

Participants

Participants were recruited from Columbia University and rowing clubs in the greater New York City area. The background of participants was varied, with some learning to row on a university sponsored team and others learning to row at local rowing clubs. Active rowers were defined as those participating in rowing at least twice per week. Novice participants were defined as individuals rowing regularly for at least three months, but not longer than 24 months or two competitive 1,000m or 2,000m race seasons. 1,000m racing is standard for masters level rowing and 2,000m racing is standard for club, collegiate, or elite rowing. Participation was open to both categories of rowers, as long as they met the remaining criteria. Study procedures were reviewed and approved by the Internal Review Board at Teachers College, Columbia University prior to enrolling participants. Informed consent was obtained from all participants.

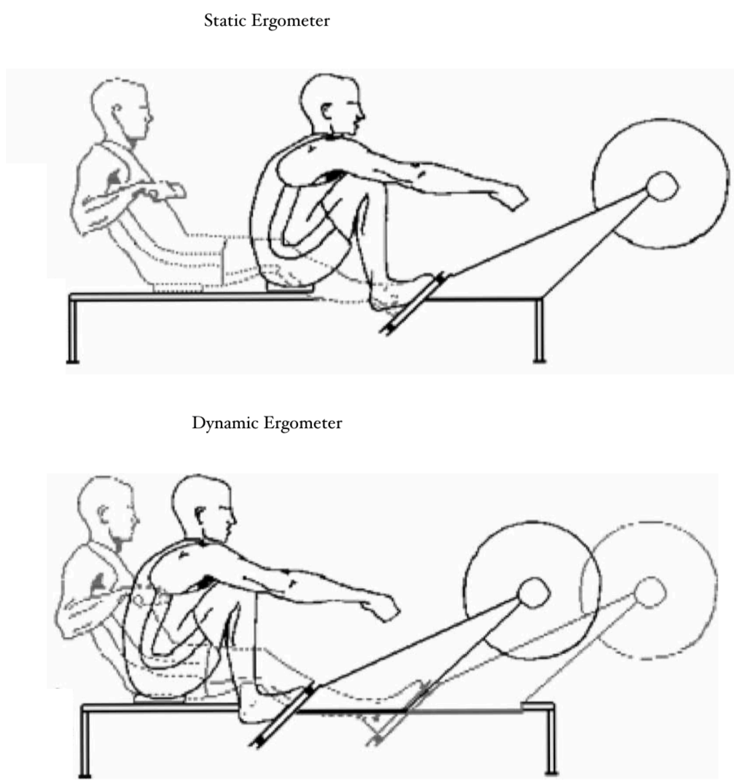
Equipment

Hardware

All sessions involved the use of an RP3 Model S Dynamic Indoor Rower (RP3). The RP3 used an air-braked flywheel housed within a perforated metal cage to protect rowers from the fast-moving components. The flywheel was driven by a chain and pulley system that connected to a handle, mimicking the rowing stroke when pulled. A comparison of the RP3 dynamic rower and a static indoor rower can be viewed in Figure 4. The RP3 was chosen over static ergometers because it more closely mimics the physics of on-water rowing and has been validated through previous research (I. A. Bernstein, Webber, & Woledge, 2002; Bourdin et al., 2004; Kleshnev, 2008; Rekers & Esch, 1993). Appendix B contains a review on the development of rowing machines and explains the advantages of the RP3 for a study of this type.

Figure 4

Comparison of Static & Dynamic Ergometers



Note. Comparison of Static & Dynamic Ergometers. *Top*. Static ergometer. During the drive phase of the rowing stroke, the rower's seat slides on the rail and the flywheel remains stationary. *Bottom*. Dynamic ergometer. During the drive phase of the rowing stroke, the flywheel slides on the rail and the rower remains stationary. Reprinted from "Fixed versus free-floating foot-stretcher mechanisms in rowing erometers: mechanical aspects," by Colloud et al., 2006, *Journal of Sport Sciences,* p. 483.

The flywheel housing has markers ranging from 1 to 10 that indicate the amount of air resistance reaching the flywheel. In the present study, vents were adjusted to level three for all participants. Data from the RP3 were transmitted from the measurement devices on the RP3 to a Samsung Galaxy Tab A, which connected to the RP3 via bluetooth. Video was captured on an iPhone XR at 60 FPS on a stand located three meters from the seat of the RP3 and positioned at seat height in order to capture the sagittal plane.

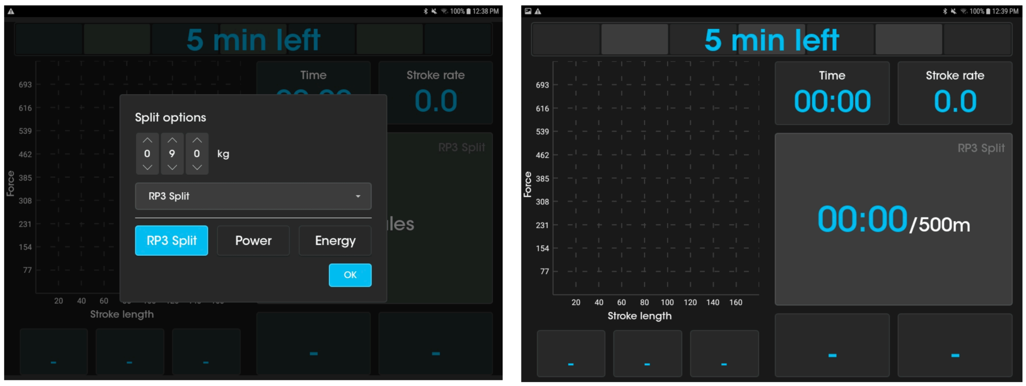
Software

Data were transferred from standard measurement systems within the RP3 to the connected Samsung Galaxy Tab A tablet. The tablet captured data via the RP3 Rowing application (app) for Android (Version 2.13.5, RowPerfect, LLC). A limitation is that although an earlier version (Version 1.6) of the app was validated, no such validation exists for current iteration (Fleming, Donne, & Mahony, 2014). Rowing research has demonstrated that constraints related to the individual and the boat-class in which he or she is racing significantly affect outcomes (Kleshnev, 2008). The app provided the ability to alter these parameters. Adjustments to those inputs, however, would affect the performance measures recorded within the app (Figure 5).

The relationship between mean boat speed (V) and power (P) is described by the following formula: P = K x V^b, where K is the drag caused by the rower's weight and b is a boat-class dependent value (Kleshnev, 2011; Korner & Schwanitz, 1987). As such, any change in weight would affect the value of K and adjustments to boat-class would alter b. For the purpose of standardization across all participants, trials used settings of 90kg to represent participant weight (K) and "RP3 Split" to represent boat-class (b). These are the default settings for the app.

Figure 5

The RP3 Rowing App



Note. The RP3 Rowing App. *Left*. The setup screen where individuals can input weight and boat-class to simulate on-water outcomes. *Right*. The start screen. The modules were set to blank. The RP3 split and force signature module were set to blank before the first trial. The time and stroke rate modules remained as is.

The investigator programmed the RP3 Rowing app with warmup, rest intervals, and work intervals before each session. Multiple sections of the screen allow the app to provide real-time feedback to the rower. The investigator selected those sections and set them to "Blank" with the exception of the time and number of strokes per minute.

Intervention

Upon enrollment, each participant chose a time that was convenient for them to meet with the investigator in the rowing training room. After completing the informed consent and demographic survey (Appendices D & E respectively), participants were provided with the following overview of the session.

> You have chosen to participate in a study evaluating instructional cues and rowing performance. The study will require you to perform three maximal 45 second intervals at a stroke rate between 24 and 26SPM with 3 minutes of rest between. The instructions for each of these intervals will vary. When you are ready to begin, there will be a 5 minute warm up period, followed by the three trials, and then a brief questionnaire. You are able to withdraw at any time without penalty. Do you have any questions?

No knowledge of results was available to the researcher or the participant during the trials, however, the tablet's display included a timer to show the amount of time remaining in each section of the experiment and provided participants with their current stroke rating (SPM). The display during setup and as it was presented to the rower during the trials are illustrated in Figure 5.

Upon confirming the participant had no further questions after hearing the overview, he or she was instructed to warm up at a self-selected pace for five minutes. Data collection started automatically upon the first stroke. After the five minute warm-up period, the participant rested for three minutes. Rest was non-active. The length of rest was determined by the amount of time generally considered to allow physically active participants to fully recover (Bompa & Buzzichelli, 2018; Maglischo, 2003). Thirty seconds before each trial, the researcher provided the appropriate cue to the participant. Cues were both randomized and counterbalanced. For the baseline or control condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute." For the internal focus condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute. As you row, focus on pushing with your legs for each stroke throughout the piece." During the external focus condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute. As you row, focus on creating pressure on the handle for each stroke throughout the piece." The investigator reminded participants that the three minutes of rest was non-active throughout the session. That is, participants were not allowed to row lightly between trials. Participants started each trial without further prompt from the investigator once the counter reached zero.

The stroke rate of 24 to 26 was selected based on previous research demonstrating that force signatures changed when rowers crossed this threshold, although peak force did not (McGregor, Bull, & Byng-Maddick, 2004). A range was provided as opposed to an exact number to provide a degree of autonomy to participants. As rowers commonly engage in practice workouts that are constrained by stroke rating, it was not expected to overtly add to task complexity. The focus cue was changed from its original form, "focus on the sound of the flywheel," because novice participants reported struggling to connect the sound to the intensity of their performance. Participants completed a post-test questionnaire as the final component of the session, which can be found in Appendix E. The questionnaire included a manipulation check to verify what the rowers focused on during the three trials. The timing of the manipulation check was done after all trials were completed based on previous attentional focus research (Wulf, 2013). The total duration of time for the participant to complete the study was 30 minutes.

Individual results were downloaded to a password protected laptop in csv format. The outcomes for each individual were aggregated via Numbers ("Numbers", 2019) and imported to R (R Core Team, 2013) for analysis.

Outcome Measures

Three outcome measures were selected to compare attentional focus and rowing performance. The first two, distance rowed (D) and power (P), were recorded directly from the RP3 Rowing app. The third, mean peak force (PF), was derived from data in subsequent analysis after removing the first stroke from each trial. The first stroke is a known source of high variability on rowing machines, thus it was excluded (Rekers & Esch, 1993; Schabort et al., 1999). A review of the measures and their relationship to rowing performance follows in the next section. A summary table of dependent variables for study one is below in Table 1.

Table 1

Performance Measures

Performance Measure	Unit	Variable Abbreviation
Distance	Meters	D
Peak Force (Mean)	Newtons	PF
Power	Watts	P

Force Production Measures

Distance. The outcome variable distance (D) represents the mean velocity achieved by the rower over the duration of the 45 second trial. Mean velocity (V) is determined by the formula: $v = \sqrt[b]{\frac{P}{k}}$, where b is a boat class determined drag coefficient value, k is the weight of the rower or rowers, and P is power in watts. P represents the sum of all force produced divided by time in seconds and its calculation is further reviewed below. D was directly recorded in meters from the RP3 Rowing app.

Peak force. Peak force (PF) was selected as a dependent variable after previous research indicated it was a significant predictor of rowing performance (Bourdin et al., 2004). Additionally, PF remained consistent across multiple stroke rates in a study by McGregor, Bull, and Byng-Maddick (2004). PF, measured in newtons, was determined by the mean peak force achieved in each stroke through the trial.

Power. Power (P) was selected as a dependent variable for its ubiquitous use within rowing research and the rowing community as a measure of performance (Jensen, Freedson, & Hamill, 1996). P is a primary component in calculating distance rowed, as shown above. P reflects the total mechanical output of the participant during the trial. It is determined by quotient of the total energy produced in joules and time: $P = E/v$. The RP3 Rowing app produces the energy value for each stroke cycle independently, capturing the force produced at each 1/4 rotation of the flywheel. That value determines the total energy created by the rower in joules. When divided by the total time in seconds, it results in P, which is measured in watts.

Data Analysis

Two primary questions were addressed in the statistical analysis: 1) did attentional focus affect the primary outcome of distance in novice participants; 2) did attentional focus affect novice participants peak force and power measures. Data were aggregated for D, PF, and PFM in R (R Core Team, 2013). Statistical assumptions and normality were tested prior to running statistical analysis. Outliers were considered to be any data point more than 1.5 interquartile ranges below the first quartile or above the third quartile. Unusual data points were reviewed. Two participants were removed for having multiple outliers. Data were checked for normality (skewness or kurtosis of +/- 1 was considered non-normal). Data approached the limit for skewness and all outcomes presented kurtosis values outside the pre-established limit (distance at -1.26, power at -1.05, and peak force at -1.08). A Shapiro-Wilk test was conducted that further confirmed a lack of constant variance (distance at $p < .001$, power at $p < .001$, and pf at $p = .001$).

Aim 1

To evaluate the efficacy, in terms of distance rowed in 45 seconds on a dynamic ergometer, of an external focus of attention on improving rowing outcomes in novice participants.

Data analysis. Efficacy was evaluated by comparing distance rowed in baseline, internal, and external focus conditions. Friedman's test was conducted to account for severe kurtosis and lack of constant variance in outcome measures.

Aim 2

To evaluate the efficacy of attentional focus on rowing performance measures of peak force and power in novice participants using a dynamic ergometer.

Data analysis. Efficacy was evaluated by comparing power and peak force outcomes in baseline, internal, and external focus conditions. Friedman's test was conducted to account for severe kurtosis and lack of constant variance in outcome measures.

Chapter III

STUDY ONE RESULTS

Participant Characteristics

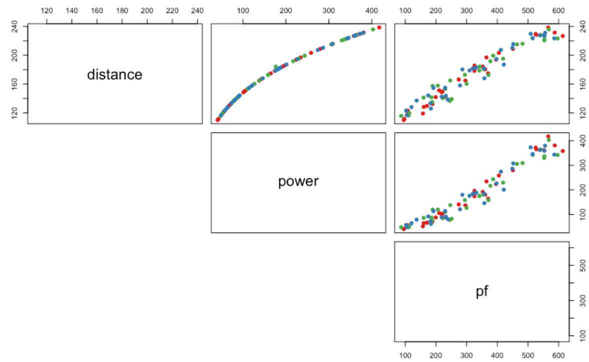
Thirty (N=30) active novice rowers enrolled in the study. Seventeen (n=17) were female and thirteen (n=13) were male. Participant ages ranged from 18 to 73 years, with a mean age of 33 years (SD = 17.35 years). Participants average height was 172cm (SD = 8.9cm) and weight was 69kg (SD = 9.6kg). Participants were in various stages of learning to row, although all met the novice rower criterion. All participants who started the study completed it.

Effects of Focus Condition on Novice Rowers

Outcomes were highly correlated for all dependent variables (Figure 6). For the main outcome of distance, there was no significant effect of condition (Figure 7, Table 2). Similarly, there was no significant difference for power or peak force at $p < .05$.

Figure 6

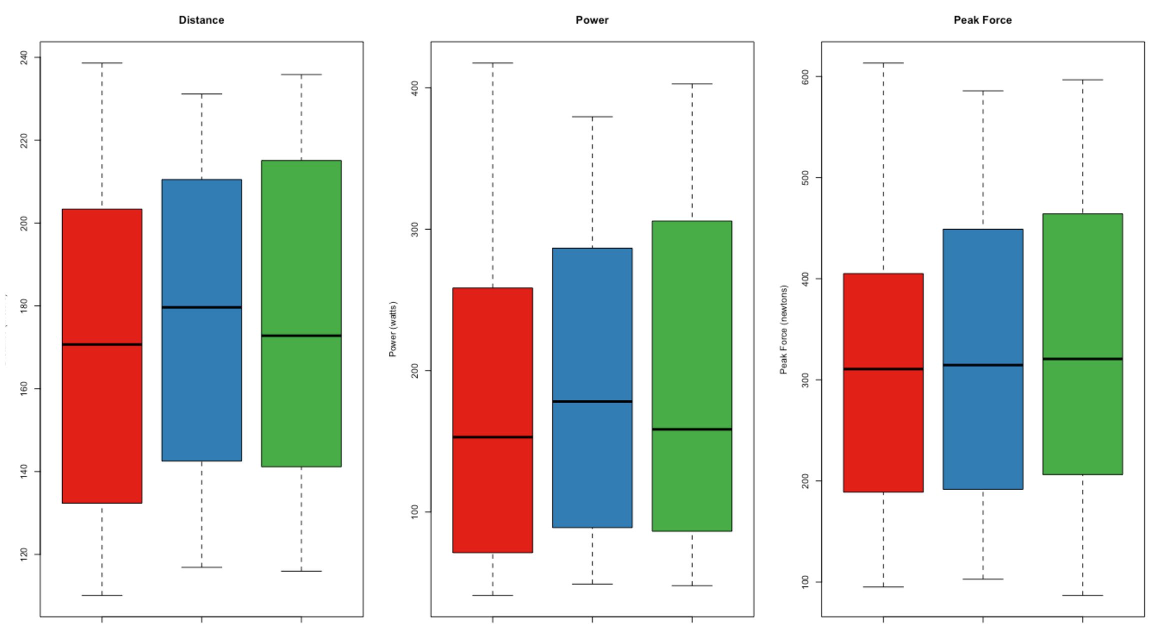
Dependent Variable Correlations



Note. Dependent Variable Outcomes. Distance and power were correlated at .98, while the remaining correlations were .97. Red, blue, and green represent correlations in baseline, external, and internal conditions respectively.

Figure 7

Median Outcomes & Condition



Note. Boxplots faceted by outcomes show median differences by condition. Baseline outcomes are shown in red, while external outcomes are shown in blue and internal in green. *Left.* Distance. *Center.* Power. *Right.* Peak Force. There were no significant differences due to attentional focus for distance, power, or peak force.

Table 2

Median Dependent Variable Outcomes

Condition	Distance (MAD)	Power (MAD)	Peak Force (MAD)
Baseline	170.7 (52.6)	153.0 (124.3)	310.7 (172.6)
External	180.0 (53.2)	178.2 (142.8)	314.6 (188.2)
Internal	172. (47.4)	158.5 (110.3)	320.7 (182.1)

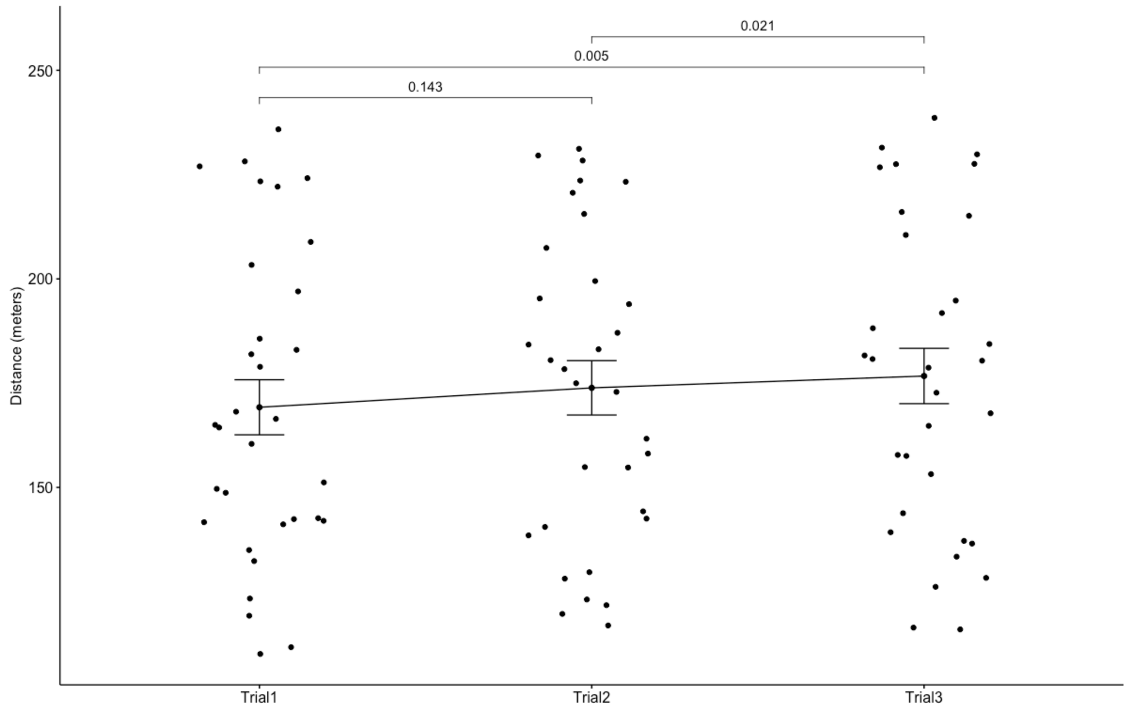
Note. MAD is the median absolute deviation for each outcome measure.

Order and Gender Effects on Distance, Power, and Peak Force

To investigate whether time-order of trials affected outcomes, additional analyses were conducted. First, a Friedman's test showed a significant effect of trial time-order, X2 F(2) = 11.8, p = .003. Subsequent analysis using a Wilcoxon signed-rank test with a Bonferroni-adjustment showed no significant difference between trials one and two, however, significant differences were present between trials one and three (p <0.01) and two and three (p = .021), as illustrated in Figure 8. Next, the six possible combination of trial-orders were added as a factor to the original analysis. The counter-balanced trial-order did not significantly affect outcomes on any performance measure.

Figure 8

Trial Time-Order Effect Analysis

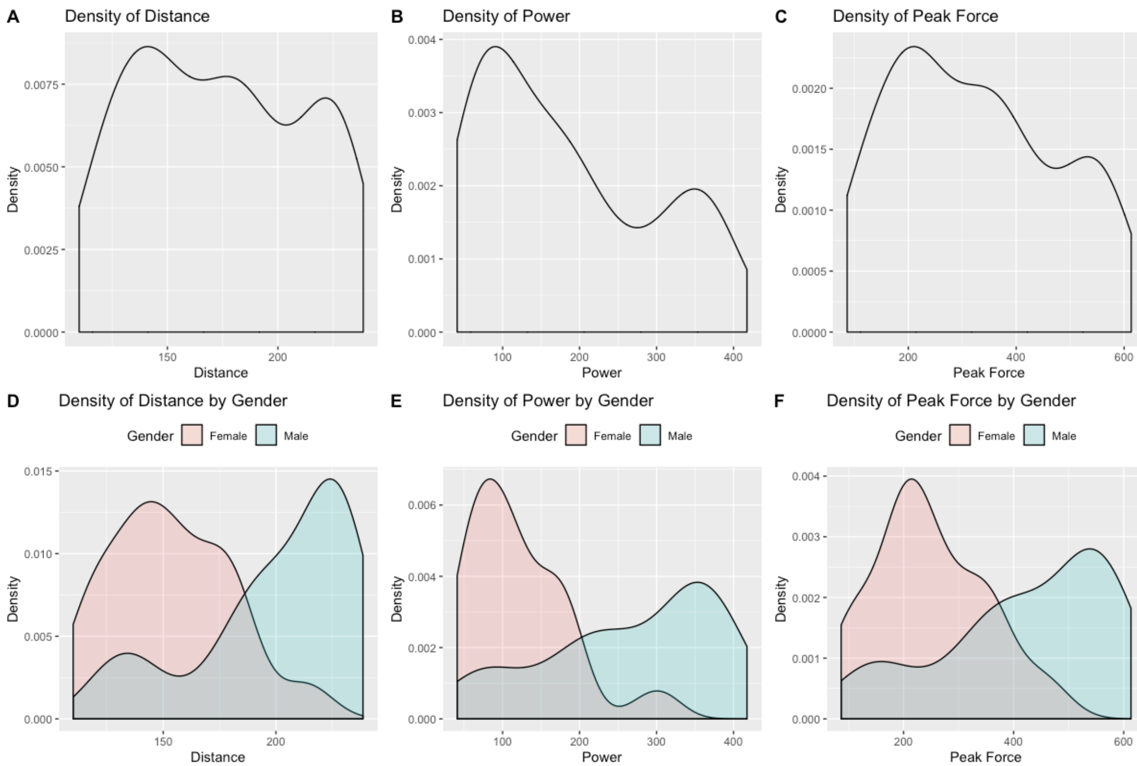


Note. Study one trial time-order effect analysis. The primary outcome of distance was analyzed based on the sequential time-order of the trials as opposed to the condition. Significant improvement was found from trial one to trial three and trial two to trial three. Connected dots represent the median distance rowed for each trial.

To further evaluate the potential sources for trial time-order effects, a comparison of between subject factors was conducted. Outcome measures were plotted for overall density as well as density by gender (Figure 9). Outcomes grouped by gender, independent of condition, were bi-modal. To determine if the gender-based groupings were significant, distance, power, and peak force were regressed on gender using a Kruskal-Wallis test. Gender significantly differentiated participant outcomes on all measures, $\chi^2(2) = 32.526$, $p = < .001$, ((Figure 10).

Figure 9

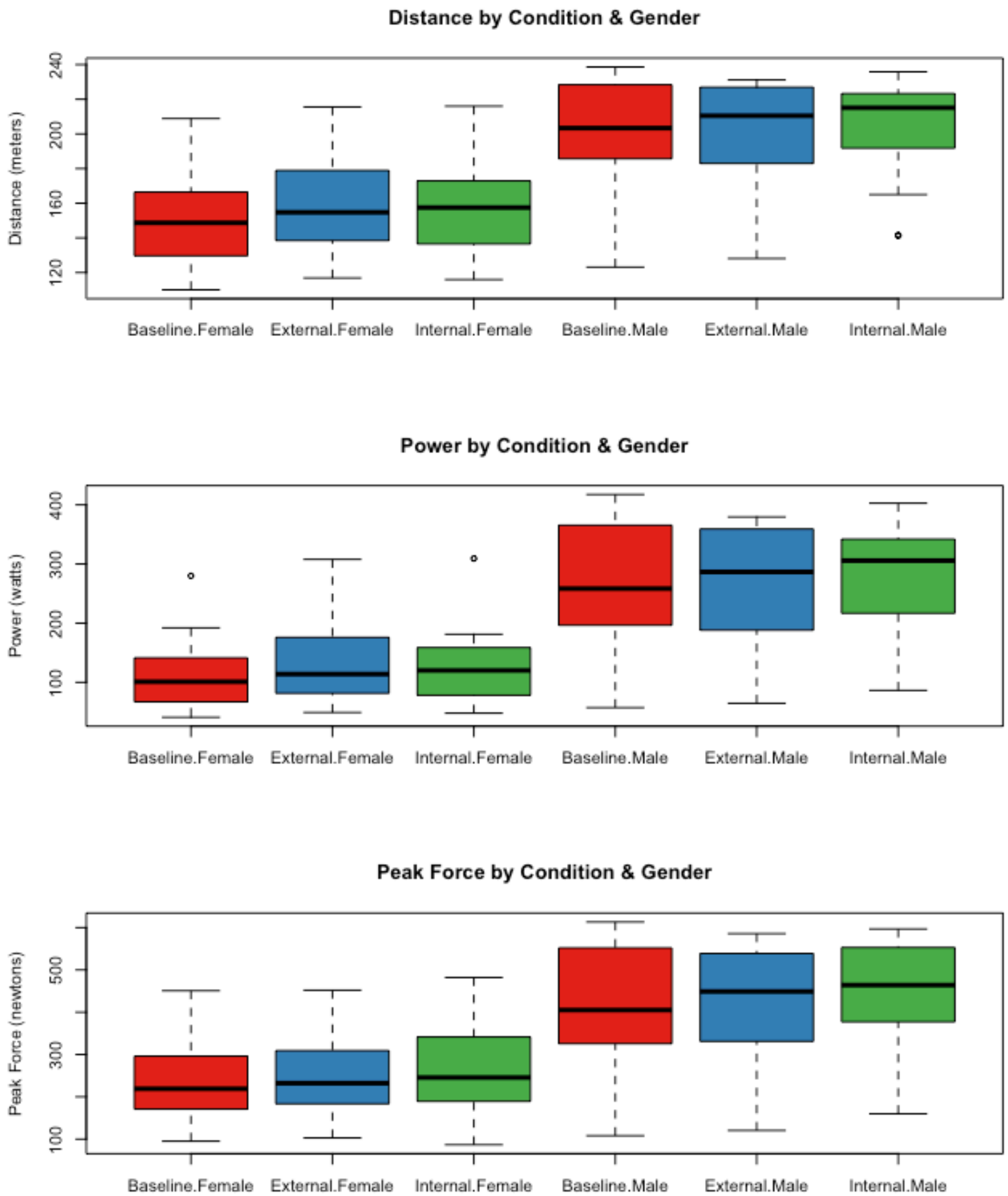
Outcome Measure Density & Gender



Note. Study one dependent variables by gender. Plots A, B, and C illustrate the density of outcomes for all participants for distance, power, and peak force, respectively. Plots D, E, and F show the same outcomes, however, the densities are separated by gender, resulting in a bi-modal distribution pattern.

Figure 10

Outcomes by Condition & Gender

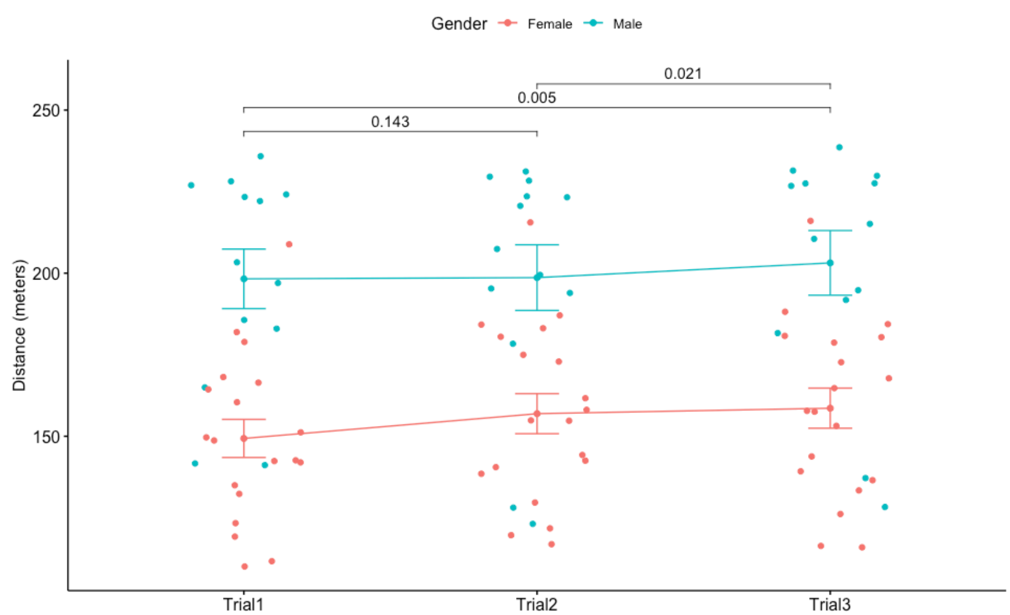


Note. Outcomes for distance, power, and peak force are shown with females represented on left half of the graph and males on the right. Significant differences between genders for all outcome measures at $p < .001$, however, no significant differences were found due to attentional focus.

Controlling for gender did not affect the influence of attentional focus on outcomes. To evaluate if gender significantly influenced trial outcomes based on time-order, it was added as an additional factor. Median differences in performance based on trial time-order and gender were not significant. Figure 11 illustrates the main outcome of distance by gender and time-order. The Bonferroni adjusted p-values in Figure 11 represent the significance of both male and female participants from trial to trial.

Figure 11

Trial Time-Order Analysis by Gender



Note. Study one trial time-order analysis by gender. *Left.* Trial 1. Middle. Trial 2. Right. Trial 3. The significance values located at the top of the graph represent the overall significance independent of gender, as was illustrated in Figure 8. This graph shows outcomes by gender and their relationship to the overall improvement seen from trial to trial.

Chapter IV

STUDY TWO METHODS

Design

A counter-balanced mixed model design was used to evaluate the efficacy of attentional focus on rowing outcomes in novice and expert participants. Distance covered in 45 seconds was the primary outcome measure. Additional data evaluating force production and force signature measures were captured. Power (P), peak force (PF), peak force max (PFM), and energy in joules (J) were the selected along with D as measurements to evaluate participant force production. The term force signature was established by Ishiko (1971) to describe the force profiles common to rowing. Measures selected to evaluate participant force signatures included stroke length (SL), peak force position (PFP), mean to peak force ratio (MPFR), and dispersion factor (DF). A subset of participants were randomly selected for kinematic analysis. Francis classification (FC) ratios were calculated and compared across attentional focus conditions and levels of expertise to assess body segment usage. Participants completed a single 30-minute session during which they completed trials in control, internal, and external focus condition. Study procedures were reviewed and approved by the Internal Review Board at Teachers College, Columbia University prior to enrolling participants.

Participants

Adult individuals were recruited from Columbia University and rowing clubs in the greater New York City area to participate in the study. Participants were selected from the general population and considered for inclusion in the study if they were actively rowing at least twice per week and over 18 years of age. Novice participants were defined as individuals rowing regularly for at least three months, but not longer than 24 months or two competitive 1,000m or 2,000m race seasons. Experts were defined as individuals rowing on a regular basis with at least 24 months of consistent experience or who had completed two competitive 1,000m or 2,000m race seasons. Expertise in the present study was determined by the amount of experience, as opposed to the athletic achievements or any other evaluations of the individual. 1,000m racing is standard for masters level rowing and 2,000m racing is standard for club, collegiate, or elite rowing. Participation was open to both categories of rowers, so long as they met the remaining criteria.

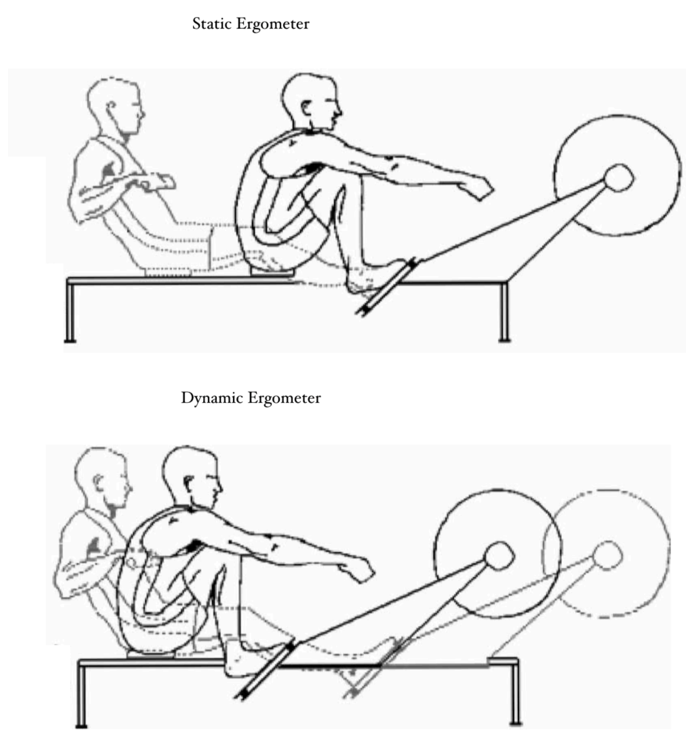
Equipment

Hardware

All sessions involved the use of an RP3 Model S Dynamic Indoor Rower. The RP3 used an air-braked flywheel housed within a perforated metal cage to create resistance. The flywheel was driven by a chain and pulley system that connected to a handle, mimicking the rowing stroke when pulled. An image of the RP3 dynamic rower compared to a static indoor rower can been seen in Figure 12. The RP3 was chosen over static ergometers because it more closely mimics the physics of on-water rowing and has been validated through previous research (I. A. Bernstein et al., 2002; Bourdin et al., 2004; Kleshnev, 2008; Rekers & Esch, 1993). A detailed review on the development of rowing machines and the advantages of dynamic indoor ergometers is available in Appendix B.

Figure 12

Comparison of Static & Dynamic Ergometers



Note. Comparison of Status & Dynamic Ergometers. *Top.* A static ergometer in use. During the drive phase of the rowing stroke, the rower's seat slides on the rail and the flywheel remains stationary. *Bottom.* A dynamic ergometer in use. During the drive phase of the rowing stroke, the flywheel slides on the rail and the rower remains stationary. Reprinted from "Fixed versus free-floating foot-stretcher mechanisms in rowing erometers: mechanical aspects," by Colloud et al., 2006, *Journal of Sport Sciences,* p. 483.

As during study one, vents controlling the amount of air resistance reaching the flywheel were standardized at level 3 out of 10. The perforated cage for the flywheel was checked for debris and cleaned to ensure consistent air flow. Data from the RP3 were transmitted from the measurement devices on the RP3 to a Samsung Galaxy Tab A, which connected to the RP3 via bluetooth. Video was captured on an iPhone XR at 60 FPS on a stand located three meters from the seat of the RP3 and positioned at seat height in order to capture the sagittal plane.

Software

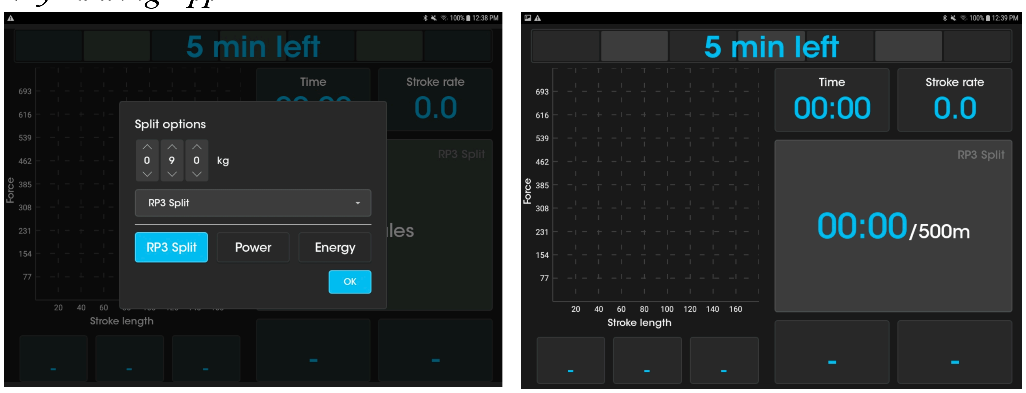
Data were transferred from standard measurement systems within the RP3 to the connected Samsung Galaxy Tab A tablet. The tablet captured data via the RP3 Rowing app for Android (Version 2.13.5, RowPerfect, LLC). A limitation is that although an earlier version (Version 1.6) of the app was validated, no such validation exists for current iteration (Fleming et al., 2014). Rowing research has demonstrated that constraints related to the individual and the boat-class in which he or she is racing significantly affect outcomes (Kleshnev, 2008). The app provided the ability to alter these parameters. Adjustments to those inputs, however, would affect the performance measures recorded by the app.

The relationship mean boat speed (V) and power (P) is described by the following formula: $P = K \times V^b$, where K is the drag caused by the rower's weight and ^{b} is a boat-class dependent value (Kleshnev, 2011; Korner & Schwanitz, 1987). As such any change in weight would affect the value of K and adjustments to boat-class would alter b. For the purpose of standardization across all participants, trials used settings of 90kg to represent participant weight (K) and “RP3 Split” to represent boat-class (b). These are the default settings for the app.

The investigator programmed the RP3 Rowing app with warmup, rest intervals, and work intervals before each session. Multiple sections of the screen allow the app to provide real-time feedback to the rower. The investigator selected those sections and set them to “Blank” with the exception of the time and number of strokes per minute. An image of the screen can be seen in Figure 13.

Figure 13

The RP3 Rowing App



Note. The RP3 Rowing App. *Left*. The setup screen where individuals can input weight and boat-class to simulate on-water outcomes. *Right.* The start screen. The modules were set to blank. The RP3 split and force signature module were set to blank before the first trial. The time and stroke rate modules were left as is.

Intervention

Upon enrollment, each participant chose a time that was convenient for them to meet with the investigator in the Rowing Training Room. After completing the informed consent and demographic survey (Appendices D & E, respectively), participants were provided with the following overview of the session.

> You have chosen to participate in a study evaluating instructional cues and rowing performance. The study will require you to perform three maximal 45 second intervals at a stroke rate between 24 and 26SPM with 3 minutes of rest between. The instructions for each of these intervals will vary. When you are ready to begin, there will be a 5 minute warm up period, followed by the three trials, and then a brief questionnaire. You are able to withdraw at anytime without penalty. Do you have any questions?

No knowledge of results was available to the researcher or the participant during the trials, however tablet's display did include a timer to show the amount of time remaining in each section of the experiment and the current number of strokes per minute (SPM) at which the participant was rowing. The display during setup and as it was presented to the rower during the trials are illustrated in Figure 13.

Upon confirming the participant had no further questions after hearing the overview, he or she was instructed to warm up at a self-selected pace for five minutes. Data collection started automatically upon the first stroke. After the five minute warm-up period, the participant rested for three minutes. This rest was non-active. The length of rest was determined as the amount of time generally considered to allow physically active participants fully recover (Bompa & Buzzichelli, 2018; Maglischo, 2003). Thirty seconds before each trial, the researcher provided the appropriate cue to the participant. These cues were both randomized and counterbalanced. For the baseline or control condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute." For the internal focus condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute. As you row, focus on pushing with your legs for each stroke throughout the piece." During the external focus condition, participants were instructed to "complete the trial as fast as possible at a stroke rate between 24 and 26 strokes per minute. As you row, focus on creating pressure on the handle for each stroke throughout the piece." The investigator reminded participants that the three minutes of rest was non-active throughout the session. That is, participants were not allowed to row lightly between trials. Participants started each trial when the counter reached zero.

The stroke rate of 24 to 26 was selected based on previous research demonstrating that force signatures changed when rowers crossed this threshold, although peak force did not (McGregor et al., 2004). A range was provided as opposed to an exact number to provide a degree of autonomy to participants. As rowers commonly engage in practice workouts that are constrained by stroke rating, it was not expected to overtly add to task complexity. The focus cue was changed from its original form, "focus on the sound of the flywheel," because novice participants reported struggling to connect the sound to the intensity of their performance. Participants completed a post-test questionnaire as the final component of the session, which can be found in Appendix E. The questionnaire included a manipulation check to verify what the rowers focused on during the three trials. The timing of the manipulation check was done after all trials were completed based on previous attentional focus research (Wulf, 2013). The total duration of time for the participant to complete the study was 30 minutes.

Individual results were downloaded to a password protected laptop in csv format. The outcomes for each individual were aggregated via Numbers ("Numbers", 2019) and imported to R (R Core Team, 2013) for analysis.

Outcome Measures

Ten outcome measures were selected to evaluation attentional focus and rowing performance. Most performance measures were directly recorded, however some were derived from the data in subsequent analysis. A review of those measures and their relationship to rowing performance follows in the next section. A summary table of dependent variables is located in Table 3.

Table 3

Study Two Outcome Measures

Outcome	Unit	Abbrev.	Group
Distance	Meters	D	Force Production
Power	Watts	P	Force Production
Peak Force (Mean)	Newtons	PF	Force Production
Peak Force Max	Newtons	PFM	Force Production
Energy	Joules	E	Force Production
Stroke Length	Centimeters	SL	Force Signature
Peak Force Position	Percentage	PFP	Force Signature
Mean to Peak Force Ratio	Ratio	MPFR	Force Signature
Dispersion Factor*	Custom	DF	Force Signature
Francis Classification	Ratio	FC	N/A
Stroke Rate	Strokes per Minute	SPM	Explanatory

* Dispersion Factor is also known as the Integrated Mean Squared Error.

Force Production Measures

Distance. The outcome variable distance (D) represents the mean velocity achieved by the rower over the duration of the 45 second trial. Mean velocity (V) is determined by the formula: $V = \sqrt[b]{\frac{P}{k}}$, where b is a boat class determined value, k is the weight of the rower or rowers, and P is the total force produced divided by time in seconds. D was directly recorded in meters from the RP3 Rowing app.

Peak force. Peak force (PF) was selected as a dependent variable after previous research indicated it was a significant predictor of rowing performance (Bourdin et al., 2004). Additionally, PF remained consistent across multiple stroke rates in a study by McGregor, Bull, and Byng-Maddick (2004). PF, measured in newtons, was determined by the mean peak force achieved in each stroke through the trial.

Peak force max. Peak force max (PFM) was selected as a performance measure for reasons similar to those reviewed for PF. It was added to determine if the apex of maximal force production during each trial was affected by condition.

Power. Power (P) was selected as a dependent variable for its ubiquitous use within rowing research and the rowing community as a measure of performance (Jensen et al., 1996). P reflects the total mechanical output of the participant during the trial. It is determined by quotient of the total energy produced in joules and time: $P = E/v$. The RP3 Rowing app produces the energy value for each stroke cycle independently, capturing the force produced at each 1/4 rotation of the flywheel.

That value determines the total energy created by the rower in joules. When divided by the total time in seconds, it results in P, which is measured in watts.

Energy. Energy (E) measures the mechanical output produced within a single rowing stroke. Energy is also known as the "area under the curve" when referencing a rower's force signature. Increases in E are associated with improved performance, especially during rate controlled evaluations (Kleshnev, 2011). It is the product of force and distance and is measured in joules. Force was measured as the product of mass times acceleration. In the present study, mass was determined by the weight (17.5kg) of the flywheel housed within the PR3's perforated metal cage and acceleration was the rate at which the flywheel increased in rotational speed during the rowing stroke. This measurement was validated by Rekers & Esch (1993).

Force Signature Measures

Stoke length. Stroke length (SL) was selected because of the relationship between force and distance when measuring joules produced during each stroke. When rowers have a longer stroke length, they increase the amount of distance during which they may apply propulsive forces. Stroke length was measured by the RP3 Rowing app, which uses the size of the sprocket in the ergometer and the number of 1/4 flywheel rotations to determine a number in centimeters.

Peak force position. Smith and Spinks (1995) found that expert rowers achieved peak force earlier in the drive phase than good or novice rowers in on-water rowing. Peak force position (PFP) was included to determine if attentional focus affected when rowers achieved peak force. PFP was determined by the location of maximal force during each stroke cycle. To account for differences in participant size, PFP was adjusted to reflect that location as a percentage of their overall stroke length.

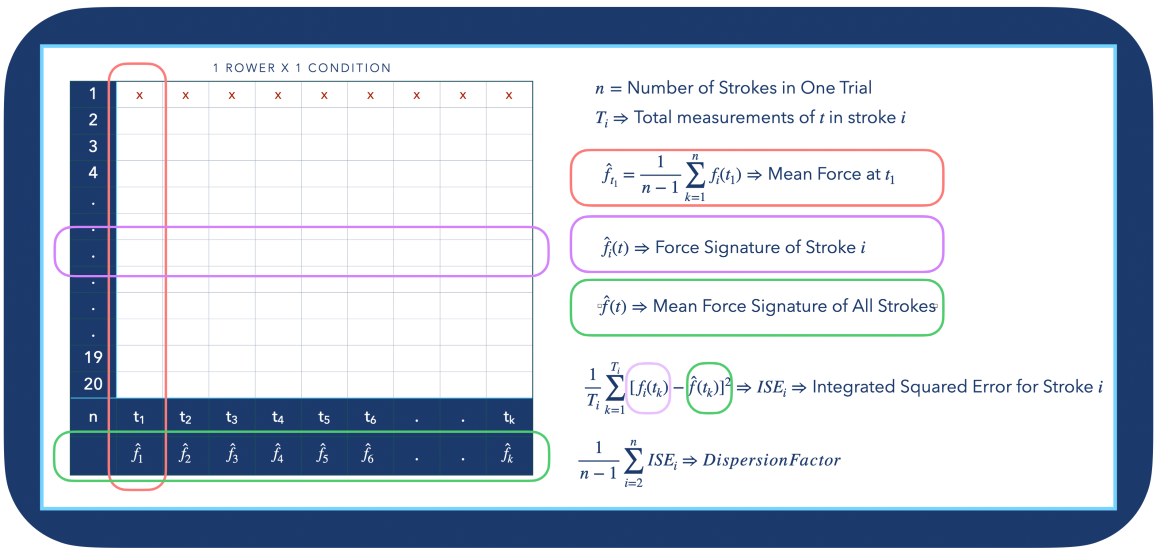
Mean to peak force ratio. Mean to peak force ratio (MPFR) was created by averaging the ratio of mean force to peak force for each stroke within a condition. Kleshnev (1998) established that increasing the average force relative to the maximal force resulted in greater energy production within the stroke. The ratio has been typically more prevalent in elite rowers (R. M. Smith & Draper, 2006). The measure was calculated by averaging all force measures for each stroke and creating the ratio by comparing it to the maximum. The mean of that ratio over all strokes in each trial was used for analysis.

Dispersion factor. Dispersion factor (DF) was created using a Functional Data Analysis (FDA) technique and is more commonly known as the integrated mean squared error (Górecki & Smaga, 2019; Ramsay & Silverman, 2005). This non-parametric, non-linear measure of variability was implemented to evaluate stroke to stroke consistency, as well as stroke smoothness. Similar to assessments of energy or the area under the curve in a force signature, the consistency and the smoothness of force application are associated with improved efficiency and levels of rowing skill (Rekers & Esch, 1993; R. M. Smith & Loschner, 2002) Previous work exploring these factors relied upon data reduction or averaging techniques (Hill, 1995).

DF was a novel creation using FDA to capture consistency and smoothness without data loss (Górecki & Smaga, 2019). FDA techniques were previously implemented in rowing to successfully analyze non-linear time series data associated with force-angle relationships (Warmenhoven et al., 2017). Warmenhoven et al. (2018) also used FDA techniques to confirm previous research from Smith & Draper (2006) that reported purposeful alterations to force production. In both of those studies, skilled rowers adjusted their force production so that shells tracked straight, improving outcomes even if force decreased.

Figure 14

Dispersion Factor Variable Formulas



Note. Dispersion factor variables formulas. The light red squares show the formula and location within the data to calculate mean force at each measurement point (1/4 rotation of the flywheel). The purple squares show the formula and location within the data to calculate the mean force of each individual stroke. The green squares show the formula to determine the overall mean for each participant in each trial. The difference between purple and green is the Mean Squared Error (MSE). Summing all MSEs results in Dispersion Factor.

Force measurements for each rower in each condition were averaged at each time-point, *t*. Average force values at each measurement point resulted in a mean force signature within each trial. Individual strokes were compared against the mean force signature and deviations were measured, creating a measure of variance for each stroke within the trial. Variance for all strokes within the trial was divided by the total number of strokes to create DF. Lower DF scores are representative of increased consistency and smoothness of force application (Hill, 1995).

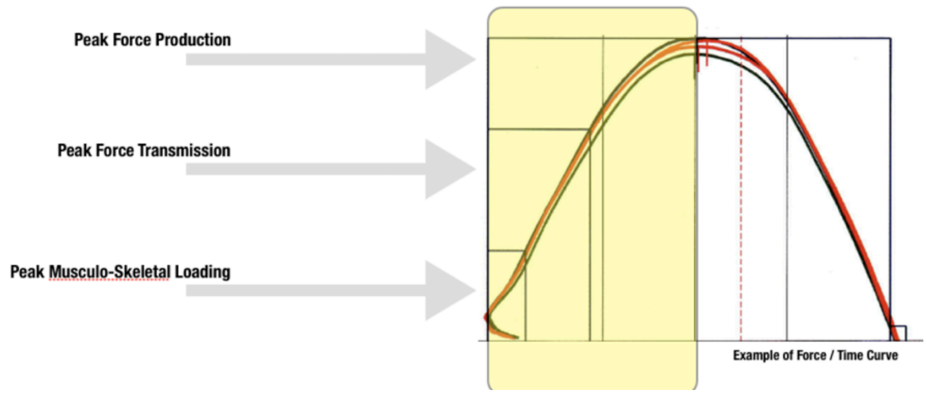
Kinematic and Control Measures

Francis classification. The Francis Classification (FC) was developed and implemented by Paul Francis with British Rowing during 2012 Olympic Games quadrennial. He found that changes in body segment usage were early indicators that an individual or crew was about to lose velocity. In the present study, FC was selected to as a form of principle component analysis by which the effects of attentional focus could be measured.

Kinematics for a randomly chosen subset the participants (n=12) were analyzed using Dartfish 360 to determine angle relationships of the hips and trunk during the drive phase (Dartfish, 2019). The FC ratio is determined by the angle relationship between the knees, hips, and shoulders at two time-points in the drive phase. Onset was defined as the first frame during which the powerhead on the dynamic rower has changed directions. Offset was an absolute value of .4 seconds after onset. This period is known as the critical drive (Francis, 2013).

Figure 15

The Critical Drive & Francis Classification

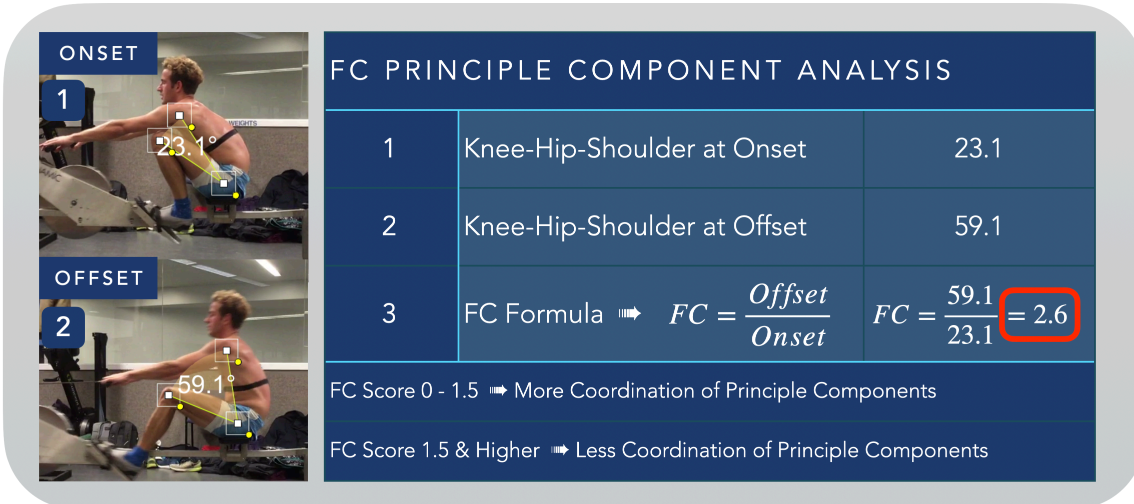


Note. The Critical Drive. Elements of the critical drive include the yellow shaded area, highlighted by peak musculoskeletal loading, peak force transmission, and peak force production. The degree of concurrent or sequential coordination of leg and trunk activity during this phase receives a value according to ratios defined by the Francis Classification guidelines. Reprinted from Coaching Power by Francis, 2013, at *The Joy of Sculling,* p. 6.

The ratios for critical drive are determined by the location of the knee, hip, and shoulder joints. The angle at onset was divided by the angle at offset to provide a ratio. Values of zero to 1.5 represent more trunk activity or concurrent body segment usage during the critical drive phase of the stroke. Values of 1.5 and higher represent more leg activity or sequential body segment usage during the critical drive phase, as shown in Figure 16.

Figure 16

Calculation of Francis Classification Scores



Note. FC scores are a ration of of trunk and leg activity at 1) onset and 2) offset timepoints in the drive. The angle relationship at offset is divided by onset to create a ratio that reflects the change in relative location during the first .4 seconds of the drive. Scores were calculated on strokes eight, nine, and ten for each participant and then averaged.

Stroke rate. Strokes per minute (SPM) was measured as a control check on the participant's activity during the trials. The number of strokes per minute for each trial was set to a rate between 24 and 26. Elliot et al. (2002) demonstrated that the RP3 matched the kinematics of on-water rowing at stroke rate 26 and above. Previous research indicated shifts in the shape of the force signature when rowers went above 26 strokes per minute (Colloud, Bahuaud, Doriot, Champely, & Chèze, 2006; McGregor et al., 2004). Thus, a balance between kinematics and force production determined the stroke rate for this study.

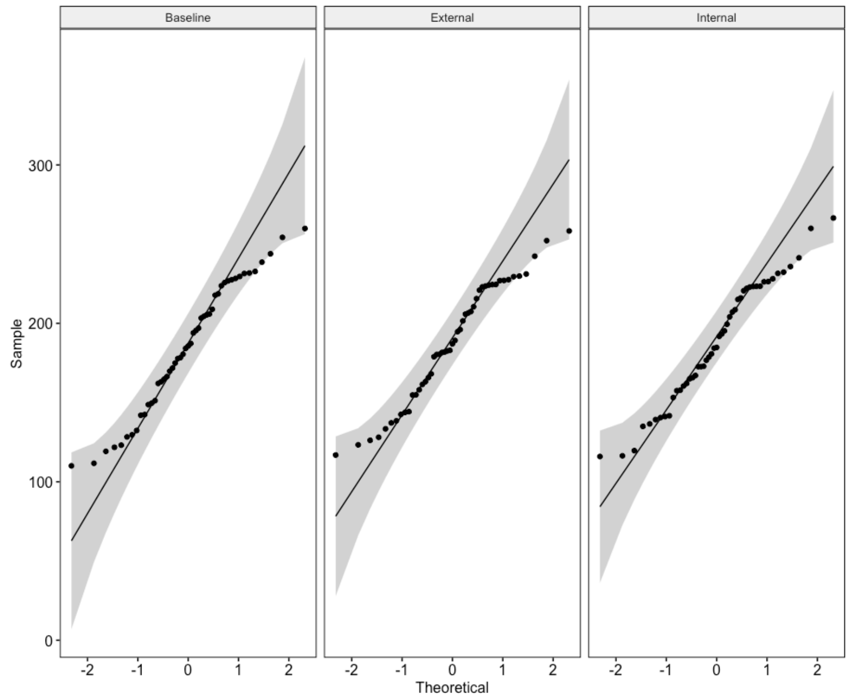
Data Analysis

Three primary questions were to be addressed in the statistical analysis: 1) did attentional focus affect the outcome of distance for novice and expert rowers; 2) did attentional focus affect force production and force signature performance measures for novice and expert rowers; and 3) did attentional focus affect body segment usage for novice and expert rowers. Additional measures from the demographic survey were used as covariates to examine their potential influence on dependent variables. These included total height and weight.

Data were aggregated in R (R Core Team, 2013). Statistical assumptions were tested prior to running statistical analysis. Outliers were considered to be any data point more than 1.5 interquartile ranges below the first quartile or above the third quartile. Two participants were removed for having multiple outliers. Data were checked for skewness and kurtosis, where a value of +/- 1 was considered non-normal. Levene's test confirmed the data were of constant variance. The more conservative Shapiro-Wilk test indicated some potential issues with normality, however, qq plots showed most residuals for the primary outcome of distance were within an acceptable range (Figure 17). Residuals located farther at the high and low ends of the three graphs in Figure 17 were associated with consistent individual performances from athletes representing the ends of the performance spectrum (novice on the left and elite rowers on the right) and not removed.

Figure 17

Distance Residuals & Normality Assumptions



Note. Study two distance residuals plotted against the theoretical distribution line. For the primary outcome distance, residuals were plotted to assess normality. Participants near the top right and bottom left of each plot that fall nearly outside the gray were included as their trials were consistent. These individuals had participated in elite level rowing, thus their status at outliers was already established to some degree.

Aim 1

To evaluate the efficacy, in terms of distance rowed in 45 seconds on a dynamic ergometer, of an external focus of attention on improving rowing outcomes.

Data analysis. Efficacy was evaluated by comparing distance outcomes in baseline, external, and internal focus conditions. A two-way repeated measures ANOVA (expertise: novice, expert x condition: baseline, external, internal) was conducted on distance to determine main effects and interactions.

Aim 2

To evaluate the efficacy of attentional focus on rowing force production performance measures of power, peak force, peak force max, and joules as well as force signature measures of peak force position, stroke length, mean to peak force ratio, and dispersion factor in novice and expert participants.

Data analysis. Efficacy was evaluated by comparing force production and force signature outcomes in baseline, external, and internal focus conditions. A two-way repeated measures ANOVA (expertise: novice, expert x condition: baseline, external, internal) was conducted to determine main effects of expertise and condition, as well as possible interactions.

Aim 3

To determine the relationship between outcomes and attentional focus when controlling for height and weight.

Data analysis. Rowing research has indicated that differences in height and weight significantly affect performance across the rowing population (Barrett & Manning, 2004; Kerr et al., 2007; Mikulic, 2009). Anthropometric measures of height and weight were evaluated for significant effects as covariates in separate one-way ANCOVA models comparing dependent variable outcomes in baseline, external, and internal focus conditions.

Aim 4

To assess body segment usage under control, internal, and external attentional focus conditions for a subgroup of novice and expert participants during dynamic indoor rowing.

Data analysis. The ratio of body segment usage was evaluated by calculating FC scores for a randomly chosen subset of novice (n=6) and expert (n=6) participants. Friedman's test was performed to determine if there were significant effects of condition. A Kruskal-Wallis test was used to evaluate expertise and FC.

Chapter V

STUDY TWO RESULTS

Participant Characteristics

A total of 49 (N = 49) individuals participated in study two. Of those, thirty were novice rowers and 19 were expert rowers. Novice participants included 13 males (n = 13) and 17 females (n = 17). The expert participants included 12 males and seven females. Age amongst participants was widely dispersed with a mean of 32.59 years (SD = 15.89 years) and a median of 25 years. The youngest participant was 18 and the oldest was 72. The mean height for all participants was 174.31cm (SD = 11.00) and weight was 70.45kg (SD = 14.55). The range of experience was varied from novice participants to current Under-23 and former senior national team rowers. Further subject characteristics specific to covariate analysis on height and weight are located in Table 4.

Table 4

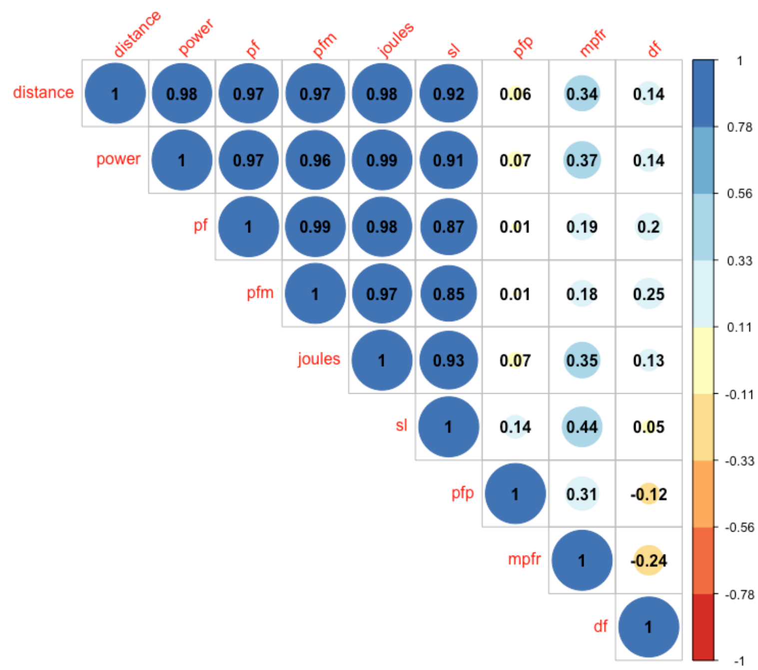
Subject Characteristics & Expertise

	Novice (n = 30)			Expert (n = 19)			All (N = 49)		
	Age	Height	Weight	Age	Height	Weight	Age	Height	Weight
Mean	34.1	172.4	69.8	31.2	178.2	76.0	33.0	174.7	72.2
SD	17.5	9.0	9.4	13.2	12.8	13.7	16.0	11.0	11.7
Median	26.5	173.0	69.5	25.0	178.0	73.0	26.0	175.0	71.0
Min	18.0	155.0	53.0	18.0	160.0	54.0	18.0	155.0	53.0
Max	73.0	192.0	90.0	56.0	201.0	109.0	73.0	201.0	201.0

Outcomes amongst force production measures were highly correlated (Figure 18). Force signature outcomes had low correlations compared to force production. The exception was for stroke length, a measure that has a degree of multicollinearity with force production values as it is one of the inputs for their calculation. The lack of strong correlations between force production and force signature measures indicated independence. That is, participants' strength and endurance appeared weakly or not at all connected to measures that described how they apply force while rowing.

Figure 18

Dependent Variable Correlations



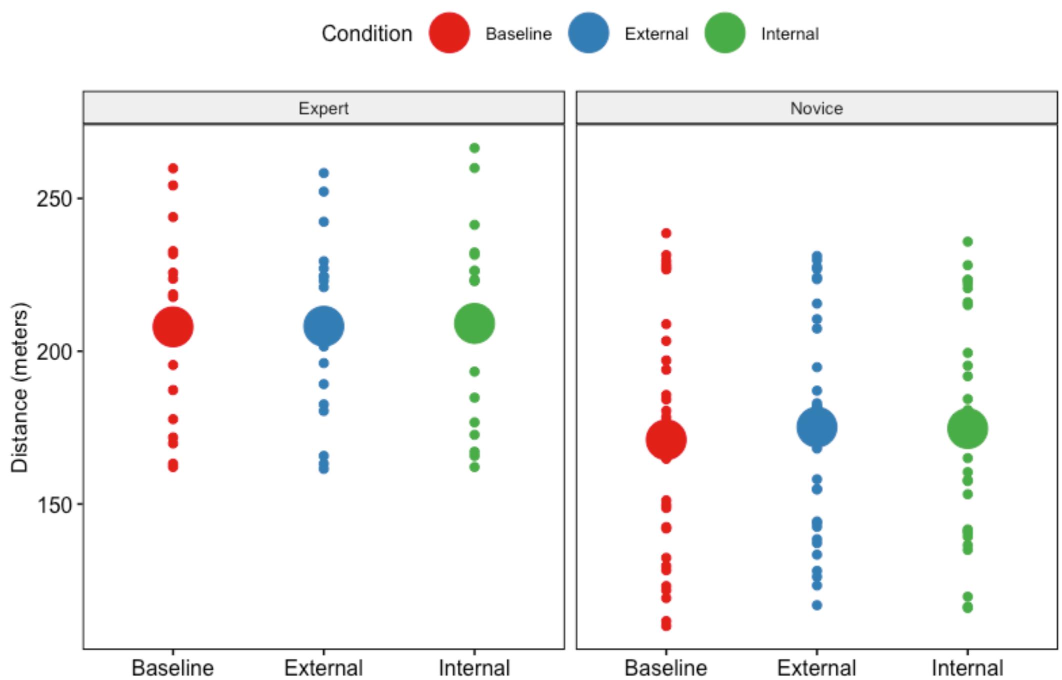
Note. Study two dependent variable correlations. Outcome measures for all participants were correlated. Force production measures of distance, power, peak force, peak force max, and joules were highly correlated. Stroke length, a force signature measure, was highly correlated with force production measures because of its role as an input into their calculation. Low correlation values for force signature measures suggest their independence from force production measures.

Efficacy of Attentional Focus on Distance Rowed

Distance rowed, the primary outcome of interest, was calculated for all participants by the RP3 Rowing app. Rowers averaged 187.1 meters (SD = 38.9) across all trials during the study. When rowing under baseline, external, and internal focus conditions, rowers covered 185.4 meters (SD = 41.0), 188.0 meters (SD = 37.7), and 188.0 meters (SD = 38.5) respectively. To investigate if participant's attentional focus condition or level of expertise had a significant relationship with distance rowed, a two-way (expertise x condition) repeated measures ANOVA was conducted. There was no main effect of condition, $F(1.44,67.58) = 1.653$, $p > .05$, $\eta^2 = .196$, however, there was a main effect of expertise, $F(1,47) = 11.47$, $p = .001$, $\eta^2 = .196$ (Figure 19). A Greenhouse-Geisser correction was applied the condition ANOVA to adjust for a lack of sphericity. There was no interaction between expertise and condition.

Figure 19

Distance Rowed by Expertise & Condition



Note. Distance rowed by expertise and condition. Small circles represent individual outcomes. Large circles represent the mean distance rowed for all participants in each condition for the given level of expertise. Although there was no significant effect of condition, there was a significant effect of expertise at p = .001.

Pairwise comparisons, considering the Bonferroni adjusted p-value, found a main effect of expertise for distance rowed during baseline (p = .003), external (p =

.006), and internal (p = .006) trials. Pairwise comparisons further demonstrated that mean distance rowed was significantly different between expert and novice participants for baseline ($p < .001$), external ($p = .002$), and internal ($p < .001$) trials.

Efficacy of Attentional Focus on Force Production

Force production measures, an additional set of measures commonly used in rowing research that describe the magnitude and duration of force application, were evaluated. A two-way (expertise x condition) repeated measures ANOVA was conducted to compare effects of expertise and attentional focus condition on outcomes of power, peak force, peak force max, and energy. Mean outcomes for force production measures grouped by condition are located in Table 6. Similar to the post-hoc comparisons from study one, density plots comparing the outcome measures and levels of expertise were created for an initial evaluation (Figure 20).

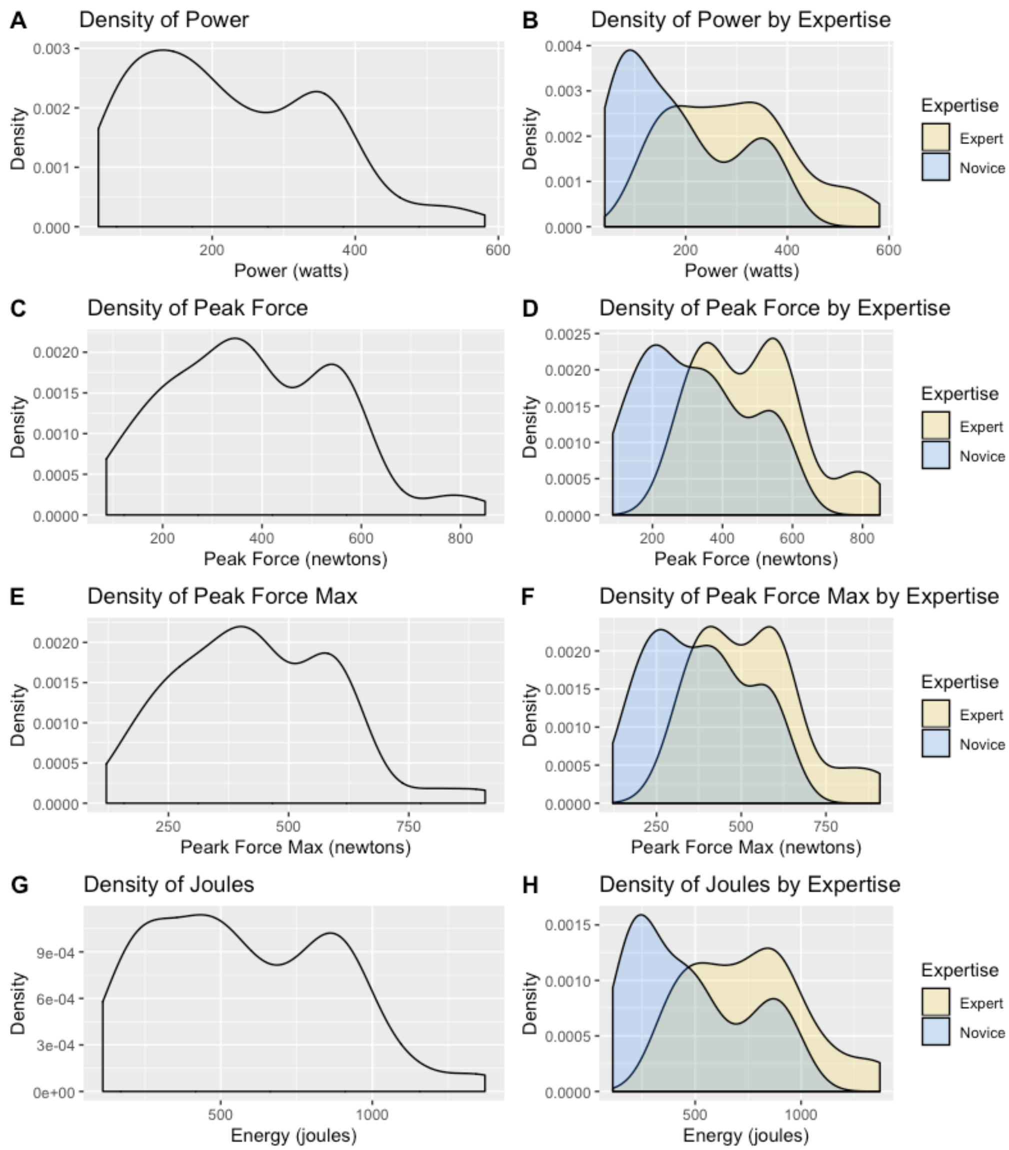
Table 6

Force Production Outcomes & Attentional Focus Condition

	Baseline		External		Internal	
Outcomes	Mean	SD	Mean	SD	Mean	SD
Distance	185.35	40.96	187.95	37.73	188.03	38.52
Power	221.79	131.19	227.92	124.41	228.98	130.33
Peak Force	377.41	174.01	384.26	167.44	391.04	170.32
Peak Force Max	429.91	165.88	431.44	165.53	438.66	169.71
Energy	576.35	308.88	590.57	306.68	584.39	301.63

Figure 20

Force Production Outcome Measures & Expertise



Note. Force production outcomes for power, peak force, peak force max, and energy (joules). *Left*. The density of each outcome for all participants. *Right*. The density of each outcome for participants sorted by level of expertise with experts shaded in yellow and novice shaded in blue.

Comparably to the findings of distance rowed, there were no significant effects of condition on force production measures of power, peak force, peak force max, or energy. There were, however, main effects of expertise. Expertise had a robust impact on all force production measures, regardless of condition. As expertise was not the focus of this study, the follow-up one-way ANOVA analysis and pairwise comparisons performed for the primary outcome of distance were not conducted. The F table for the two-way ANOVA on the remaining force production measures is located in Table 7.

Table 7

Force Production Main Effects & Interactions

	Main Effects		Interaction
Outcome	Expertise	Condition	Expertise x Condition
Power			
Dfn	1	2	2
Dfd	47	94	94
F	10.309	1.985	0.640
p	0.002	0.143	0.530
η^2	0.180	0.041	0.013
Peak Force			
Dfn	1	2	2
Dfd	47	94	94
F	12.430	2.725	0.204
p	0.001	0.071	0.815
η^2	0.209	0.055	0.004
PFM			
Dfn	1	2	2
Dfd	47	94	94
F	11.089	1.445	0.431
p	0.002	0.241	0.651
η^2	0.191	0.030	0.009
Joules			
Dfn	1	2	2
Dfd	47	94	94
F	11.724	1.636	0.006
p	0.001	0.200	0.994
η^2	0.200	0.034	0.000

Effects of Attentional Focus on Force Signatures

Force signature measures of stroke length, peak force position, mean to peak force ratio, and dispersion factor were averaged and compared across attentional focus conditions (Table 8). The low correlations between force production outcomes and force signature measures reflect their relative independence. It suggests that even if force production measures were not affected by attentional focus, force signature measures could capture differences. Those differences would reflect kinetic and possibly kinematic changes in the performer's movement. On the outcome of stroke length, main effects were detected for expertise, $F(1,47) = 10.123$, $p = .003$, $\eta^2 = .177$, and condition, $F(2,94) = 4.979$, $p = .009$, $\eta^2 = .096$. A post-hoc confirmed statistical significance of condition within experts, $F(2,36) = 3.66$, $p = .036$, $\eta^2 = .006$. However, the Bonferroni adjusted p value of .072 was not significant. The associated pairwise comparison within experts also showed no significant differences across condition (Figure 21).

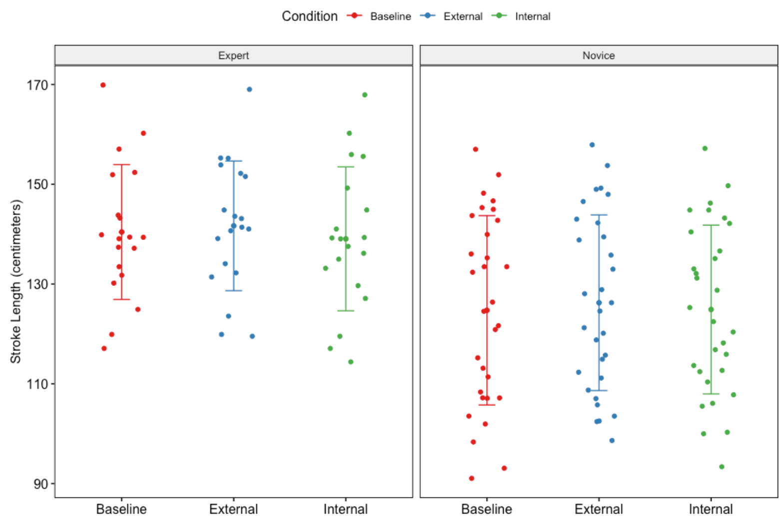
Table 8

Force Signature Outcomes & Condition

	Baseline		External		Internal	
Outcomes	Mean	SD	Mean	SD	Mean	SD
SL	130.82	18.60	132.23	17.56	130.39	17.31
PFP	41.41	7.58	41.64	8.14	41.37	8.67
MPFR	0.62	0.04	0.62	0.04	0.61	0.04
DF	455.30	287.80	516.80	322.40	451.10	293.80

Figure 21

Stroke Length by Condition & Expertise



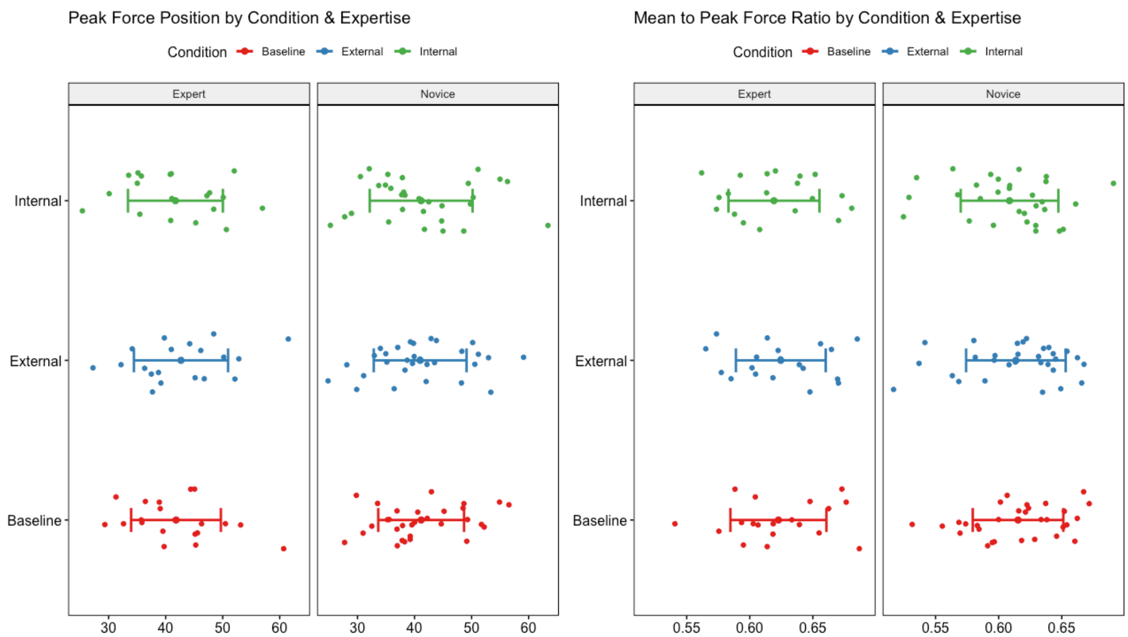
Note. There was a significant difference in stroke length between novice and experts at p = .003. *Left*. Experts stroke lengths are plotted by condition. External stroke length was significantly longer than baseline and internal conditions in the omnibus F test, although pairwise comparisons were not significant. *Right*. Novice stroke lengths plotted by condition. There were no significant effects of stroke length for novice participants.

Peak force position was converted from an absolute value to a percentage of the total stroke length, a standard output from the RP3 Rowing app for analyzing the location of peak force within the drive phase of the rowing stroke. A two-way (expertise x condition) repeated measures ANOVA found no main effects of expertise, $F(1,47) = .172$, $p > .05$, $\eta^2 = .004$, or condition, $F(2,94) = .450$, $p > .05$, $\eta^2 = .009$, on the location of peak force (Figure 22). Although previous research demonstrated expert rowers achieved peak force earlier in the drive sequence, that research was isolated to on-water rowing and may not have applications to dynamic indoor rowing (R. M. Smith & Spinks, 1995). In addition to PFP, changes in MPFR have also been found to reflect levels of expertise (R. M. Smith & Spinks, 1995).

MPFR was calculated per stroke before and then averaged to create a final ratio for each condition. A two-way (expertise x condition) repeated measures ANOVA compared MPFR ratios and found no significant main effects or interactions of expertise or condition (Figure 22).

Figure 22

Peak Force Position & Mean to Peak Force Ratio



Note. Left. Peak force position was not significantly affected by condition or expertise.*Right.* Simiarly, mean to peak force rations were also not significantly affected by condition or expertise.

Similar to the previous force signature measures, results for dispersion factor showed no significant main effects of condition. Also similar to previous measures, there was a significant main effect for expertise. Expert rowers completed trials with significantly less variability in their force signatures compared to novice participants. Reduced variability has been consistently shown to reflect higher levels of expertise

(Hill, 1995; R. M. Smith & Draper, 2006; R. M. Smith & Spinks, 1995).A complete table of force signature outcomes is located in Table 9. Representative examples of the force signatures and the dispersion factor values associated with each condition for novice and expert participants are located in Figures 23 and 24, respectively.

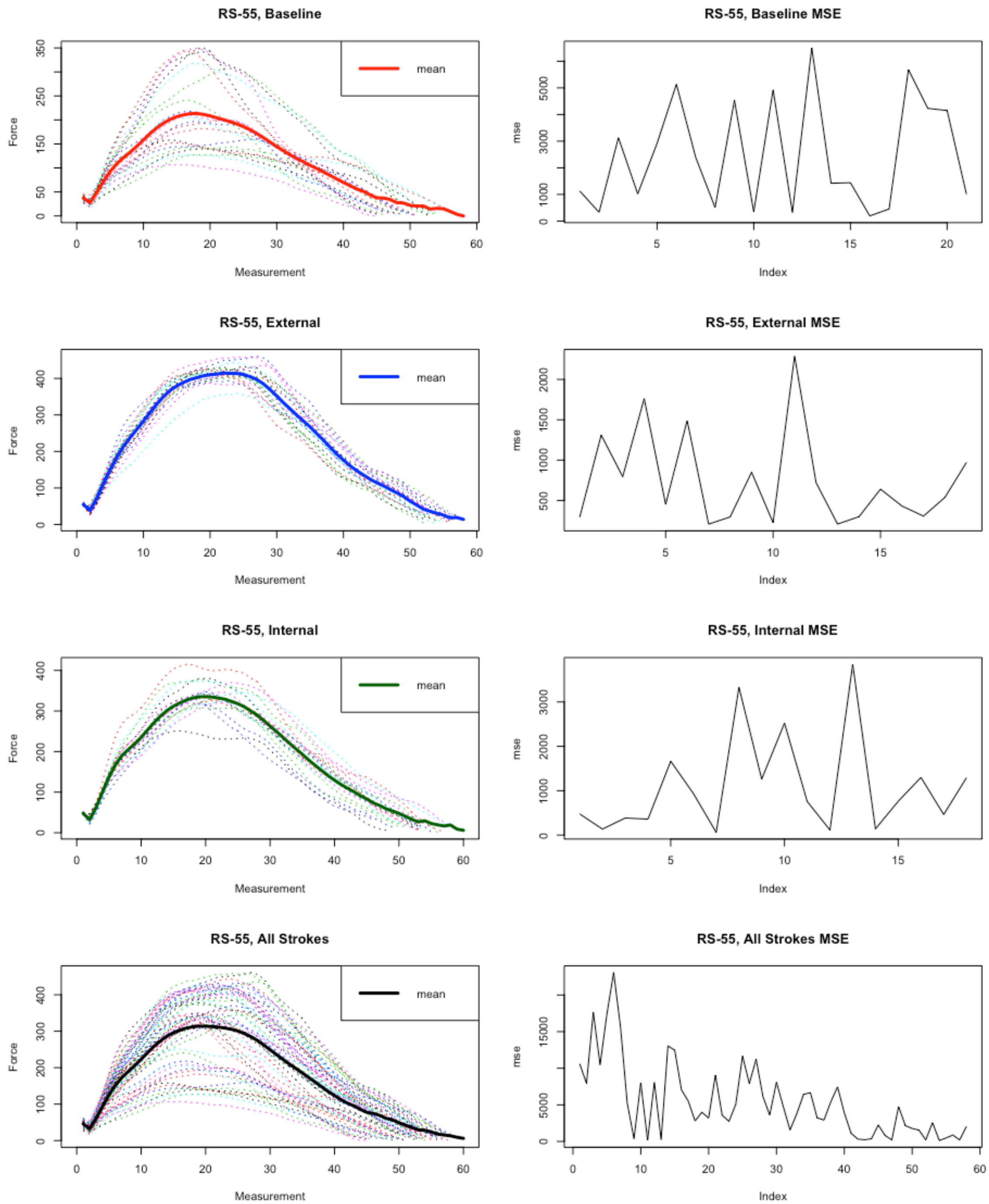
Table 9

Force Signature Main Effects & Interactions

	Main Effects		Interaction
	Expertise	Condition	Expertise x Condition
SL			
Dfn	1	2	2
Dfd	47	94	94
F	10.123	4.979	0.798
p	0.003	0.009	0.453
η^2	0.177	0.096	0.017
PFP			
Dfn	1	2	2
Dfd	47	94	94
F	0.172	0.450	0.959
p	0.680	0.639	0.387
η^2	0.004	0.009	0.020
MPFR			
Dfn	1	2	2
Dfd	47	94	94
F	0.828	2.596	0.284
p	0.367	0.080	0.753
η^2	0.017	0.052	0.006
DF			
Dfn	1	2	2
Dfd	36	72	72
F	0.691	0.530	0.020
p	0.411	0.591	0.980
η^2	0.019	0.015	0.001

Figure 23

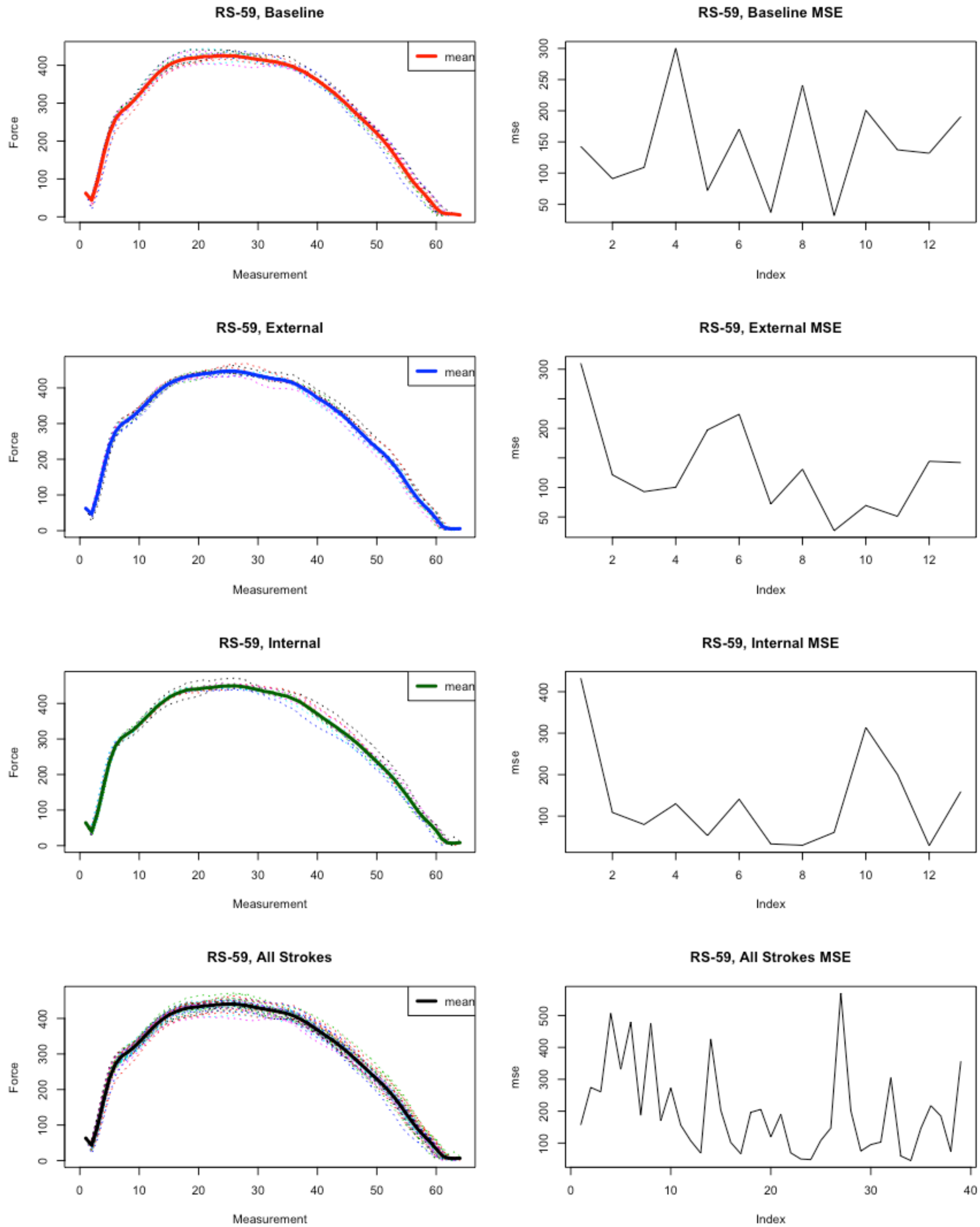
Dispersion Factor & Mean Squared Error - Novice



Note.Dispersion factor and mean squared error for a sample novice participant. *Left*. Thin colored lines represent individual strokes. The thick line represents the mean. Deviations from the mean indicate greater variability. *Right*. MSE per stroke shows a sinusoidal relationship. More and larger fluctuations indicates less stroke to stroke consistency.

Figure 24

Dispersion Factor & Mean Squared Error - Expert

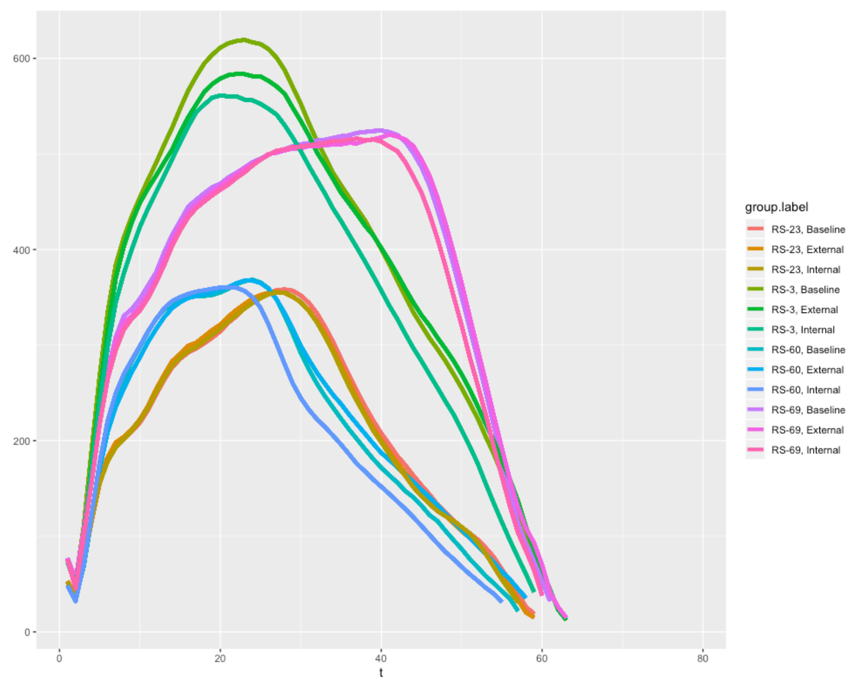


Note. Dispersion factor and mean squared error for a sample expert participant. *Left.* Thin colored lines represent individual strokes. The thick line represents the mean. Deviations from the mean indicate greater variability. *Right.* MSE per stroke shows a sinusoidal relationship, although less so than in Figure 23. Fewer and less severe changes in MSE reflect higher stroke to stroke consistency.

Mean curves shown in Figure 25 are mean curves for the three conditions for two (n=2) experts (RS-3, RS-69) and two (n=2) novice (RS-23,RS-60) participants. Curves were generally smooth overall, indicating that variance measured by DF was an indicator of stroke smoothness. The initial application of force occurs during peak skeletal loading and builds rapidly. As reported by Hill (1995) and Draper (2020), a balanced application of force between foot-stretcher and handle is necessary for increased smoothness and a faster rate force transfer. Improved levels of coordinated force application at this time point were also associated with improved performance and higher levels of expertise (Hofmijster, van Soest, & De Koning, 2008)

Figure 25

Mean Curves in Baseline, External, & Internal Conditions

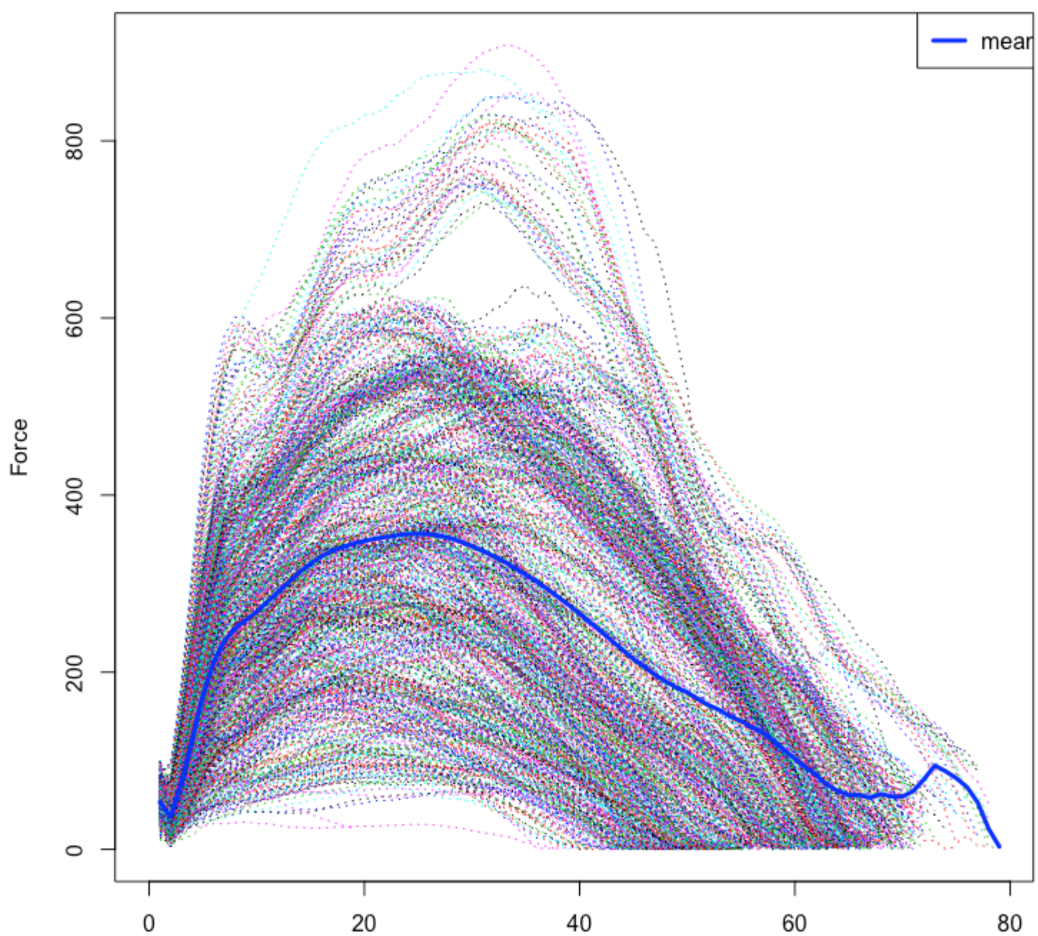


Note. Mean curves for four participants in all conditions were plotted to show that within participants, curves were similar and smooth overall. The differences between groupings highly the range of force signatures observed. The checkmark in the lower left is the result of an imbalance between foot-stretcher and handle forces during the peak skeletal loading phase of the drive.

Figure 26 shows the wide range of force signatures for participants across all trials in baseline condition. As shown in Figure 25, participant force curves remained largely smooth and consistent both between trials and within. The large variance amongst participants with respect to gender, expertise, height, and weight indicated the need for a measure of variability that remained within participants. Until now, a complete measure of that variability was unavailable. It also suggests that participants adopted individualized approaches to optimize performance.

Figure 26

All Strokes for All Participants in Baseline Condition

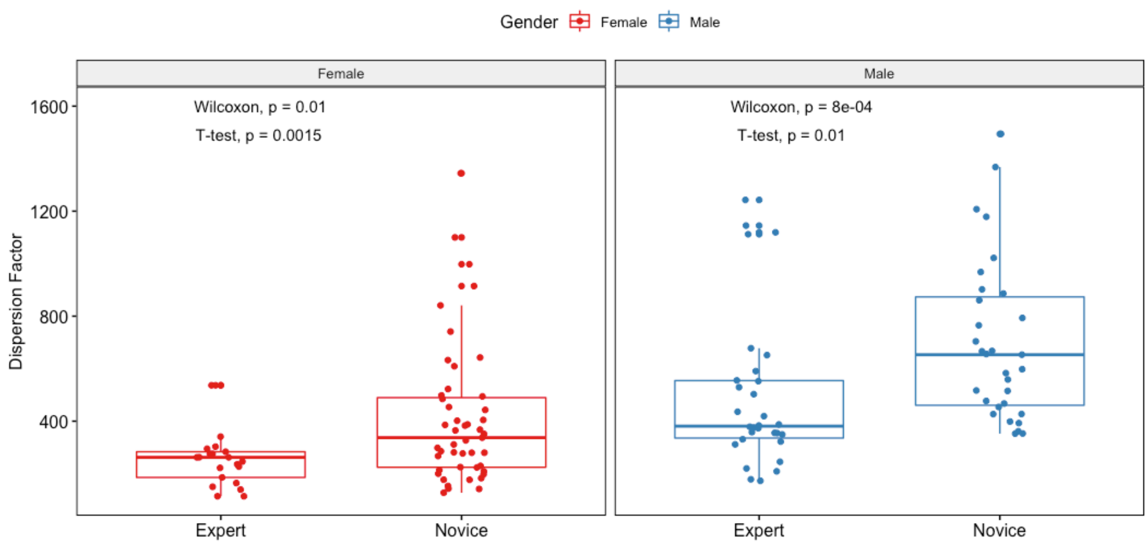


Note. All strokes for all participants were plotted (thin lines), in addition to a mean curve (thick blue line). The wide range of force signatures suggests that participants adopted individualized strategies in applying force to optimize their performance.

To further investigate the relationship between DF and subject characteristics, DF was linearity regressed on expertise and gender (Figure 27). Expertise and gender were significant predictors of DF at $p < .001$. Expert women were the least variable, followed by novice women, expert men, and novice men. Differences between all groups were significant.

Figure 27

Variability by Expertise & Gender



Note. Variability captured by DF was a significant predictor of participant gender and level of expertise. *Left*. Female variability outcomes as measured by DF indicated a significant difference between expert and novice females at $p =.01$. *Right*. Male variability outcomes as measure by DF found significant differences at $p <.001$. Decreases in variability are associated with increased stroke to stroke consistency and smoothness, two factors that reflect skill level.

Controlling for Inherent Participant Characteristics

Prior research has established the influence of anthropometric components in rowing performance (Barrett & Manning, 2004). When participant height and weight (Table 4) were included as covariates, there were significant results for multiple outcomes. For the primary outcome of distance, there was a significant effect of height, $F(1,47) = 51.240$, $p < .001$, $\eta^2 = .522$, however, no main effects for condition or interaction effects were found at $F(2,94) = 2.324$, $p = .103$, $\eta^2 = .047$ and $F(2,94) = 1.004$, $p = .370$, $\eta^2 = .021$. Similarly for weight, athlete mass significant affected total distance rowed, $F(1,47) = 35.631$, $p = < .001$, $\eta^2 = .438$. Controlling for weight did not result in a significant effect of condition, $F(2,94) = 2.301$, $p = .110$, $\eta^2 = .047$, or an interaction between weight and condition, $F(2,94) = .527$, $p = .592$, $\eta^2 = .011$.

Participant height affected total distance rowed by an average of 2.5 meters per centimeter increase in height. With respect to weight, participants rowed 1.5 meters farther for each additional kilogram of mass. Table 10 contains the full table of results for covariates of height and weight as well as effect sizes.

Table 10

ANCOVA Table

Covariate	Height						Weight					
Distance	Dn	Dd	F	p	Sig	η²	Dn	Dd	F	p	Sig	η²
Height	1	47	51.240	<.001	*	0.522	1	47	36.631	<.001	*	0.438
Condition	2	94	2.324	0.103		0.047	2	94	2.301	0.106		0.047
Height:Condition	2	94	1.004	0.370		0.021	2	94	0.527	0.592		0.011
Power												
Height	1	47	70.642	<.001	*	0.60	1	47	53.780	<.001	*	0.534
Condition	2	94	1.962	0.146		0.04	2	94	2.000	0.141		0.041
Height:Condition	2	94	0.970	0.383		0.02	2	94	1.894	0.156		0.039
Peak Force												
Height	1	47	59.873	<.001	*	0.560	1	47	50.640	<.001	*	0.519
Condition	2	94	3.023	0.053		0.060	2	94	2.992	0.550		0.060
Height:Condition	2	94	0.629	0.535		0.013	2	94	0.148	0.863		0.003
Peak Force Max												
Height	1	47	74.105	<.001	*	0.612	1	47	62.646	<.001	*	0.571
Condition	2	94	1.261	0.288		0.026	2	94	1.272	0.285		0.026
Height:Condition	2	94	0.414	0.662		0.009	2	94	0.852	0.430		0.018
Joules												
Height	1	47	64.312	<.001	*	0.578	1	47	46.642	<.001	*	0.498
Condition	2	94	1.792	0.172		0.037	2	94	1.793	0.172		0.037
Height:Condition	2	94	0.784	0.460		0.016	2	94	0.812	0.447		0.017
Stroke Length												
Height	1	47	26.453	<.001	*	0.360	1	47	15.408	<.001	*	0.247
Condition	2	94	4.722	0.011	*	0.091	2	94	4.774	<.001	*	0.092
Height:Condition	2	94	0.893	0.413		0.019	2	94	1.418	0.247		0.029
Peak Force Position												
Height	1	47	.00074	0.978		<.001	1	47	.00070	0.979		<.001
Condition	2	94	.210000	0.811		0.004	2	94	.211000	0.810		0.004
Height:Condition	2	94	.022000	0.979		0.600	2	94	.322000	0.726		0.007
Mean Peak Force Ratio												
Height	1	47	2.533	0.118		0.051	1	47	0.495	0.485		0.010
Condition	2	94	2.994	0.055		0.060	2	94	2.896	0.060		0.058
Height:Condition	2	94	1.682	0.192		0.035	2	94	0.092	0.912		0.002
Dispersion Factor												
Height	1	36	2.628	0.114		0.068	1	36	5.547	0.024	*	0.134
Condition	2	72	0.565	0.571		0.015	2	72	0.560	0.574		0.015
Height:Condition	2	72	2.591	0.082		0.067	2	72	2.227	0.115		0.058

Note. Dn denotes degrees of freedom in the numerator. Dd denotes degrees of freedom in the denominator. η^2 is the partial eta squared value. * indicates a significant result.

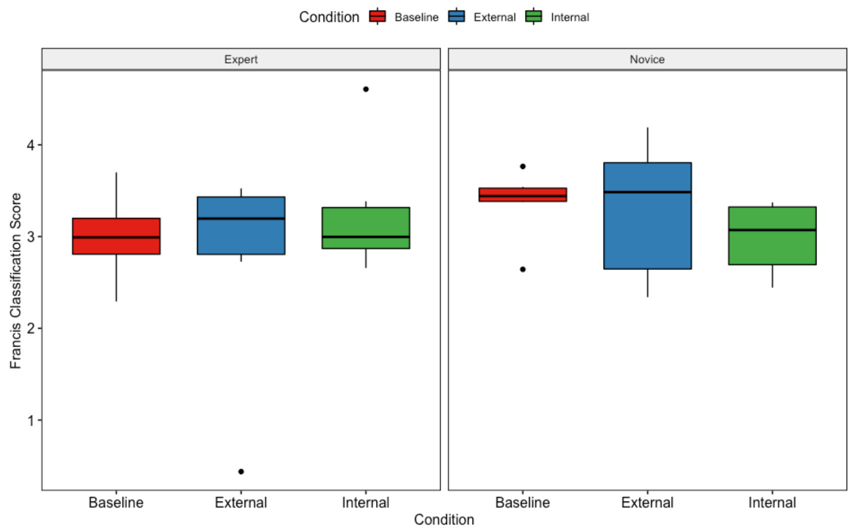
Attentional Focus and Kinematics

To investigate whether attentional focus conditions affected participants level of trunk and leg coordination, body, twelve (n=12) were randomly selected for video analysis. Six (n=6) novice and six (n=6) expert participant's videos were reviewed in Dartfish 360 and angle measurements from hip to knee and hip to shoulder were compared. The ratio of upper leg to trunk use in the first .4 seconds of the propulsive phase of the rowing stroke is the critical drive (Francis, 2013). Three strokes from each condition were measured and averaged to determine their Francis Classification score. Strokes eight, night, and ten were selected for all twelve participants.

Data were normally distributed, however, the small sample size resulted in skewness and kurtosis values beyond +/- 1. A Shapiro-Wilk test confirmed data were not suitable for parametric analysis at p = .002. As a result, Friedman's test was conducted to evaluate the median difference between FC and focus condition. No significant differences were found for condition or expertise (Figure 28).

Figure 28

Francis Classification Scores by Condition & Expertise



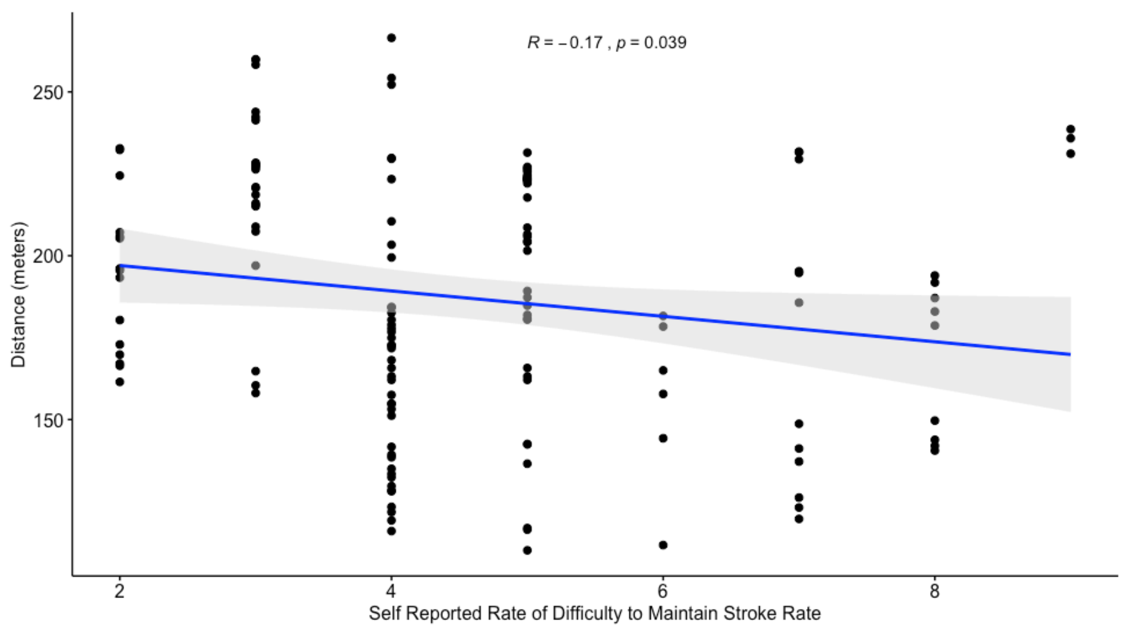
Note. FC scores represent the ratio of leg and trunk usage during the critical drive phase of the rowing strokes for experts (left) or novice (right). Scores were measures by dividing the angular relationship of the knees-hip-shoulders at initiation of the drive and .4 seconds later. Strokes eight, nine, and ten were reviewed and scores for those three strokes were averaged to determine the score for each participant in each condition.

Considerations for Attentional Focus and Rowing Research

All participants completed manipulation check as part of the survey completed after trials (Appendix E). The manipulation check was a self-reported assessment that instructions induced the correct attentional focus. Participants were asked to report their focus during baseline trials. As an additional control, participants rated their perceived level of difficulty in maintaining a stroke rate of 24 to 26 SPM while completing trials on a scale of 1 to 10 (F-SPM). F-SPM data were normally distributed amongst both novice and expert participants. Novice participants had a mean F-SPM difficulty score of 4.93 (SD = 1.80). Experts mean score was 3.95 (SD = 1.37). Distance rowed was regressed on F-SPM and Condition (Figure 30). Results showed no main effects for attentional focus, however, there was a significant effect of F-SPM (p = .042). F-SPM measures were reviewed according to level of expertise. No significant differences were found for F-SPM scores between novice and expert participants. Results suggest that the more participants struggled to maintain the correct stroke rating, the more that struggle negatively impacted their overall performance, independent of attentional focus condition (Figure 29). The findings also indicate one reason why attentional focus did not significantly affect performance in the present study, despite its robust impact in other research.

Figure 29

Self Reported Difficulty to Maintain Stroke Rate & Distance Rowed



Note. Participants self-reported scores of difficulty regarding controlling stroke rate during the study was a significant predictor of distance rowed, suggesting that effort expended to control stroke rate had a negative relationship to distance rowed. The differences were not significantly different between expert and novice participants.

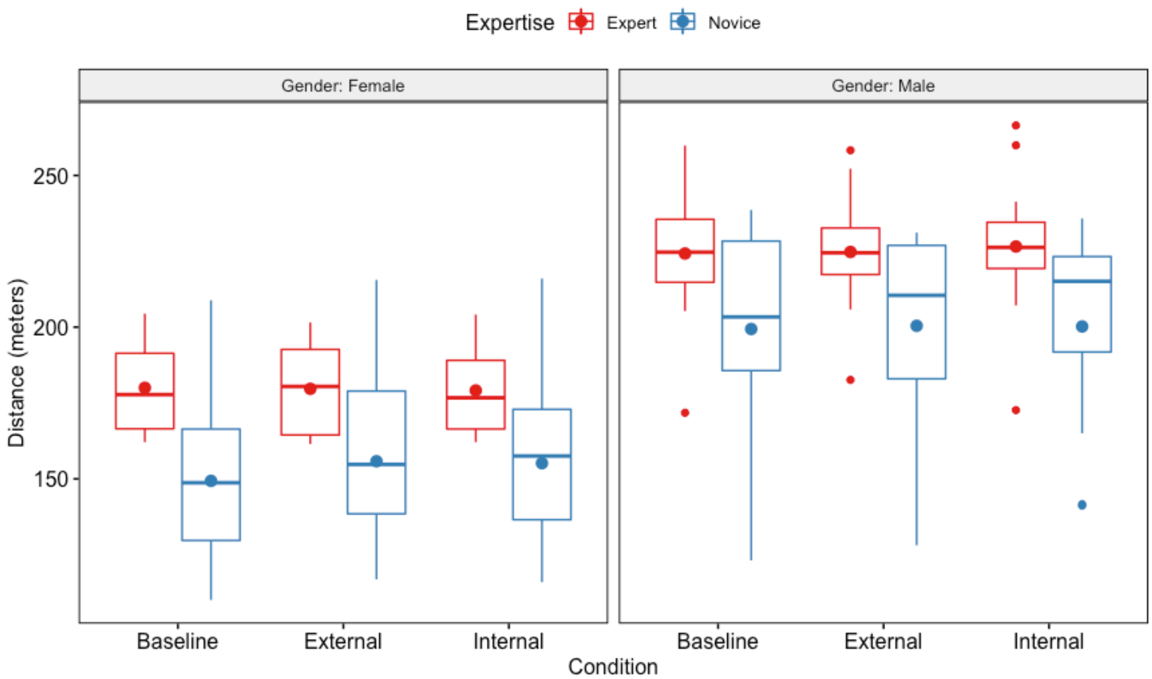
Gender, Expertise, and Attentional Focus

Although gender and expertise significantly affected outcomes in the planned two-way ANOVAs, a followup three-way ANOVA (gender x expertise x condition) was conducted (Figure 30). There were no significant main effects of attentional focus condition, however, there were main effects for gender, $F(1,48) = 32.487$, $p < .001$, $\eta^2 = .420$, and expertise, $F(2,47) = 10.087$, $p = .003$, $\eta^2 = .183$. There were no interactions.

A second three-way (gender x expertise x time-order) repeated measures ANOVA was conducted on distance outcomes according to trial-order and independent of condition. There was no significant effect of trial time-order, $F(2,47) = 3.385$, $p = .059$, $\eta^2 = .007$, although it did approach significance. Those results, in coordination with those from study one, suggest further evaluation of the study design is necessary.

Figure 30

Effects of Gender, Expertise, & Condition on Distance Rowed



Note. The effects of gender, expertise, and condition on distance rowed show significant differences for gender and expertise at p = .041 and p = .017 respectively. There was no effect of condition or interaction with condition. The results indicate that controlling for the differences between gender and expertise by adjusting the inclusion criterion may allow for increased power that would be able to discern any potential affects of attentional focus.

Chapter VI

DISCUSSION

Efficacy of Attentional Focus and Rowing Performance Outcomes

This study evaluated the efficacy of an external focus of attention on rowing performance. In addition to the primary outcome of interest, distance rowed, the study evaluated secondary measures related to force production, force signatures, and kinematics. The secondary measures provided information previous research suggested was necessary to thoroughly compare the relationship between attentional focus and skilled movement. This study is only the the second study to evaluate external focus of attention and rowing (see Parr & Button, 2009), however, it was the first to examine its potential effects on previously demonstrated biomechanical determinants of rowing performance. There was no significant effect of attentional focus on rowing performance, with the exception of stroke length. Within stroke length outcomes, differences were limited to expert participants, the overall effect size was small, and Bonferroni adjusted pairwise comparisons were not significant. Significant influences on rowing outcomes were found for participant level of expertise, gender, height, and weight. Results indicated that participant characteristics significantly influenced outcomes and served as salient factors determining rowing performance. Those findings reinforce the complexities facing practitioners when it comes to rowing interventions. The influence of attentional focus and its relationship to rowing performance has limited support and requires further investigation.

The following sections review outcomes for studies one and two. Study one evaluated novice participants only, while study two evaluated novice and experts. Potential mediating factors related to participant characteristics and the study design are discussed. Limitations of the present study are reviewed and findings are further discussed through a motor learning lens. Suggestions for future research to isolate the potential effects of motor learning strategies that may explain the 2-3% gain per decade in rowing performance are prescribed.

Attentional Focus and Novice Rowing Outcomes

Study one evaluated the efficacy of attentional focus on novice rowers. Subjects in this group were active rowers who had not competed beyond their first season of racing. The classification approach is the same as that used by USRowing when athletes register for competition. We hypothesized that participants would row farther during trials when they adopted an external focus of attention. Additionally, we hypothesized that they would increase total mechanical power output and achieve higher levels of peak force. Prior to analysis, results were reviewed and found to violate statistical assumptions for the planned repeated measures ANOVA. As data were distributed bi-modally according to gender (Figure 9), Friedman's test, a non-parametric technique, was employed to compare median differences. Results did not show significant differences for distance, power, or peak force between conditions, although gender was a significant factor influencing rowing performance.

Differences between genders in rowing performance are well documented, and support for those differences is increasing (Warmenhoven, Cobley, Draper, Harrison, et al., 2018). The primary source of those differences is strength and power disparity (i.e. force production), physiological categories the present study assessed (Bompa & Buzzichelli, 2018). Jenson, Freedson, and Hamill (1996) reported that rowing outcomes were largely power based, and that power was significantly correlated to leg extension strength. Increasing the strength of the quadriceps was the primary recommendation to improve rowing outcomes. The application of that recommendation, however, has limits. One study evaluating gender differences in lower body strength found that trained women were 66% as strong as trained men (Miller, MacDougall, Tarnopolsky, & Sale, 1993). Additional studies controlling for gender-based strength, neuromuscular, and anthropometric differences reported a reduced, but not removed, degree of separation between males and females (Mayhew & Salm, 1990). For that reason, transforming outcomes according to participant characteristics was considered, but not carried out. Unsurprisingly, and similar to findings from Mayhew and Salm (1990), controlling for gender in the present study reduced, but did not remove, differences and did not indicate a significant effect of attentional focus.

While counter-balanced designs are helpful in reducing variance and increasing the ability to detect differences between trials of different conditions, the possibility of an order effect remains. Results from study one were reviewed relative to trial time-order in a post-hoc analysis. Friedman's test reported significant differences between trials one and three, as well as trials two and three. Warm up routines could potentially explain this effect. Research investigating the effects of general, specific, and combined warm-up routines on explosive muscular performance reported that warm-up specificity directly affects subsequent outcomes (Andrade et al., 2015). That is, the more a warm-up reflects the actual structure and intensity of the exercise being evaluated, the better the individual is likely to perform. In addition to the physiological component of the warm-up, motor learning theory has suggested that both warm-up duration and specificity increase movement accuracy (Ajemian, D'Ausilio, Moorman, & Bizzi, 2010).

Participants were allowed to warm up for five minutes at a self-selected pace. Participants were also informed that this period would be followed by three minutes of rest, to assuage any concerns regarding fatigue before the first trial. An assumption was made that this period would meet the requirements reviewed above. One additional factor influencing this design parameter was that a self-selected pace would create a sense of autonomy for participants, another factor known to improve performance (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf & Lewthwaite, 2016). Despite participants knowing trials would consist of maximal effort at a stroke rate between 24 and 26 SPM, no participant used their warm-up to practice such a trial. Some participants chose to take harder strokes and a few performed maximal effort strokes, but specificity to the trials was limited at best. Consequently, improvements from trial to trial suggest that the first, and possibly the second, trial served as a primer for later performance.

These results further support appropriate amounts of warm-up duration, specificity, and adaptability. Although a pre-determined warm up for indoor rowing has fewer variables for which coaches must account, these warm-up routines can still significantly influence performance. During on-water rowing, the increase in variables create additional challenges for coaches in designing a warm up that will optimally prepare their athletes for practice or compeition. Wind conditions, for example, have a significant effect on outcomes. A shift from a strong tailwind to a strong headwind can effect times by as much as a minute and it can happen in the middle of a race. Coaches must therefore design warm-ups that are specific, but highly adaptable. Rowers must understand how to shift between strategies that work (at least for them) in one set of constraints, but not in another. For coaches, the research supporting these types of challenges is not nearly as established for rowing technique as it is for other determinants of improved performance.In addition to the potential warm-up effects, there is also a possible interaction between task novelty, or complexity, or both, and the level of participant experience may also have contributed to the trial-order effect. Rowing at maximal effort while maintaining a stroke rate between 24 and 26 increases the number of elements participants were required to actively control. As task complexity increases, participants require more time to learn and ultimately improve performance (Magill, 2016). It is possible that the improvement between the first two trials and the third resulted from participants learning how to manage maximal effort while controlling the stroke rate.

That possibility is further supported by the novelty of the task. While it is common to use stroke rates and effort as limiting factors in training, it is unlikely that any novice participant had completed a workout similar in structure and intensity. That novelty, alone or combined with the task complexity, may explain the significant effect of trial-order.

Task novelty was unlikely to play a role in previous research that influenced the design and approach in the present study. When the effects of attentional focus and swimming were evaluated, individuals completed a single 25-yard long swim under different foci (Stoate & Wulf, 2011). By doing so, the task and environment for the study was nearly indistinguishable from the participant's normal practice. Moreover, swimmers were not asked to control how many strokes they took to swim the length of the pool. Altogether, it is reasonable to assume that participants were already familiar with the task and had reliable internal representations of what it entailed. Therefore, novelty was isolated to the attentional focus cue, allowing the study to measure the efficacy of focus. Despite no significant differences for condition being found in the present study, knowing that gender-based strength differences, variable warm-up periods, and learning effects have affected outcomes in other research suggests that a re-evaluation of the design parameters is necessary before any firm conclusions regarding attentional focus and rowing performance are made.

Attentional Focus and Rowing Outcomes for Novice and Experts

Study two evaluated the efficacy of attentional focus in novice and expert rowers. We hypothesized that force production measures would increase for novice and expert participants when rowing under an external focus of attention compared to both baseline and internal conditions. Additionally, we hypothesized that participant force signatures would be significantly influenced by attentional focus conditions. Outcomes for force signature analysis included stroke length, timing of reaching peak force, the ratio of mean force to peak force, as well as a new measure of variability. Effects of external focus were predicted to increase stroke length, attain peak force earlier, lower the ratio of mean to peak force, and reduce variability by improving stroke to stroke consistency and smoothness. Results did not show a significant effect of attentional focus on force production outcomes, although there was a significant main effect of gender and expertise. Similarly, results for force signature measures did not show an effect of attentional focus, but replicated findings for the significance of gender and expertise. In addition, anthropometric characteristics of rowers were found to have a significant influence on multiple outcomes.

There was one force signature measure for which attentional focus was significant — stroke length. Significance was, however, limited to expert rowers. While rowing with an external focus of attention, experts increased stroke length compared to both internal and baseline conditions at $p = .010$. The overall effect size of that difference was small, however, at $\eta 2 = .096$. A follow-up analysis found that pairwise comparisons did not meet the $p < .05$ standard after a Bonferroni correction. The use of such a correction in this instance, however, was not warranted due to the use of pre-planned hypotheses and the small sample size.The combination of a small effect size and a small sample contributed to the outcome. In addition, this finding provides additional support to the differences not only between novice and expert performance, but also how novices and experts respond to motor learning or motor performance strategies. In this instance, an external focus of attention did propel experts forwards towards a state of improved performance. A universal application of performance cues to varying levels of expertise is not supported. When coaches choose to start providing that feedback is one additional challenge they face in supporting optimal athlete development and performance.

Increased stroke length is one of the key determinants for improving rowing performance. The strength of its impact on performance is its relationship to both force production and force signature. When energy per stroke is calculated, stroke length is one of two factors that determine its value (the other is force in Newtons). Although rowers may reach a physiological limit as to how much force they can produce, extending the stroke length and maintaining (or even reducing, depending on the situation) that force will result in an overall increase in energy. Energy produced over time determines total mechanical power output

The average power output for elite male rowers ranges from 480 to 600 watts (Nolte, 2011). If a rower producing 540 watts reduced his stroke length by 10%, the new output of 486 watts would be a significant change — a number moving him from the middle to the low end for elite performance standards. Stroke length forms the foundation from which force production is made possible. Experienced rowers appear to inherently understand this. A study exploring the kinematics of rowing performance found that experience significantly influenced rower's ability to manipulate stroke length (Richter, Hamilton, & Roemer, 2011). Specifically, experienced rowers found ways to coordinate force production in order to achieve longer strokes. The study's results provide limited, support for the use of external feedback as a motor learning strategy to improve performance.

Although the primary outcome of distance, as well as all other force production measures, showed no significant effects of attentional focus condition, there were significant effects for both expertise and gender. Expertise reflects not only time spent developing the skilled needed to coordinate body and limb segments, but also time spent training the physiological systems needed to produce force. Strength and power disparities were reviewed earlier as a critical difference that helps explain the gap between male and female rowing outcomes. A similar response to training over time separates novice and expert rowers. Expert rowers can expect to see improvements in peak power production by as much as 18% during a six month intensive training period (Mahler, Parker, & Andresen, 1985). The strength of such an improvement is one reason coaches may choose to emphasize training methods over rowing technique.

When rowers train for many years at a high level, there is a corresponding increase in levels of IGF-1, a growth hormone that can lead to cardiac hypertrophy or enlargement of the heart muscle (Society for Endocrinology, 2008, August 15). Although that growth has been the subject of debate with respect to athlete health, its contributions to increased performance have been accepted for over a century (Hagerman et al., 1979; Lee, Dodd, & Young Jr, 1915; Nolte, 2011). The present study did not assess the rigor of training history for expert participants. It is possible that physiological responses to training in experts, such as IGF-1, could interact with other factors. What those factors are and how they may relate to force production is not clear. Similar to results from study one and the impact of gender, controlling for expertise in study two reduced, but did not eliminate, variance that would allow for a more powerful evaluation of attentional focus and force production outcomes.

The significance of force production measures in evaluating rowing performance has increased as methods of data capture improve with technology (Warmenhoven, Cobley, Draper, & Smith, 2018). Smith and Spinks (1995) established that biomechanical measures such as peak force can successfully classify athletes of different physiological and technical skill capacities. They also reported that changes in biomechanical parameters indicate trends and ultimately shifts in classification level. One premise of the present study was that rowers adopting an external focus of attention would be "propelled" forward towards a higher state of performance (Wulf & Lewthwaite, 2016). In that case, an external focus would more closely resemble the biomechanical determinants reported by Smith and Loschner (2002). Peak force was chosen as a biomechanical measure not only because it has strong support in rowing literature, but also because it remains stable across a wide range of stroke rates (Jensen et al., 1996; McGregor et al., 2004). In contract, force signature and kinematic measures fluctuate with stroke rate (Buckeridge, Bull, & McGregor, 2015). As a result, any changes in peak force that were due to attentional focus conditions, but potentially offset by changes in other areas of the rowing stroke, should have been captured. There were no increases in peak force to suggest that athletes were being "propelled" forward while rowing with an external focus of attention.

Force signature measures have been used to compare and identify rowers of various skill into distinct categories (R. M. Smith & Spinks, 1995; Williams, 1967). Similar to the suggestion that increases in peak force would indicate rowers being "propelled" forward, changes in the shape of the force signature were also hypothesized to indicate such a shift. One recent study evaluating the location of peak force max during an extended indoor rowing test was sensitive enough to distinguish between national team rowers who had, and had not, finished in the top six during international competition (den Hartigh, Cox, Gernigon, Van Yperen, & Van Geert, 2015). The lack of significance in the present study with respect to force signature measures was therefore surprising, especially given the large body of evidence in other activities (Marchant, 2011; Wulf, 2013). Even when studies reported conflicting outcomes, such as jumping studies with different results concerning force production, overall differences in performance were still detected. Nonetheless, the roles of gender and expertise in rowing may provide some degree of explanation. It also supports that coaches may need to consider individualized instruction in order to develop rowing technique that maximizes performance.

In addition to the gender-based disparity of strength and power, coordination differences as a result of anthropometric and physiological characteristics have been reported (Warmenhoven, Cobley, Draper, Harrison, et al., 2018). During indoor rowing, females demonstrate improved lumbo-pelvic rhythm as a result of greater anterior pelvic rotation at the catch (McGregor, Patankar, & Bull, 2008). Improved rhythm was linked to improved performance. Those coordination differences extend to on-water rowing as strategies to improve performance. Force signatures were reviewed using a Functional Data Analysis (FDA) technique. Significant differences between genders were found, with females reaching peak force earlier (lumbo-pelvic rhythm) and then allowing force production to diminish compared to male counterparts (Warmenhoven, Cobley, Draper, Harrison, et al., 2018). Similar effects have been reported during indoor rowing (Attenborough, Smith, & Sinclair, 2012). In those studies, the authors concluded the shift was a result of reduced upper body strength, specifically the use of the arms in the final stages of the drive phase. Greater anterior pelvic rotation was a strategy to improve performance. The results of the present study support that innate differences exist between male and female rowers. However, the reduced upper body strength in female participants may also have had a positive impact on their performance.

Warmenhoven, Cobley, Draper, & Harrison et al. (2018) relied upon the sensitivity of a FDA technique to discern differences between rower's force signatures. In the present study, FDA was employed to develop a measure of variability called Dispersion Factor (DF). Although there was no significant effect of attentional focus in reducing force signature variability, DF outcomes were significantly different between participants of different genders and skill level (Figure 27). Expert females were the least variable performers across all trials, followed by novice females, expert males, and the most variable group of participants, male novice rowers. Reduced DF scores for female experts were reflective of an increase in stroke to stroke consistency and stroke smoothness compared to other participants. At present, no study has determined the degree to which stroke to stroke consistency and smoothness affect all rowing performance outcomes, however, its significance as in indicator of skill suggest a need for that knowledge.

The positive impact of reduced upper body strength for female participants is that they likely refrained from attempting to “muscle” it. That leads to smaller variations in velocity, which are the largest contributors to drag. In 2,000 meter racing, use of the trapezius, rhomboids, shoulders, and arms are typically reduced by the performer as they represent around 20% or less of the overall force production (McNeely, 2012). In addition, these muscles tend to fatigue faster than lower body muscles (Bompa & Buzzichelli, 2018). During shorter “power” pieces, however, physique traits of elite rowers suggest a relationship between decreased race duration, increased upper body muscle activation, and accelerated fatigue (McGregor et al., 2004; Slater, O'Connor, & Pelly, 2011; Slater et al., 2005). One explanation for DF outcomes, which takes into account the gender-based differences already reviewed, is that male and female rowers adopted different strategies based on musculature. Males may have opted to increase use of the upper body, especially novice males who have limited experience and had the highest DF outcomes. As fatigue accelerated, the use of the upper body resulted in an increase in variability that was captured by DF.

An example from on-water rowing lends credence to this possibility. Competitive rowers are familiar with the concept of “seat-racing”. In seat-racing, coaches race two boats for a set distance. Two rowers are switched between the shells, and the race is re-rowed. The difference in times is generally assumed to indicate the faster rower. Rowers who rely on brute force in these comparisons are so ubiquitous, they have a nickname — "hammers". In fact, the award for winning the indoor rowing world championship is a trophy in the shape of a hammer. Despite seeming far-fetched, anecdotes such as "the rower who lost a seat-race to a ham sandwich or twinkie" are often rooted in fact, not fiction. Extreme variability creates instability in boats that are narrow and negatively impacted by erratic movement. As Hill (1995) reported, even when force production goes up, reduced coordination can lead to an overall decrease performance. In some cases (such as the ham sandwich), the negatives of poor coordination can literally outweigh everything else. Although no measures in the present study were taken to assess muscle activation, the suggestion that gender-based physiological differences, or strategy choices, or both explain reduced DF outcomes in female participants has support in the literature. Applied to on-water rowing, it also offers an explanation why female rowers who may be 66% as strong as their male counterparts, may also complete races in times that significantly beat that margin. These seat-racing scenarios demonstrate the importance of force production and coordination.

Mean to peak force ratio (MPFR) was not affected by focus condition. Although MPFR had been used in previous work by Smith & Draper (2006) to distinguish between elite and sub-elite rowers, it was not a significant predictor of expertise the present study. The significance of this outcome suggests that ongoing development of FDA techniques with regards to force signature evaluation should be encouraged.

Concerning kinematics, there were no significant influences of attentional focus on Francis classification scores. Body segment usage is presently determined by what coaches view as "correct" or what "style" has recently won a championship. The trunk and legs are the focal point of the ongoing debate regarding an "ideal" technique, having been found to contribute most to peak force generation (Lamb, 1989). The legs initiate the drive followed by sequential trunk movement. Although some research indicates that the trunk should initiate the drive, empirical support for that position is limited (Soper & Hume, 2004; Williams, 1967). The length of delay from leg drive initiation to trunk swing is the primary kinematic concern. In the present study, predicted kinematic outcomes were developed under the assumption that external focus enhances coordinative structures (Barris et al., 2014; Davids, Glazier, Araujo, & Bartlett, 2003; Glazier et al., 2003; Loosch & Müller, 1999). No kinematic changes were detected, however, the same challenges previously reviewed for gender, expertise, and study design are all factors which could have impacted the kinematics. Apart from that, the smaller sample size (n = 12) decreased the power of the analysis. Implications for future research are reviewed in the next section. We maintain that kinematic analysis remains an important aspect of understanding rowing performance and a critical measure by which the impact of motor learning strategies on rowing performance should be evaluated.

Study Limitations

The study was a counter-balanced repeated measures design similar to Wu, Porter, and Brown's (2012) evaluation of attentional focus and standing long jump.

The present study included baseline as part of the counter-balancing, although Wu, Porter, and Brown did not. That may explain a portion of the trial-order effect seen during study one. Even though the methodology has demonstrated its effectiveness, there were aspects of implementation for dynamic indoor rowing that presented considerable challenges. The use of a dynamic indoor rower allowed for detailed data collection, but it was not on-water rowing. During on-water rowing, directing the rower to focus on their blade provides a natural external focus related to the desired outcome (increasing mean speed). The blade was isolated by Baudouin & Hawkins (2002) as the only point of contact where rowers could significantly compensate for drag factors. Furthermore, learning improvements from focusing on the blade were described in the early 20th centruy by Steve Fairbairn (1951). The coach, often described as "father of modern rowing", taught rowers to concentrate on the blade, suggesting that the body would then take care of itself. During dynamic indoor rowing, however, there is no blade upon which to focus.

Verbal instructions were originally piloted to direct participant focus on the sound of the flywheel increasing in speed during the drive, "as you row, focus on the sound of the wheel increasing in speed as much as possible." Novice participants, however, struggled to connect the sound of the flywheel to their rowing. As such, instructions were modified. The new instructions, "as you row, focus on creating pressure on the handle" were easier to understand for novice rowers, but the location of focus was in close proximity to the body (internal focus). Previous research on external focus established that more distally focused cues were more effective in electing improved learning and performance (McNevin, Shea, & Wulf, 2003). The need for verbal instructions that correctly induce focus was further supported in a review of studies that did not show support for external focus (Wulf, 2013). In a majority of those cases, cues failed to adequately direct the participant's attention to the effect of the movement. Instead, cues suggested focusing on the movement form, which can easily be perceived as in internal focus. A similar result is likely for the present study.

The challenge in selecting an appropriate external focus cue stems not only from indoor rowing on an RP3 as opposed to on-water rowing, but also that rowing has elements of dual tasking. In the present study, all participants were instructed to row as fast as possible while controlling their stroke rate to a moderately paced 24 to 26 strokes per minute. Although rowing does not meet the definition of dual task, defined as "the concurrent performance of two tasks with distinct and separate goals", the interaction between these factors stretches the limits of single task complexity (McIsaac, Lamberg, & Muratori, 2015, p. 2). Siu and Woollacott proposed the Attentional Allocation Index (AAI) as a measure of task complexity. Originally used to evaluate postural control, it provides an index by which to rate the challenge that confronted study participants. The AAI rates tasks by novelty and complexity. The complex sequencing of the rowing stroke, combined with the novelty of maximal effort at a moderate stroke rating, resulted in a "high-high" complexity index score. Typically, rowing as fast as possible for a short period of time would result in rates of 32 strokes per minute or higher. In some instances, rowing at rates of 45+ would be "normal". The comparable conflict in running would be to run as fast as possible while only taking 120 steps per minute, when a normal rate is closer to 170 or 180 steps per minute (Friel, 2012). As such, there are multiple sets of conflicting foci. First, rowers had to balance maximal effort while actively restricting rate. Next, rowers had to remain engaged on balancing those two inputs while also following instructions to focus internally or externally. Additionally, participants were subject to fatigue, a factor that has a tendency to direct attentional internally (Noakes et al., 2004). Even if attentional focus has a significant influence on rowing, it may have been masked by additional demands.

One element of those additional demands was attention switching. As participants invariably realized they were above the stroke limit, they prioritized attentional demands, ultimately choosing to emphasize rating, force production, or the focus cue. Weiss (2011) showed that this type of attention switching negatively impacts performance, particularly if attention is redirected internally. Combined with the previous challenges, it appeared that the attentional demands created by the instructions likely exceeded participant capacity, even for experienced rowers. Results suggests optimal learning environments for rowing require settings and organization that reduce attentional focus demands, allowing the performer to remained engaged on salient features of the desired movement outcome.

Ironically, indoor rowing is an environment where that organization and structure should have been possible. The near frictionless ball bearings upon which the RP3's seat and the flywheel rest create some amount of slipperiness, but the instability is located on a singular axis and its platform remains stable. In on-water rowing, a racing shell experiences instability along the x (yaw), y (roll), and z (pitch) planes. Changes in yaw occur when the balance of force application is asymmetrical, although these can be purposeful (Warmenhoven, Smith, et al., 2018). Instability along the y plane occurs with the shell rolls from port to starboard, a frequent occurrence in racing shells with ratios as high as 25 to 1 when comparing length to width. Changes in pitch are known as porpoising, and are the result of rower's weight shifting back and forth within the shell. Feedback from movement of the shell on these three planes occurs proportionally to the amount of drag they create on the system (R. M. Smith & Loschner, 2002). On the Rp3, those feedback systems upon which rowers rely during on-water rowing are reduced or eliminated. Previous research has reported that rowers adapt their force production to account for perceptual feedback and that the adaptations occur relatively quickly in elite athletes (after 40 strokes) (Hill, 2002; R. M. Smith & Draper, 2006; Warmenhoven, Smith, et al., 2018). Those purposeful alterations to force production lead to improved performance, but they require the perception of that feedback. The present study may not have allowed enough time for rowers to perceive what feedback was available, or more likely, it was not strong enough for the rower to detect it. Newell's (1986) model of constraints proposes a feedback loop in which performers use feedback in order to adapt future movements. Lieberman (2014) demonstrated how simple changes could inhibit those feedback systems, altering previously stable movement patterns. When runners replaced thin soled shoes with thicker padding, both strike type variations and surface type adjustments were diminished or complete eliminated (Lieberman, 2014; Lieberman, Bramble, Raichlen, & Shea, 2009).

The RP3 monitor typically displays a wide range of feedback for rowers that is constantly in use during training. In the present study, knowledge of performance (KP) was reduced to the current stroke rate only. The setup also had the potential to add to the novelty of the task, increasing its complexity. Some novice participants in the study reported that it was the first time they had used any rowing machine without the monitor being present to provide KP. Similar situations exploring test environments were investigated by Beilock and Carr (2001). The authors reported that changes in procedure, even for well practiced activities, resulted in increased rates of "choking" and reduced performance. The removal of KP for participants comprised a significant change to normal practice that may have had similar negative effects.

Returning to one of the original limits of the present study, dynamic indoor rowing is a representation of rowing, but it is only a representation. When considered according to guidelines established by Gentile for task classification, the two are distinct enough to reside within separate categories (Gentile, 1987). As such, it may be that dynamic indoor rowing does not afford the opportunity for the improvements that motor learning strategies can effect during on-water rowing to emerge. One of the principle means by which technique is suggested to increase performance is through increased stability of the rowing shell. As previously discussed, the rowing shell tracks on three axes. Purposeful alterations to the rowing stroke have resulted in improved overall performance, even if force production decreased (Draper, 2020; R. M. Smith & Draper, 2006; Warmenhoven, Smith, et al., 2018). An external focus of attention during on-water rowing may not improve force production or coordination, but it has already demonstrated the ability to improve blade height off the water — a critical aspect of improving balance and stability (Parr & Button, 2009).

Future Research

Future evaluations of motor learning strategies and rowing performance are increasingly likely to occur during on-water rowing. Presently, "reliable" on-water measurement systems can cost in excess of $50,000 and require a high degree of technical knowledge. For most practitioners, the intricacy of such a measurement system forces a choice between coaching or data. However, a number of new commercially available measurement systems are in development. As those measurement systems are validated, opportunities to evaluate motor learning strategies and their impact on rowing will increase. Beyond rowing focused technology, developments of inertial accelerometers, such as Moveo Explorer by APDM, offer new possibilities for data capture analysis. The present study suggests three main considerations for that research.

First, the variance amongst outcomes by participant gender, expertise, and stature was significant for nearly all performance measures. As such, future research should consider limiting participants based on those criteria in order reduce variance and increase the study's ability to detect changes in performance. Hill's (1995, 2002) work evaluating the dynamics of coordination in rowing involved twenty lightweight German national team rowers. Lightweight rowing requires athletes to weigh-in no more than 2 hours prior to racing at a limit of 72.5kg per individual and an average crew weight of 70.0kg. Deviations for height and weight exist, but they are significantly smaller compared their heavyweight national team counterparts (Kerr et al., 2007). As an additional factor, Hill collected data over a decade, during which all athletes were training under the same program, thereby reducing external influences on athlete performance. Lightweight men's and women's rowing may be an ideal "proving ground" in which to evaluate not only the biomechanical determinants of performance, but also test motor learning strategies. Results from those studies could then be expanded to larger populations with more participants to determine their efficacy.

Next, the use of FDA should be embraced in coordination with enhanced data technology capture. Opportunities to integrate current measurement systems with new ones should be actively explored. The use of four inertial accelerometers should be evaluated to determine if the resultant kinematic data was a valid measure of movement. If so, integrating the kinematic data with force signature results to create a more holistic view of rowing performance may help discern factors influencing the emergence of biomechanical determinants.

These first two guidelines form the foundation of next step research evaluating the relationship between motor learning or motor performance and rowing technique. Future research should evaluate the efficacy of attentional focus on dynamic indoor rowing for lightweight and heavyweight expert rowers. The inclusion criterion for expertise should be limited to rowers who are currently training and representing their country on the international level. Verbal instructions for internal focus should consist of, "push with your legs". Verbal instructions for external focus should consist of, "push through the foot-stretcher". These closely imitate those used in strength-training studies evaluating attentional focus and force production. Stroke rate should not be controlled. The length of the test should include six short tests of peak power, lasting no more than 10 seconds, and a longer evaluation for 20 minutes at steady state or "UT2" intensity. Elite rowers are familiar with steady state, as it forms 80% of more of their training volume. During this 20 minute long piece, participants should be instructed to shift between internal and external focus every two minutes. The repeated evaluations will help to account for warm-up specificity or learning effects as rowers process the cues. Additionally, the manipulation check should occur after each trial or cue, instead of after all trials. FDA techniques should be applied to assess variability during all tests. Outcome measures should consist of power, peak force, stroke length, and dispersion factor. If no significant differences are detected for attentional focus with respect to force production and dynamic indoor rowing, the findings would provide guidance to look for other methods of evaluating rowing performance. It may be that the positive effects of attentional focus seen in other activities are limited to on-water rowing, where bladework and smooth movements have a greater effect on the outcome than in dynamic indoor rowing (R. M. Smith & Loschner, 2002; Warmenhoven, Smith, et al., 2018)

Finally, it is time for rowing to consider a broader approach to understanding performance. One reason that an "ideal" technique has yet to emerge despite 150 years of research, is that the dynamics of individual coordination for the rowing stroke are just that — individual. Newell's model of constraints predicts that changes to the individual, task, or environment affect *how* movement is performed, regardless of *what* happens to the final outcome. As the first study to evaluate the effects of attentional focus on force production in rowing, results indicate limited support for an external focus of attention for expert rowers. The limited population for rowers to which that outcome applies further demonstrates that biomechanical determinants of performance may not have the universal application generally accepted. For this reason, investigatory methods that evaluate *how* rowers improve in consideration of Newell's constraints and motor learning strategies are critical for defining an "ideal" technique.

REFERENCES

Adams, J. A., Gopher, D., & Lintern, G. (1975). The Effects of Visual and Proprioceptive Feedback on Motor Learning. *Proceedings of the Human Factors Society Annual Meeting, 19*(2), 162-165. https://doi.org/10.1177/154193127501900204

Ajemian, R., D'Ausilio, A., Moorman, H., & Bizzi, E. (2010). Why professional athletes need a prolonged period of warm-up and other peculiarities of human motor learning. *Journal of Motor Behavior, 42*(6), 381-388.

Andrade, D. C., Henriquez–Olguín, C., Beltran, A. R., Ramirez, M. A., Labarca, C., Cornejo, M., Alvarez, C., & Ramirez-Campillo, R. (2015). Effects of general, specific and combined warm-up on explosive muscular performance. *Biology of Sport, 32*(2), 123.

Attenborough, A. S., Smith, R. M., & Sinclair, P. J. (2012). Effect of gender and stroke rate on joint power characteristics of the upper extremity during simulated rowing. *Journal of Sports Sciences, 30*(5), 449-458.

Baca, A., Kornfeind, P., & Heller, M. (2006). Comparison of foot-stretcher force profiles between on-water and ergometer rowing. International Symposium on Biomechanics in Sport.

Balyi, I., Way, R., & Higgs, C. (2013). *Long-term athlete development*. Human Kinetics.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215. https://doi.org/10.1037/0033-295X.84.2.191

Barrett, R. S., & Manning, J. M. (2004). Rowing: Relationships between rigging set–up, anthropometry, physical capacity, rowing kinematics and rowing performance. *Sports Biomechanics, 3*(2), 221-235. (Sports Biomechanics)

Barris, S., Farrow, D., & Davids, K. (2014). Increasing functional variability in the preparatory phase of the takeoff improves elite springboard diving performance. *Research Quarterly for Exercise and Sport, 85*(1), 97-106.

Bartlett, R. M., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics, 6*(2), 224-243. https://doi.org/10.1080/14763140701322994

Baudouin, A., & Hawkins, D. (2002). A biomechanical review of factors affecting rowing performance. *British Journal of Sports Medicine, 36*(6), 396-402; discussion 402.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*(4), 701.

Bernstein, I. A., Webber, O., & Woledge, R. (2002). An ergonomic comparison of rowing machine designs: possible implications for safety. *British Journal of Sports Medicine, 36*(2), 108-112. https://doi.org/10.1136/bjsm.36.2.108

Bernstein, N. (1967). The Co-ordination and Regulation of Movements. *Psyccritiques, 12*(9).

Bompa, T., & Buzzichelli, C. (2018). *Periodization: theory and methodology of training*. Human Kinetics.

Bourdin, M., Messonnier, L., Hager, J. P., & Lacour, J. R. (2004). Peak power output predicts rowing ergometer performance in elite male rowers. *International Journal of Sports Medicine, 25*(5), 368-373.

Buckeridge, E. M., Bull, A. M. J., & McGregor, A. H. (2015). Biomechanical determinants of elite rowing technique and performance. *Scandinavian Journal of Medicine & Science in Sports, 25*(2).

Carr, J. H., & Shepherd, R. B. (2011). Enhancing physical activity and brain reorganization after stroke. *Neurology Research International, 2011*.

Carr, J. H., & Shepherd, R. B. (2012). Should exercises and training be specific in motor learning? *Journal of Physiotherapy, 58*(3), 206-207.

Colloud, F., Bahuaud, P., Doriot, N., Champely, S., & Chèze, L. (2006). Fixed versus free-floating stretcher mechanism in rowing ergometers: mechanical aspects. *Journal of Sports Sciences, 24*(5), 479-493. https://doi.org/10.1080/02640410500189256

Dal Monte, A., & Komor, A. (1989). Rowing and sculling mechanics. *Biomechanics of Sport, 3*, 53-119.

Dartfish. (2019). *Dartfish 360*. (Version 6.9)

Davids, K., Glazier, P., Araujo, D., & Bartlett, R. M. (2003). Movement systems as dynamical systems. *Sports Medicine, 33*(4), 245-260. https://doi.org/10.2165/00007256-200333040-00001

Deci, E. L., Betley, G., Kahle, J., Abrams, L., & Porac, J. (1981). When trying to win: Competition and intrinsic motivation. *Personality and Social Psychology Bulletin, 7*(1), 79-83.

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*(6), 627-668; discussion 692. https://doi.org/10.1037/0033-2909.125.6.627

den Hartigh, R. J. R., Cox, R. F. A., Gernigon, C., Van Yperen, N. W., & Van Geert, P. (2015). Pink Noise in Ergometer Rowing: Sport Performance Likely Emerges from Complexity. *Motor Control, 19*(4), 355-369. https://doi.org/doi:10.1123/mc.2014-0039

Doyon, J., & Benali, H. (2005). Reorganization and plasticity in the adult brain during learning of motor skills. *Current Opinion in Neurobiology, 15*(2), 161-167.

Draper, C. (2020, January 19, 2020). Is measuring force on the gate misleading? R4, Eton Dorney.

Dudhia, A. (1999). *The physics of rowing*. Retrieved from http://eodg.atm.ox.ac.uk/user/dudhia/rowing/physics/basics.html

Elliott, B., Lyttle, A., & Birkett, O. (2002). Rowing: The RowPerfect Ergometer: a training aid for on–water single scull rowing. *Sports Biomechanics, 1*(2), 123-134.

Fairbairn, S. (1951). *The complete Steve Fairbairn on rowing*. London: Kingswood Press.

Ferris, D. P., Liang, D., & Farley, C. T. (1999). Runners adjust leg stiffness for their first step on a new running surface. *Journal of Biomechanics, 32*(8), 787-794. https://doi.org/10.1016/S0021-9290(99)00078-0

Filter, B. K. (2019). Design and materials in rowing. In *Materials in Sports Equipment* (pp. 375-401). Elsevier.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*(6), 381-391. https://doi.org/10.1037/h0055392

Fleming, N., Donne, B., & Mahony, N. (2014). A comparison of electromyography and stroke kinematics during ergometer and on-water rowing. *Journal of Sports Sciences, 32*(12), 1127-1138.

Francis, P. (2013). *Coaching Power* Joy of Sculling, Saratoga Springs, NY.

Friel, J. (2012). *The triathlete's training bible*. VeloPress.

Gentile, A. M. (1987). Skill Acquisition: Action, Movement, and Neuromotor Processes. In J. Carr & R. Sheperd (Eds.), *Movement Science Foundations for Physical Therapy in Rehabilitation* (pp. 111-187). Movement Science: Foundations for Physical Therapy ....

Glazier, P. S., Davids, K., & Bartlett, R. M. (2003). Dynamical systems theory: a relevant framework for performance-oriented sports biomechanics research. *Sportscience, 7*.

Gordon, A. M., Hung, Y.-C., Brandao, M., Ferre, C. L., Kuo, H.-C., Friel, K., Petra, E., Chinnan, A., & Charles, J. R. (2011). Bimanual training and constraint-induced movement therapy in children with hemiplegic cerebral palsy: a randomized trial. *Neurorehabilitation and Neural Repair, 25*(8), 692-702.

Górecki, T., & Smaga, Ł. (2019). fdANOVA: an R software package for analysis of variance for univariate and multivariate functional data. *Computational Statistics, 34*(2), 571-597.

Hagerman, F. C., Hagerman, G. R., & Mickelson, T. C. (1979). Physiological profiles of elite rowers. *The Physician and Sportsmedicine, 7*(7), 74-83. https://doi.org/10.1080/00913847.1979.11948457

Harlow, H. F. (1949). The formation of learning sets. *Psychological Review, 56*(1), 51.

Haywood, K. M., & Getchell, N. (2019). *Life span motor development*. Human Kinetics.

Hickey, G. J., Fricker, P. A., & McDonald, W. A. (1997). Injuries to elite rowers over a 10-yr period. *Medicine and Science in Sports and Exercise, 29*(12), 1567-1572.

Hill, H. (1995). Inter-und intraindividuelle Veränderungen von Koordinationsmustern im Rudern. Roderer.

Hill, H. (2002). Dynamics of coordination within elite rowing crews: evidence from force pattern analysis. *Journal of Sports Sciences, 20*(2), 101-117.

Hofmijster, M. J., van Soest, A. J., & De Koning, J. J. (2008). Rowing skill affects power loss on a modified rowing ergometer. *Medicine & Science in Sports & Exercise, 40*(6), 1101-1110.

Holt, P. J. E., Bull, A. M. J., Cashman, P. M. M., & McGregor, A. H. (2003). Kinematics of spinal motion during prolonged rowing. *International Journal of Sports Medicine, 24*(8), 597-602. https://doi.org/10.1055/s-2003-43273

Hooper, I. (2006). *A Discussion of : Fixed vs Dynamic Ergometers*. Paper presented at the Rowing Australia Conference, Sydney.

Horstman, D. H., Morgan, W. P., Cymerman, A., & Stokes, J. (1979). Perception of Effort during Constant Work to Self-Imposed Exhaustion. *Perceptual and Motor Skills, 48*(3_suppl), 1111-1126. https://doi.org/10.2466/pms.1979.48.3c.1111

Hänyes, B. (1983). *Die biomechanische Leistungsdiagnose*. Zenturm für Wissenschaftsinformation Körperkultur und Sport.

Ishiko, T. (1971). Biomechanics of rowing. In *Biomechanics II* (Vol. 6, pp. 249-252). Karger Publishers.

James, W. (1890). Attention. The Principles of Psychology, 1, 402-458.

Jensen, R. L., Freedson, P. S., & Hamill, J. (1996). The prediction of power and efficiency during near-maximal rowing. *European Journal of Applied Physiology and Occupational Physiology, 73*(1-2), 98-104.

Joy, J. (2013). *Hanlan's Spirit*. Rowperfect.

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Kal, E. C., van der Kamp, J., & Houdijk, H. (2013). External attentional focus enhances movement automatization: a comprehensive test of the constrained action hypothesis. *Human Movement Science, 32*(4), 527-539. https://doi.org/10.1016/j.humov.2013.04.001

Kelso, J. S., Fuchs, A., Lancaster, R., Holroyd, T., Cheyne, D., & Weinberg, H. (1998). Dynamic cortical activity in the human brain reveals motor equivalence. *Nature, 392*(6678), 814-818.

Kerr, D. A., Ross, W. D., Norton, K., Hume, P., Kagawa, M., & Ackland, T. R. (2007). Olympic lightweight and open-class rowers possess distinctive physical and proportionality characteristics. *Journal of Sports Sciences, 25*(1), 43-53.

Kleshnev, V. (1998). Estimation of biomechanical parameters and propulsive efficiency of rowing. *Australian Institute of Sport*.

Kleshnev, V. (2005). Rowing biomechanics newsletter. *January 2005*.

Kleshnev, V. (2008). *Comparison of on-water rowing with its simulation on Concept2 and Rowperfect machines.* Paper presented at the International Conference on Biomechanics in Sport, Korea.

Kleshnev, V. (2010). Boat acceleration, temporal structure of the stroke cycle, and effectiveness in rowing. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 224(1), 63-74. https://doi.org/10.1243/17543371JSET40

Kleshnev, V. (2011). Biomechanics of Rowing. In V. Nolte (Ed.), *Rowing Faster* (2nd Edition ed., pp. 107-125). Human Kinetics.

Kleshnev, V. (2019, Nov-Dec). Trends in speed. *Row360*, (29), 5.

Kleshnev, V., & Kleshnev, I. (1998). Dependence of rowing performance and efficiency on motor coordination of the main body segments. *Journal of Sport Sciences, 16*(5), 418-419.

Korner, T., & Schwanitz, P. (1987). *Rudern*. Sportverlag.

Lamb, D. H. (1989). A kinematic comparison of ergometer and on-water rowing. *The American Journal of Sports Medicine, 17*(3), 367-373.

Lee, R. I., Dodd, W. J., & Young Jr, E. L. (1915). A study of the effect of rowing on the heart. *The Boston Medical and Surgical Journal, 173*(14), 499-502.

Lewthwaite, R., Chiviacowsky, S., Drews, R., & Wulf, G. (2015). Choose to move: The motivational impact of autonomy support on motor learning. *Psychonomic Bulletin & Review, 22*(5), 1383-1388. https://doi.org/10.3758/s13423-015-0814-7

Lewthwaite, R., & Wulf, G. (2012). Motor learning through a motivational lens. *Skill Acquisition in Sport: Research, Theory and Practice*, 173.

Lieberman, D. E. (2014). Strike type variation among Tarahumara Indians in minimal sandals versus conventional running shoes. *Journal of Sport and Health Science, 3*(2), 86-94.

Lieberman, D. E., Bramble, D. M., Raichlen, D. A., & Shea, J. J. (2009). Brains, brawn, and the evolution of human endurance running capabilities. In *The First Humans: Origin and Early Evolution of the Genus Homo* (pp. 77-92). Springer.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science, 29*(4), 542-555.

Loosch, E., & Müller, H. (1999). Functional variability and an equifinal path of movement during targeted throwing. *Journal of Human Movement Studies, 36*, 103-126.

Magill, R. A. (2016). *A Movement Problem Solving Hypothesis: Practice Conditions Implications from Gentile's Learning Stages Model.* Paper presented at the Ann Gentile Memorial Conference, New York.

Magill, R. A., & Hall, K. G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science, 9*(3-5), 241-289. https://doi.org/10.1016/0167-9457(90)90005-X

Maglischo, E. W. (2003). *Swimming fastest*. Human Kinetics.

Mahler, D., Parker, H., & Andresen, D. (1985). Physiologic changes in rowing performance associated with training in collegiate women rowers. *International Journal of Sports Medicine, 6*(04), 229-233.

Mallory, P. (2011). The Sport of Rowing: Two Centuries of Competition in Four Volumes. *The Sport of Rowing: Two Centuries of Competition in Four Volumes*.

Marchant, D. C. (2011). Attentional Focusing Instructions and Force Production. *Frontiers in Psychology, 1*. https://doi.org/10.3389/fpsyg.2010.00210

Marchant, D. C., Greig, M., Bullough, J., & Hitchen, D. (2011). Instructions to Adopt an External Focus Enhance Muscular Endurance. *Research Quarterly for Exercise and Sport, 82*(3), 466-473. https://doi.org/10.1080/02701367.2011.10599779

Marchant, D. C., Greig, M., & Scott, C. (2009). Attentional focusing instructions influence force production and muscular activity during isokinetic elbow flexions. *The Journal of Strength & Conditioning Research, 23*(8), 2358-2366.

Mayhew, J., & Salm, P. C. (1990). Gender differences in anaerobic power tests. *European Journal of Applied Physiology and Occupational Physiology, 60*(2), 133-138.

McGregor, A. H., Bull, A. M. J., & Byng-Maddick, R. (2004). A comparison of rowing technique at different stroke rates: a description of sequencing, force production and kinematics. *International Journal of Sports Medicine, 25*(06), 465-470.

McGregor, A. H., Patankar, Z. S., & Bull, A. M. J. (2008). Do men and women row differently? A spinal kinematic and force perspective. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 222*(2), 77-83.

McIsaac, T. L., Lamberg, E. M., & Muratori, L. M. (2015). Building a framework for a dual task taxonomy. *Biomed Research International, 2015*, 591475. https://doi.org/10.1155/2015/591475

McNeely, E. (2012). *Strength Program Design*. The Joy of Sculling, Saratoga Springs, NY.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research, 67*(1), 22-29.

Meister, I., Krings, T., Foltys, H., Boroojerdi, B., Müller, M., Töpper, R., & Thron, A. (2005). Effects of long-term practice and task complexity in musicians and nonmusicians performing simple and complex motor tasks: Implications for cortical motor organization. *Human Brain Mapping, 25*(3), 345-352. https://doi.org/10.1002/hbm.20112

Mikulic, P. (2009). Anthropometric and metabolic determinants of 6,000-m rowing ergometer performance in internationally competitive rowers. *The Journal of Strength & Conditioning Research, 23*(6), 1851-1857.

Miller, A. E. J., MacDougall, J., Tarnopolsky, M., & Sale, D. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology and Occupational Physiology, 66*(3), 254-262.

Milton, J., Solodkin, A., Hluštík, P., & Small, S. L. (2007). The mind of expert motor performance is cool and focused. *35*(2), 804-813. https://doi.org/10.1016/j.neuroimage.2007.01.003

Newell, K. M. (1974). Knowledge of results and motor learning. *Journal of Motor Behavior,* 6(4), 235-244.

Newell, K. M. (1986). Constraints on the development of coordination. In *Motor development in children: aspects of coordination and control.* (Vol. 34, pp. 341-360).

Nideffer, R. M. (1989). Anxiety, attention, and performance in sports: Theoretical and practical considerations. In D. Hackfort & C. D. Spielberger (Eds.), *Anxiety in sports: an international perspective* (pp. 117-136).

Nideffer, R. M. (1993). *Predicting human behavior*. Enhanced Performance Systems.

Noakes, T. D., St Clair Gibson, A., & Lambert, E. V. (2004). From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans. *British Journal of Sports Medicine, 38*(4), 511-514. https://doi.org/10.1136/bjsm.2003.009860

Nolte, V. (1981). Zur Struktur des Kraftverlaufs als individuelles Merkmal beim Rudern. *Leistungssport, ll (suppl. 26)*, 46-61.

Nolte, V. (2011). Rowing Faster 2nd Edition. *Rowing Faster 2nd Edition*.

Panjkota, A., Šupuk, T., & Zanchi, V. (2006). Correlation of EMG activity and kinematics in case of ergometer rowing. Paper presented at the 7th WSEAS International Conference on Automation & Information, Cavtat, Croatia.

Parr, R., & Button, C. (2009). End-point focus of attention: learning the'catch'in rowing. *International Journal of Sport Psychology, 40*(4), 616-635.

Pink, D. H. (2011). Drive: The surprising truth about what motivates us. Penguin.

Porter, J. M., Ostrowski, E. J., Nolan, R. P., & Wu, W. F. W. (2010). Standing long-jump performance is enhanced when using an external focus of attention. *The Journal of Strength & Conditioning Research, 24*(7), 1746-1750.

Preatoni, E., Hamill, J., Harrison, A. J., Hayes, K., Van Emmerik, R. E. A., Wilson, C., & Rodano, R. (2013). Movement variability and skills monitoring in sports. *Sports Biomechanics, 12*(2), 69-92. https://doi.org/10.1080/14763141.2012.738700

Prinz, W. (1997). Perception and Action Planning. *European Journal of Cognitive Psychology, 9*(2), 129-154. https://doi.org/10.1080/713752551

Ramsay, J., & Silverman, B. (2005). Principal components analysis for functional data. *Functional Data Analysis*, 147-172.

Reid, D. A., & McNair, P. J. (2000). Factors contributing to low back pain in rowers. *British Journal of Sports Medicine, 34*(5), 321-322.

Rekers, I., & Esch, B. (1993). Verification of the Rowperfect Ergometer. FISA Senior Rowing Conference, London.

Richter, C., Hamilton, S., & Roemer, K. (2011). *The impact of body mass and skill level on rowing kinematics*. Paper presented at the International Conference on Biomechanics in Sport, Portugal.

Schabort, E. J., Hawley, J. A., Hopkins, W. G., & Blum, H. (1999). High reliability of performance of well-trained rowers on a rowing ergometer. *Journal of Sports Sciences, 17*(8), 627-632. https://doi.org/10.1080/026404199365650

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*(4), 225.

Schmidt, R. A., Zelaznik, H., Hawkins, B., Frank, J. S., & Quinn, J. T. J. (1979). Motor-output variability: A theory for the accuracy of rapid motor acts. *86*(5), 415-451. https://doi.org/10.1037/0033-295x.86.5.415

Schücker, L., Hagemann, N., Strauss, B., & Völker, K. (2009). The effect of attentional focus on running economy. *Journal of Sports Sciences, 27*(12), 1241-1248.

Seiler, S. (2015). 150 years of rowing faster: what are the sources of more and more speed? *BMC Sports Science, Medicine and Rehabilitation, 7*(S1), O12. https://doi.org/10.1186/2052-1847-7-s1-o12

Slater, G. J., O'Connor, H., & Pelly, F. (2011). Physique Assessment of Athletes: Concepts, Methods, and Applications. In *Nutrient Assessment of Athletes, 2nd edition* (pp. 73-119). CRC Press.

Slater, G. J., Rice, A. J., Mujika, I., Hahn, A. G., Sharpe, K., & Jenkins, D. G. (2005). Physique traits of lightweight rowers and their relationship to competitive success. *British Journal of Sports Medicine, 39*(10), 736-741.

Smith, M. A., Brandt, J., & Shadmehr, R. (2000). Motor disorder in Huntington's disease begins as a dysfunction in error feedback control. *Nature, 403*(6769), 544.

Smith, R. M., & Draper, C. (2006). *Skill variables discriminate between the elite and sub-elite in coxless pair-oared rowing.* Paper presented at the International Conference on Biomechanics in Sport, Austria.

Smith, R. M., & Loschner, C. (2002). Biomechanics feedback for rowing. *Journal of Sports Sciences, 20*(10), 783-791. (Journal of sports sciences)

Smith, R. M., & Spinks, W. L. (1995). Discriminant analysis of biomechanical differences between novice, good and elite rowers. *Journal of Sports Sciences, 13*(5), 377-385. https://doi.org/10.1080/02640419508732253

Society for Endocrinology. (2008, August 15). Why Elite Rowers Have Bigger, Stronger Hearts. *ScienceDaily, 2020*. http://www.sciencedaily.com/releases/2008/08/080807222006.htm

Soper, C., & Hume, P. A. (2004). Towards an ideal rowing technique for performance. *Sports Medicine, 34*(12), 825-848.

Stallard, M. C. (1994). Getting basic about backs. *Regatta, 66*, 22-23.

Stoate, I., & Wulf, G. (2011). Does the attentional focus adopted by swimmers affect their performance? *International Journal of Sports Science & Coaching, 6*(1), 99-108.

Sward, R. (1983). *The Toronto Islands*. Dreadnaught.

Thelen, E. (1995). Motor development: A new synthesis. *American Psychologist, 50*(2), 79.

Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior, 36*(4), 450-459.

Warmenhoven, J., Cobley, S., Draper, C., Harrison, A., Bargary, N., & Smith, R. (2018). How gender and boat-side affect shape characteristics of force–angle profiles in single sculling: Insights from functional data analysis. *Journal of Science and Medicine in Sport, 21*(5), 533-537.

Warmenhoven, J., Cobley, S., Draper, C., Harrison, A. J., Bargary, N., & Smith, R. M. (2017). Assessment of propulsive pin force and oar angle time-series using functional data analysis in on-water rowing. *Scandinavian Journal of Medicine & Science in Sports, 27*(12), 1688-1696. https://doi.org/10.1111/sms.12871

Warmenhoven, J., Cobley, S., Draper, C., & Smith, R. M. (2018). Over 50 years of researching force profiles in rowing: what do we know? *Sports Medicine (Auckland, N.Z.), 48*(12), 2703-2714. https://doi.org/10.1007/s40279-018-0992-3

Warmenhoven, J., Smith, R. M., Draper, C., Harrison, A. J., Bargary, N., & Cobley, S. (2018). Force coordination strategies in on-water single sculling: Are asymmetries related to better rowing performance? *Scandinavian Journal of Medicine & Science in Sports, 28*(4), 1379-1388. https://doi.org/10.1111/sms.13031

Weiss, S. M. (2011). The effects of reinvestment of conscious processing on switching focus of attention. *Research Quarterly for Exercise and Sport, 82*(1), 28-36.

Williams, J. (1967). Some biomechanical aspects of rowing. In A. C. Scott (Ed.), *Rowing: A Scientific Approach* (pp. 81-109).

Wolpert, D. M., Pearson, K. G., & Ghez, C. P. J. (2013). The organization and planning of movement. *Principles of Neural Science, 5*, 743-767.

World Rowing. (2016, August 13). *2016 olympic games regatta*. http://www.worldrowing.com/events/2016-olympic-games-regatta/mens-single-sculls/

World Rowing. (2020). *World best times*. Retrieved May 14 from

Wu, W. F. W., Porter, J. M., & Brown, L. E. (2012). Effect of attentional focus strategies on peak force and performance in the standing long jump. *The Journal of Strength & Conditioning Research, 26*(5), 1226-1231.

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport and Exercise Psychology, 6*(1), 77-104. https://doi.org/10.1080/1750984X.2012.723728

Wulf, G., Lauterbach, B., & Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport, 70*(2), 120-126.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review, 23*(5), 1382-1414. https://doi.org/10.3758/s13423-015-0999-9

Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the Learning of Sport Skills Through External-Focus Feedback. *Journal of Motor Behavior, 34*(2), 171-182. https://doi.org/10.1080/00222890209601939

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology: Section A, 54*(4), 1143-1154.

Wulf, G., & Weigelt, C. (1997). Instructions about Physical Principles in Learning a Complex Motor Skill: To Tell or Not to Tell.... *Research Quarterly for Exercise and Sport, 68*(4), 362-367. https://doi.org/10.1080/02701367.1997.10608018

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67*(4), 304-309.

Appendix A

Literature Review

Introduction

Rowing is a fickle sport. It appears at one moment a simple act of placing the oar in the water, followed by taking it out. The next, it overwhelms the senses with the amount of precision and control elite athletes produce while under extreme stress and pain. Consider the margins during the 2016 Rio Olympic Games, where the men's single scull was won by .000, an amount so small the measurement system could not quantify it (World Rowing, 2016, August 13). Yes, the photo finish shows the slightest of advantages to the Kiwi sculler, but current technology precludes knowing that each rower raced exactly 2000m. The smallest of discrepancies between the lanes and Damir Martin goes home with a gold medal around his neck instead of Mahe Drysdale. Putting aside the technical challenges required to determine outcomes of such a close race, the performances themselves are incredible feats. Even more important is asking the question, "how are athletes learning to perform at such high levels?" That problem requires a collaboration of rowers, coaches, and researchers in sport science and related fields in order to solve.

The purpose of this review is to provide an overview of the requisite knowledge supporting peak performance with respect to rowing technique, as well as a framework for its application. It is written for athletes, coaches, and researchers so that a baseline of the principles known to affect learning skilled movements, such as the rowing stroke, and elite athlete performance are shared as a foundation for future exploration. Elite rowing is often the sole focus of rowing performance (See Soper & Hume, 2004 for a review). It represents the highest level of learning to perform within the sport. However, it should be noted that novice and youth-aged rowers are theoretically learning the foundations to become the next group of elite competitors. There is an undeniable relationship between how current young athletes are learning the sport and their level of preparedness on the start line at the Olympic Games in 8 to 12 years (Balyi, Way, & Higgs, 2013). In addition, the lack of consensus surrounding an ideal technique, including the two styles that virtually tied at the 2016 Rio Olympic Games, suggests a broader approach is necessary. The goal of this review is not there to define "ideal" technique, but rather to review those factors impacting the performance of the highly skilled movements known as rowing.

Coaches — Why do you need to read this? First, as educators, the primary role of a coach is to teach. The following information is a baseline of proven concepts, theories, and best practices to guide instruction. Next, coaches are unwitting experts in the field of motor learning, the science that explores how people learn to perform motor skills (Magill, 2016). Steve Fairbairn (1951), the father of modern rowing, encouraged athletes to focus on the blade, as opposed to the body in the early 1900s. His experience as a coach allowed him to recognize a concept that was not empirically demonstrated to be true in complex movements until 1997 (Wulf & Weigelt). Finally, by integrating basic principles of motor learning into coaching at all levels, the likelihood of an improved experience or performance or both increases. As coaches, that is a defining component of success in the role.

Researchers — Why do you need to read this? First, as sport scientists or researchers working in related fields, understanding the relationship between concepts, theories, and their application is critical. In principle, this is readily apparent. In practice, that is not always the case. From a coach's perspective, the research in rowing (and likely other sports) has demonstrated important findings, but often without the context necessary for successful application. That gap needs to be addressed. In 2018, a group of researchers led by John Warmenhoven published a review of force profiles in rowing. One of the key conclusions was to direct future research based on a proven model of constraints impacting learning and performance. However, as the authors surely recognized, a primary concern is that the widely accepted model of constraints they reference was originally published by Karl Newell in 1986. In over three decades, only a few published articles seem to recognize the potential impact of these constraints on rowing performance, despite the model's prevalence as a foundation of motor learning and motor development in textbooks (Haywood & Getchell, 2019; Magill, 2016). Second, there are emerging lines of research showing significant promise in understanding how motor skills are learned and performed, but these advances are not always rooted in performance-based sports science (Meister et al., 2005; Milton, Solodkin, Hluštík, & Small, 2007; Wolpert, Pearson, & Ghez, 2013). Some of the most insightful developments on the mediating effects of motor learning and performance have come from researchers and therapists whose primary goal is assisting persons with cerebral palsy, stroke, or Huntington's Disease (Carr & Shepherd, 2011; Doyon & Benali, 2005; Gordon et al., 2011; M. A. Smith, Brandt, & Shadmehr, 2000). For example, Shepherd and Carr's

(2012) work on neurorehabilitation after stroke has carryover into the sports performance domain. Finally, if rowers and coaches are going to use the research produced, it needs to connect with the application of learning and performance in a way that everyone can understand. The information contained here is not exhaustive, but it creates a baseline of knowledge that all interested persons should understand. That shared language sets an expectation to avoid mis-steps, such as decades of rowing research without accounting for a proven concept such as Newell's model of constraints.

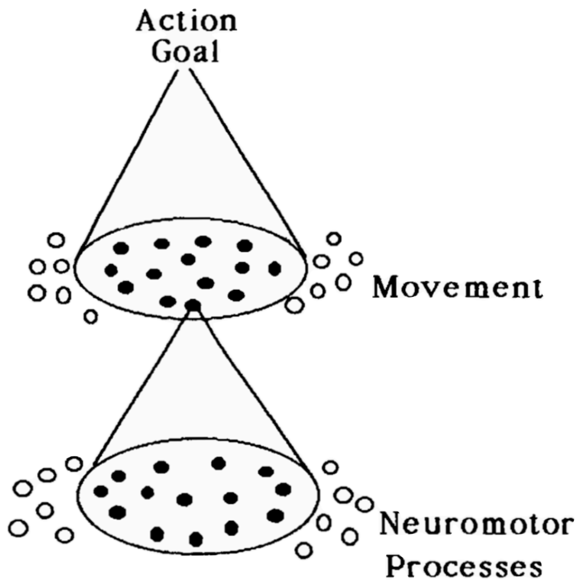
The structure of this review is organized into four primary sections. Each section first discusses an important concept or theory that should be considered by rower, coach, and researcher alike before exploring the implications for use in rowing. Although rowing will be used as an example when reviewing concepts or theories, other sports may adapt the framework and adjust the examples accordingly. The first section describes motor performance, along with its structured hierarchy and measures. Next, theoretical constructs concerning how motor skills are learned are reviewed. The third section explores new lines of behavioral research in motivation and attention that are reshaping theories of motor learning and control. Applying them presently will guide rowing forward, avoiding the mistake of Newell's constraints and a multiple decade gap. The fourth and final section is a synthesis of the previous sections along with new information on how to practice to develop expertise. A series of reflective questions is proposed as a filter to identify elements that affect the salient features of motor learning and performance.

What is Performance?

Performance, in the realm of motor skills, is the result of three primary factors — actions, movements, and neuromotor processes (Gentile, 1987). Actions are the observable outcomes of movement. Movement is the means through which an action occurs. Where action-goals describe what happened, movement describes how it happened. Movements are also the result of one or more neuromotor processes. Neuromotor processes are one of the less understood components of motor skill learning and performance. In spite of this, they are accepted as plans for movement based in multiple locations throughout the central nervous system. When motor performance is discussed or evaluated, all three of these factors must be considered (Gentile, 1987). The relationship between each of these constructs can be seen in Figure A-1. The small filled in circles represent potential neuromotor processes or movement plans that could achieve the task goal. In those cases, many different ways of achieving the desired outcome are possible, a concept known as motor equivalence. Determining which filled in circle best achieves the task goal however requires further inquiry into what they represent.

Figure A-1

Outcomes (Action-Goal), Movement, and Neuromotor Processes



Note. Outcomes (Action-Goal), Movement, and Neuromotor Processes. Diagrammatic representation of the relationship between levels of analysis. At the "Movement" level, filled circles represent the many movement patterns that can be used to successfully achieve the "Action-Goal"; unfilled circles are unsuccessful patterns. At the level of "Neuromotor Processes," filled circles represent the many ways neural processes can be organized to produce a specific movement; unfilled circles are unsuccessful modes of organization. Reprinted from "Skill Acquisition: Action, Movement, and Neuromotor Processes," by A. M. Gentile, 1987, *Movement Science: Foundations for Physical Therapy in Rehabilitation,* (p. 117).

The Performance Hierarchy

Performance Outcomes

Performance outcomes, or the action-goal as seen in Figure II.1, represent the first level in the hierarchy of performance. The outcomes are defined by the goal of the motor skill being performed. In rowing, the action-goal typically refers to an absolute measure — the time taken to cover a distance of 2000m. However, performance outcomes can take other forms. As categories, an outcome may be either successful or unsuccessful, such as completing the race or not. As a subjective measure, an outcome may be captured by a observation based scores, such as those in figure skating and gymnastics (although the goal is to be objective, bias may occur). Most action-goals have a singular focus that drive the performance outcome. As such, the performance outcomes that measure an action-goal are typically unidimensional (i.e., rowing outcomes are determined by time and time alone). Even if the desired outcome for a race was to place in the top 3, which could categorically be defined as successful or unsuccessful, the determining factor will still be time.

Performance Measures

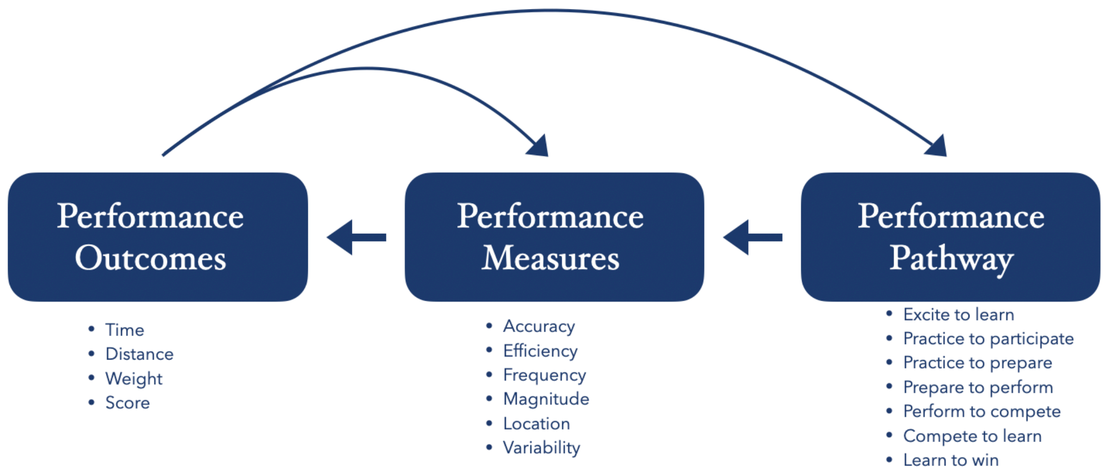
The second level of the performance hierarchy addresses how action-goals are achieved. Limb kinematics, force production, and muscle activation, for example, are used to describe how a movement functions to achieve its desired action-goal (Gentile, 1987; Magill, 2016). The magnitude, timing, and interaction of body segments captured by these measures are called performance measures. The measures are used independently, and in combination, to create movement signatures, which represent characteristics of movement, or in this case, rowing technique (Hill, 1995; Nolte, 1981). Common examples that have been used in rowing are EMG capturing muscle activation patterns, peak force capturing the magnitude and timing of force applicaiton, and a force signature that graphically displays the interaction between force production and time.

Performance Pathway

The third and final component of the performance pathway is Long Term Athlete Development (LTAD). LTAD describes the development of motor skills and physical activity over a lifespan (Balyi et al., 2013). It represents a developmental pathway for individuals that includes, but is not limited to elite rowing performance. Stages on the performance pathway are specific to individual, environment, and task, thereby affording generalizability as well as specificity, i.e. novice and elite rowers with the same goal of winning their next race will have both similar and different structural elements in their preparation. As such, the pathway recognizes that skilled movements are learned and refined over time through stages that are functionally distinct. The practice strategies of Olympic athletes and typically-developing high school athletes should reflect the needs of those individuals, teams, and environments. The performance pathway provides a lens for viewing development and performance from a broader perspective — a perspective that this review suggests is necessary to better understand factors influencing the "ideal" rowing technique (Figure A-2).

Figure A-2

The Performance Pathway



Notes. Performance outcomes are the most common uni-dimensional measure by which a movement or a task is evaluated. Performance measures are those which describe how a movement was performed. The performance pathway is a construct developed to describe the overall learning process for participants, independent of their goal to be an Olympic athlete or participate in general physical activity.

Measuring Performance

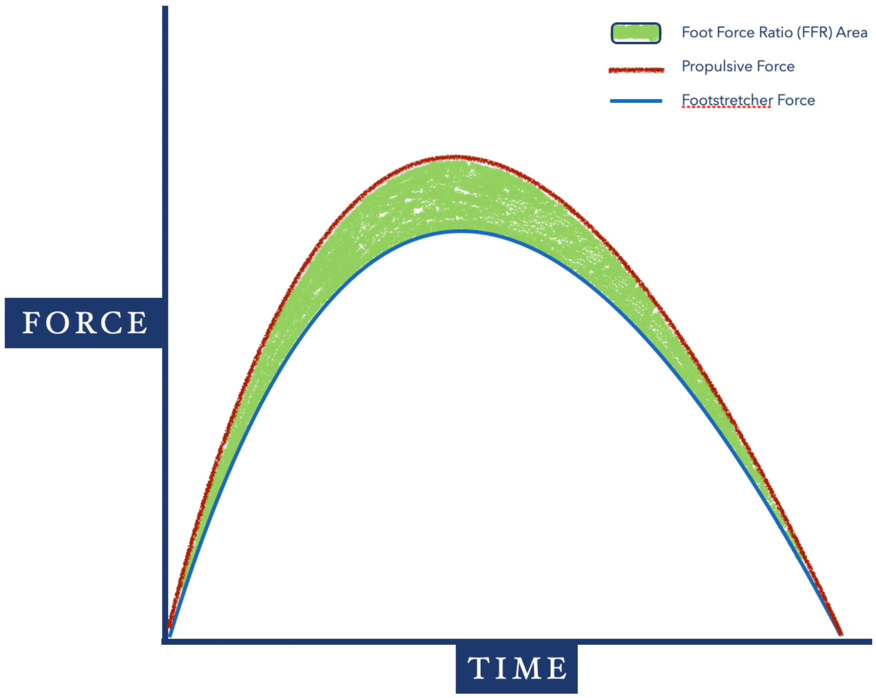
This review strategies measures of performance into two categories The first dimension is the measure that defines the desired outcome. In rowing, the time to cover 2,000m. Dimension one's measure of performance has clear limits. Even though it describes *what* happened, it does not describe *how* it happened or what neuromotor processes were involved. Dimension two performance measures address this shortfall by capturing information that specifically describes *how* an outcome was achieved, i.e. the rower achieved a new world best time by increasing total power output to 600 watts during the race. Where dimension one outcomes have a singular performance measure, dimension two outcomes have nearly unlimited measures. An important feature of dimension two performance measures is that they not only describe the movement, but they also allow for error within the performance to be reviewed. Both aspects of dimension two performance measures (movement measures and movement error) are necessary to understand the relationship between different techniques that have won championships. One final note regarding error. It is the perception of error that allows the individual to know what changes to make and how to improve their performance (Gentile, 1987; Magill, 2016). Far from being a source of disruption, it is a critical part of the feedback system needed to improve.

Biomechanical Determinants of Rowing Performance

Feedback during rowing plays an important part in the rower adapting movements for optimal performance (R. M. Smith & Loschner, 2002). The performance measures described above have been used to create a map of factors influencing 2,000m rowing performance. To move faster, rowers must change the relationship between propulsive forces and drag forces acting on the system. Increasing net propulsive forces on the pin, foot-stretcher, and seat are the main factors contributing to an increase in mean velocity. Drag forces acting on the system include air and water resistance related to the rowers and the equipment. The interaction between these competing forces is complex. As researchers advanced dimension two performance measures to determine which factors were critical biomechanical determinants of rowing outcomes, they found that the difference between propulsive and drag forces was relatively small (Ishiko, 1971). The shaded area in Figure A-3 between the drag forces (blue line) and propulsive forces (red line) illustrates the relatively small proportion of the overall force that contributes to speed, also known as the Foot Force Ratio (FFR).

Figure A-3

Comparison of Propulsive & Drag Forces



Note. Comparison of propulsive and drag forces. The shaded area represents the forces leftover that create velocity in rowing. Adapted from "*Is measuring the force on the gate misleading*," by Draper, 2020, *R4*.

Higher levels of skill are associated with a number of improved dimension two performance measures. Baca, Kornfeind, and Heller (2006)showed that improved technical skill was captured by an increase in FFR outcomes. That is, as athletes developed more skill, independent of a physiological change in strength or endurance, they were able to apply forces in a way that maximized the difference between drag and propulsion. The key takeaway for readers is that as athletes develop skill, they rely on perceptual feedback in order to make adjustments. Refining skilled movements takes time, especially in rowing where the margins between drag and propulsive are narrow. That narrowness means it is possible for a rower to increase propulsive forces, but apply them so haphazardly that mean velocity decreases (Hill, 1995). Exploring how to "hack" the learning process in order to accelerate the aquisition of skilled movement is the focus of motor learning research.

Motor Learning

Motor learning is the study of how actions, movements, and neuromotor processes combine in order to achieve a task (Magill, 2016). Researchers in this field investigate the relationship between motor skills and motor performance over time. Coaches explore the same relationship, which is how they can be unwitting experts in the practical application of motor learning theories. At the highest level, a successful motor skill must ultimately demonstrate three qualities. It must be consistent in its ability to achieve the task goal, remain reliable for the performer to use in many situations, and possess an economy of motion (Guthrie, 1952). Movements that meet these three criteria are considered to be skilled movements.

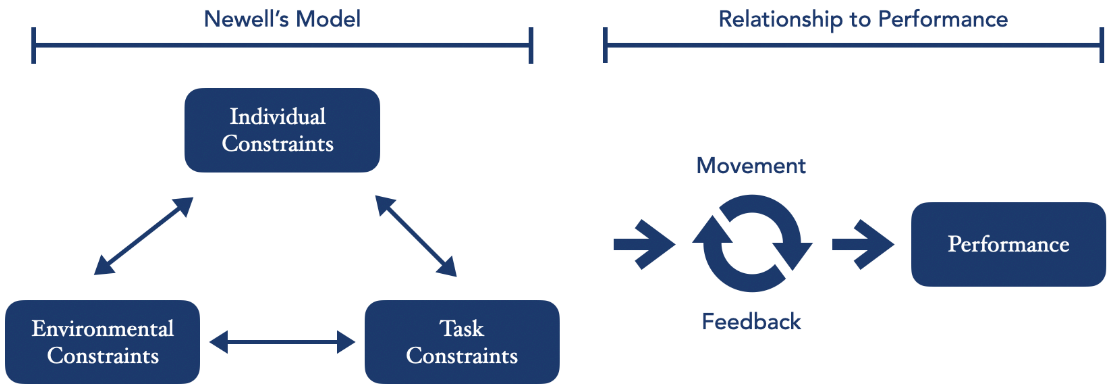
Skilled Movement and Newell's Model of Constraints

Skilled movements that demonstrate reliability and efficiency are the means by which peak performances occur. Figure 32, Gentile's (1987) illustration of outcomes, movements, and neuromotor processes, shows filled-in circles representing successful plans and movements. All of these fill-in combinations will achieve the desired outcome. That does not mean, however, that one is better than the other per se. The set of plans and movements that are the most effective from within that group have multiple factors affecting them. For example, a rower that tends to perform exceptionally well in a tailwind, but fails to meet the same performance standard in a headwind, might be able to correctly select the fill-in circles representing optimal performance in the tailwind conditions, but has yet to identify them for a headwind. That is one reason why identifying an "ideal" or "best" technique has been challenging to rowers, coaches, and researchers. Understanding what factors are influencing performance is necessary to improving dimension one outcomes and understanding the dimension two measures that contributed to the change in performance.

Newell's (1986) model model lists three constraints that affect motor performance: individual, environment, and task (Figure A-4). Individual constraints may be structural, such as the person's height or muscle mass. They may also be functional, such as level of motivation. Environmental constraints are determined by the world around the individual. Examples of environmental constraints in rowing not only include the wind and water conditions, but also the cultural norms associated with the sport or program. Task constraints are outside of the body, but directly involved in performing the task. Rules surrounding equipment, such as the minimum weight of a racing shell and type of outrigger that may be used are good examples. Figure A-4 shows not only Newell's model, but also its relationship to feedback and performance that was discussed in the pervious section.

Figure A-4

Newell's Model of Constraints



Notes. Newell's model of constraints and the relationship to feedback and performance. Individual constraints relate to the performer. Task constraints concern the activity. Environmental constraints are those which impact the setting or area in which the activity is taking place. During and after performance, the individual receives feedback that allows them to adjust the movement and refine it towards improved levels of consistency, reliability, and efficiency.

Movement Variability

In motor learning, the adage "repetition without repetition" is an oft repeated phrase to emphasize that no two movements can ever truly be the same (N. Bernstein, 1967). There was a period where that variability in performance was considered noise reflecting the inability to produce an exact movement. New theories and research, however, are changing that view (Davids et al., 2003; Thelen, 1995). Instead of being considered as a source of noise that interferes with movement, variability is emerging as a form of explicit and implicit feedback guiding future performances. That is, variability is a major source of the feedback described as contributing towards movement adaptation. Those adaptations all contribute towards the three factors that define a skilled movement — effective, reliable under varied conditions, and efficient (Guthrie, 1952).

Experienced rowers can immediately perceive the difference between a pliant racing shell and a stiff racing shell. A stiff shell provides increased feedback, but requires higher levels of skill. A pliant shell provides decreased feedback, but that reduced feedback also absorbs mechanical power and technical deficiencies. The stiffness of the racing shell is a task constraint, viewed from Newell's model. It is inherently variable and has an effect on all dimensions of rowing performance. The relationship between the individuals and how they turn that feedback and its inherent variability into something that improves performance is one of the major goals of motor learning research.

Rowing is not alone in its use of feedback and movement execution. Movement patterns from discus throwing, to basketball shooting, and locomotion have all indicated that even the most elite athletes are unable to reproduce exact movements from trial to trial (Bartlett, Wheat, & Robins, 2007). Variable movement patterns have positive values, such as when runners approach a chance in surface type. Ferris, Liang, and Farley (1999) found that individuals identify upcoming changes in surface type while running and adjust their stride pattern before arriving. The variability of their running forms affords the ability to make a change when necessary, although it is something that must be learned. Theories of motor learning and control provide a framework to explain that aspect of learning. Even though theories are abstract, they provide critical information to correctly apply research findings. There is always a gap between research and application, but narrowing the gap has the capacity to improve learning and performance. Without understanding theories and concepts, rowers and coaches are more likely to use methods that appear to help, but in fact, reduce performance.

Functional Variability

Functional variability is a concept that refers to an optimal state of variability. When dart throwing was evaluated, researchers found that experts coordinated multiple limb and body segments to produce a movement that was effective, reliable, and efficient (Lohse et al., 2010). In contrast, novice dart throwers tended to freeze body segments. The ability of individual segments to compensate for others during a task is known as functional variability.

Rowers also engage in their own form of functional variability. In a pair, the rower sitting closer to the bow has a greater mechanical advantage. If both rowers exert the same force at the same time, it will create a yawing force, causing the boat to turn (Hill, 1995; R. M. Smith & Draper, 2006). Experienced rowers learn to adapt their application of force in order to compensate for this factor. That requires the rowers to have the skill to manipulate the individual body segments responsible for producing force. The variability in those movements when done in order to compensate for an external perturbation is considered functional variability. Without understanding this concept, rowers or coaches may try to "freeze" segments of the body during rowing to gain control, when in fact, the opposite is necessary. Viewed more broadly, the result of functional variability within the rowing stroke is increased stroke to stroke consistency and smoothness of force application (Hill, 2002).

Motivation and Attention

The role of motivation and attention has largely been viewed through the lens of psychology. Their role in evaluating human movement and performance, however, is rapidly expanding to compliment many of those findings. When researchers measured ratings of perceived exertion (RPE), not only did they accurately predict an individual's maximal oxygen uptake (VO2Max), but they also predicted when the individual would reach a self-imposed point of exhaustion and cease exercise (Horstman, Morgan, Cymerman, & Stokes, 1979; Noakes et al., 2004). The results suggest that during an endurance based activity, such as rowing, emotions regulate performance. That is, when rowers are of a similar strength and skill level, the winning rower chooses to win. Beyond that direct outcome, motivation and attention also have significant roles in the acquisition and performance of skill.

Motivation has generally been considered to have two levels (Pink, 2011). The first, is based on the drive to survive — thirst, hunger, sleep, etc. The second stems from the concept of rewards and punishments. A third level of motivation, intrinsic motivation, was discovered when a study on primates found them solving puzzles intently before the rewards that were to be tested had been introduced (Harlow, 1949). Intrinsic motivation, or the sense of satisfaction that comes from pursuing and achieving a task, was found to improve the time taken to solve puzzles and increase interest in solving complex problems across a wide array of studies in multiple fields of the social sciences (Deci, Betley, Kahle, Abrams, & Porac, 1981; Deci, Koestner, & Ryan, 1999). That includes motor learning and athletic performance.

Attention represents the ability of an individual to concentrate on a discrete component of behavior or a cognitive task (for a review of attention, see Kahneman, 2011). Attention has three main constructs. First, it may be viewed as associate or dissociative. An associative focus of attention directs the performer to focus on aspects of the task, such as stroke rate, feeling of the boat, or breathing patterns during rowing. A dissociative focus directs the performer to focus on unrelated items, such as watching a tv while walking on the treadmill. Attention can also be narrow or wide. A narrow focus of attention aids in threading a needle, while a wide focus is necessary for navigating a crowded sidewalk (Nideffer, 1989, 1993). The third construct of attention is internal or external. An internal focus directs attention towards the body (i.e., think about your legs), while an external directs attention towards the desired effects of the movement (i.e., think about pushing the water back).

The evolution of these constructs resulted in the publication of a new theory of motor learning by Gaby Wulf and Rebecca Lewthwaite in 20166, called Optimizing Performance through Intrinsic Motivation and Attention for Learning (OPTIMAL). In the authors' own words, "factors influencing motor learning have been viewed almost invariably from a motivationally neutral…perspective. Given the considerable advances in our understanding of motor skill learning over the past few decades, a new theory that encompasses these findings — some of which are the result of new methodologies—is needed" (Wulf & Lewthwaite, 2016, p. 1383). The focus of the theory is motor behavior. That is, it addresses the question originally put forth in this review of *how* complex skills are performed. Although there are many theories of motor learning (for a review, see Chapter 5; Magill, 2016), the motivation and attentional focus aspects of OPTIMAL are the focus of this review.

OPTIMAL and Motivation

Two constructs of motivation define its role in OPTIMAL — enhanced expectancies and learner's autonomy. When individuals expect a positive outcome and have autonomy in the practice and performance environment, learning and performance improves. That improvement is the result of a rise in intrinsic motivation.

Enhanced expectancies are the result of increases in self-efficacy, a term that describes the level of confidence one feels regarding an outcome (Bandura, 1977; Wulf & Lewthwaite, 2016). There are four determinants that influence levels of self-efficacy: 1) previous success in the task, 2) vicarious experience, 3) verbal persuasion, and 4) physiological states. The first determinant was found to significantly influence learning and performance in motor learning during a golf study evaluating putting (Lewthwaite & Wulf, 2012). Participants putted towards a hole with a large or small circle surrounding it. Any put that stopped inside the circle was said to be a positive outcome. In a follow-up evaluation, participants who had putted towards the larger circle were more accurate, even though no differences were present between groups in the original task. The authors identified previous success in the task as a significant influence on learning and performance. In rowing, creating situations that allow for success but still provide feedback on performance could similarly improve technical skill.

Autonomy is an inherent component of intrinsic motivation. Creating an environment where participants have a degree of autonomy contributes towards improvements in learning and performing motor skills (Lewthwaite et al., 2015). In this two-part study, participants who were allowed to choose the color of their ball performed better. In the second part, participants who were asked their opinion regarding which piece of artwork the professor should hang on the wall also performed better. Even when autonomy is not directly related to the task, providing it increases levels of self-efficacy, thereby also increasing performance. As such, allowing rowers to choose technical goals and creating a degree of autonomy in their practice is suggested to similarly improve rowing skill.

Wulf and Lewthwaite (2016) proposed the dopaminergic system as the mechanism for enhanced expectancies. Dopamine, a neurotransmitter associated with reward and positive affect, is released in anticipation of a positive outcome. Of vital importance is that the release of dopamine is not triggered by receiving a reward, but rather the desire for the reward. Autonomy likely acts through an improved perception of self as well as enhanced expectancies to create a feedback loop that augment learning and performance.

OPTIMAL and Attention

Attention is the other component of the feedback loop augmenting learning and performance. When individuals adopt an external focus, improvements are observed in 1) accuracy 2) efficiency, 3) learning (Wulf et al., 1999). This component of the review will discuss attentional focus as an area of research within motor learning as well as applications that may help rowers create optimal levels of force production (accuracy) and coordination (efficiency) (Marchant, 2011; Wulf, 2013; Wulf et al., 2001).

As early as 1890, researchers hypothesized that directing attention to the "remote effects" or outcomes of simple movements would lead to better performance (James). More recently, a growing body of evidence has emerged indicating that attentional focus, more specifically, an external focus of attention, is a critical feature in the acquisition and refinement of complex motor skills (Prinz, 1997; Wulf, 2013; Wulf & Lewthwaite, 2016). When participants are instructed to focus externally on movement outcomes, they demonstrate improved accuracy, efficiency, and learning. The motor skills and activities reviewed have included golf (Wulf et al., 1999), basketball (Zachry et al., 2005), dart throwing (Lohse et al., 2010), weight-lifting (Marchant et al., 2009; Vance et al., 2004), running (Schücker et al., 2009), swimming (Stoate & Wulf, 2011), and rowing (Parr & Button, 2009), among others.

Most outcomes have a singular focus which determines the level of success, such as time in swimming or accuracy with basketball free throws. These outcome measures represent the first level by which the effects of attentional focus have been evaluated and shown to influence performance. In darts, throwers were more accurate when instructed to "visually focus on the bulls-eye" as opposed to the movements of their arm (Lohse et al., 2010, p. 548). Porter, Ostrowski, Nolan, and Wu (2010) investigated the effects of attentional focus during a standing long jump. They reported a significant increase in jump distance during external focus trials. Increased jump distance describes the outcome, or *what* happened. *How* the individual achieved that improvement is equally important (*how* describes the movement component of Figure 1). As such, a follow-up study by Wu, Porter, and Brown (2012) repeated the experiment, but added a force plate beneath participants to measure ground reaction forces. The researchers believed that an increase in force production would explain the increase in distance jumped. Despite confirming increased jump distance under external focus conditions, there were no significant differences in ground reaction forces between conditions. Similarly to arguments made in rowing by Kleshnev (1998) that higher levels of coordination improve efficiency, the authors suggested that improved whole-body coordination under external conditions provided an advantage. That is, individuals jumped farther even though there was no increase in force production. That aspect of jumping has yet to be evaluated, but additional research on coordination does support the hypothesis (Marchant et al., 2011; Preatoni et al., 2013).

Even though performance improved in the studies above, it could have come at a cost to the performer's efficiency. Vance et al. (2004) used a two-part bicep curl study to evaluate this possibility. Participants were asked to bicep curl a weight 10 times under counter-balanced conditions of control, internal, and external focus conditions. The time to complete the movement was recorded, as well as the electromyography (EMG) activity of the bicep. Analysis revealed that under external control conditions, not only did the participants complete the 10 repetitions in less time, but they also showed less muscle activation of the involved muscle groups. To test if the lower EMG scores were a reflection of the shorter duration of the trial, a second experiment was done with the bicep curls being set to a metronome. This controlled for the time duration of each trial. Again, EMG activity during the external focus trial was lower. Participants also reported lower rates of perceived exertion, a critical factor for performance when force production over time is a primary consideration (Noakes et al., 2004). The findings suggest that performance under external focus conditions not only improves force production dependent outcomes, but also improves efficiency.

Wulf, McNevin, and Shea (2001) proposed the "constrained action" hypothesis as the mechanism by which external focus improves performance. It posits that an internal focus "interferes with the automatic control processes that would normally regulate movement" (Wulf et al., 2001, p. 1144). In contrast, an external focus of attention promotes automaticity and allows body segments to move with improved levels of coordination (Kal et al., 2013). Higher levels of coordination allow for improved timing and intensity with respect to the muscles involved in a specific movement. The constrained action hypothesis explains the conclusions reported in research on standing long jump regarding whole-body coordination.

Swimming, like rowing, is an activity that is sensitive to force production, coordination, and efficiency (Maglischo, 2003). Stoate and Wulf (2011) compared the results of novice and expert swimmers under internal, external, and control conditions. The use of novice and expert participants allowed the researcher to examine the effects of attentional focus on different levels of expertise. The authors reported that novice swimmers were faster using external focus compared to internal or control conditions. Similarly, expert swimmers were faster under external and control focus compared to internal conditions (Stoate & Wulf, 2011). Wulf and

Lewthwaite (2016) suggested that an external focus of attention "propels" the performer towards improved performance states. In this particular study, the authors hypothesized that expertise in swimmers automatically induces a state of external focus.

In rowing, there is support for an external focus of attention improving the accuracy of blade height during the recovery (Parr & Button, 2009). The potential effects of an external focus of attention on force production and coordination have not been fully evaluated. Despite a lack of direct empirical evidence, the breadth of support for external focus in similar activities suggests that it should similarly contribute to improved performances.

Synthesis into Practice

The goal of this review has been to provide an overview of five factors that are known to significantly influence learning and performing skilled movements, such as rowing. The first three factors (individual, task, and environmental constraints) are components of Newell's model of constraints (Newell, 1986). The remaining two (autonomy and external focus) are salient aspects of OPTIMAL (Wulf & Lewthwaite, 2016). All five of these factors are suggested to form a baseline of questions that rowers, coaches, and researchers should consider when evaluating rowing performance and seeking to understand *how* rowers use different techniques and strategies to achieve similar (down to the 1,000th of a second in the case of the Rio Olympics) results.

Experienced coaches often develop an inherent sense of these relationships. Rowing in small boats (singles, pairs, doubles) is generally considered a best practice for improving technique. The five factors reviewed above help to explain why. In a single, the individual becomes the focus of the training session (autonomy). The task, especially when the individual has been informed that the use of a small boat is to improve their technical skill, creates a sense of future performance gains (enhanced expectancies). In the smaller boat, the influence of a rower's movement on the shell is easier to discern (task). The rower, now able to better perceive the frequency and intensity of negative effects, is able to practice corrective changes (environment & individual). Structured correctly and with the appropriate guidance, small boat training provides the individual with experience necessary to improve technique. The transfer, however, is not without its own set of constraints. As Bill Manning wrote in his *RowingNews* article, "Small boats, big gains? That's not always the case", when athletes from small boats into larger boats, they require time to adapt. His observations are supported by researching evaluating how parameters vary between boat classes (Baudouin & Hawkins, 2002). Timing and coordination of force application in a boat moving at 5 meters/second is different from one moving at 4 meters/second. Rowers require practice during those transitions to "relearn" skilled movements and adapt to the new constraints (Hill, 2002).

Although a number of motor learning theories and strategies contribute to peak performances in rowing, the five factors reviewed here are suggested as a foundation for coaches, rowers, and researchers to consider. As discussed in the comparison of propulsive vs drag forces (Figure 34), small changes can have significant impacts on performance. For coaches, applying these five factors provides a baseline from which motor learning knowledge can not only have an immediate impact, but also lead to further considerations. The goal is to accelerate the coaching process, improving outcomes with fewer years of coaching needed to perceive limits, such as those reviewed by Manning. For researchers, the goal is to consider how these five factors may influence not only the performance of rowing technique, but also the identification of salient features corresponding to an "ideal" technique. An integrated collaboration presents the best opportunity to continue improving development and performance for all rowers.

Appendix B

(Dynamic) Indoor Rowers

Introduction

Competitive rowing developed out of competition between watermen who ferried individuals across the river Thames in London. In order to demonstrate who could cross the river fastest, races were held. Those races evolved into events that spanned multiple days and were filled with various types of boats and crews. In the early 1800s, as bridges became a common site throughout the area, rowing further evolved. It transitioned from a practical method of transportation into a sport that spread across the region and throughout the various socio-economic classes. As with other sports of the time, betting on the outcome of races also grew. Rowers quickly discovered that increased training specificity resulted in faster boats. These anecdotal and experience based findings were later demonstrated by Hagerman (Hagerman, Hagerman, & Mickelson, 1979), when he investigated the physiological profiles of elite rowers. In contrast to most other endurance sports where athletes set a pace, rowers start with extreme resistance and the resultant "burning sensation" of metabolic byproducts that they must endure throughout the race. As the amount of money increased during the late 1800s and early 1900s, some rowers turned "professional". In areas where rowing was not always possible, rowers and coaches looked to new innovations to improve the likelihood of their success. This search ultimately led them to the invention of the modern indoor rowing machine.

Although there have been many innovations in the sport over the past 100 years, few have had more effect on the sport than the use of rowing machines, also called ergometers or "ergs" (Mallory, 2011). The erg has evolved into a tool for rowers, coaches, and researchers who wish to further athlete development, test performance, and better understand the salient characteristics of the rowing stroke (Schabort et al., 1999). The initial form was a device called a dockbox (Mallory, 2011). The dockbox was designed to be bolted at the edge of the rowing dock and remain fixed in position. It contained a sliding seat, foot-stretcher, and an outrigger into which an oar could be placed. The primary advantage was that rowers no longer had to be in a boat to train both physically and technically. Oars were resized to accommodate the difference in pressure on the oar since the dockbox was stationary.

In addition to the dockbox, a company called Naraggansett Rowing produced a hydraulic ergometer (Rowing News, 2002). The hydraulic ergometer was similar in design and function to the dockbox, however it was connected to a hydraulically based resistance system. This allowed the device to be used indoors. The major challenge for these devices is these devices were not only fragile and required a significant amount of maintenance, but they were also expensive. This prevented their widespread use as a means of training.

The dockbox and the hydraulic erg (for those who could afford it) remained the primary methods of land-based training outside of running, swimming, and weights until the 1960s. At this time a new product called the Gamut ergometer entered the market. The main difference between the hydraulic ergometer and the gamut was the type of resistance that could be employed. Instead of hydraulics, the gamut relied on free weights which were attached to a pulley system. The rower or coach could vary the amount of weight on the system to change the amount of friction applied to the flywheel. One of the most significant improvements in this design was the ability to measure work. The flywheel had a magnet that would turn over a counter every time it went past. The harder the individual rowed, the faster it turned over. Now, for the first time, coaches could set a time or a count and rowers could achieve a score by which they were compared (Mallory, 2011).

One of the primary issues with the gamut was that it was friction based. As the flywheel heated up with use, it would spin faster. Rowers quickly learned that training after the machine had been thoroughly used by others would result in a faster score. The solution to this problem came in 1981 with the introduction of the Concept2 Model A ergometer. The design was a revolutionary change as it used an air-braked flywheel within a perforated cage that controlled resistance by controlling the amount of air reaching the flywheel. In contrast with the gamut, extended use of an air-braked flywheel remained reliable. It took an additional three years for Concept2 to develop the Performance Monitor. The Performance Monitor provided a new set of tools for both rowers and coaches. The reliability of the air-braked flywheel, combined with measured outputs allowed for highly accurate logs, changed how rowers trained. Indoor races grew in popularity and a list of world records for races on the Concept2 indoor was established. Erg scores became standards by which rowers were not only selected for crews, but also by which national teams would invite people to try out. The Concept2 indoor rower is widely used not only in rowing, but also in fitness clubs and in Crossfit. It has achieved what previous alternative training methods in rowing had not: ubiquity.

The evolution of indoor rowing machines has continued over the past three decades since the Concept2 became the standard training tool in the sport. The erg is presently on its 5th design iteration. It has a highly developed monitor to capture and display data, as well as connect to online tracking systems. Other indoor rowers have attempted to break into the market, but with little success until the RowPerfect. The RowPerfect was first introduced in 1988, although it did not gain widespread use until its designer, Cas Rekers, reviewed it at the 1993 London Senior Rowing Conference The RowPerfect sought to adjust the mechanics of the indoor rower by creating a dynamic system that more closely resembled the forces and characteristics associated with on water rowing. As a result, the designer changed the flywheel once more. Although it is still air-braked, Rekers new design allowed the flywheel cage (also known as the power head) to slide back and forth on a rail. In contrast to the fixed power head on the Concept2, where only the rowers slides back and forth. These differences represent significant deviations that have impact not only on the design, but also on related studies concerning power production, technical evaluation, injuries, and using the ergometer as a selection tool.

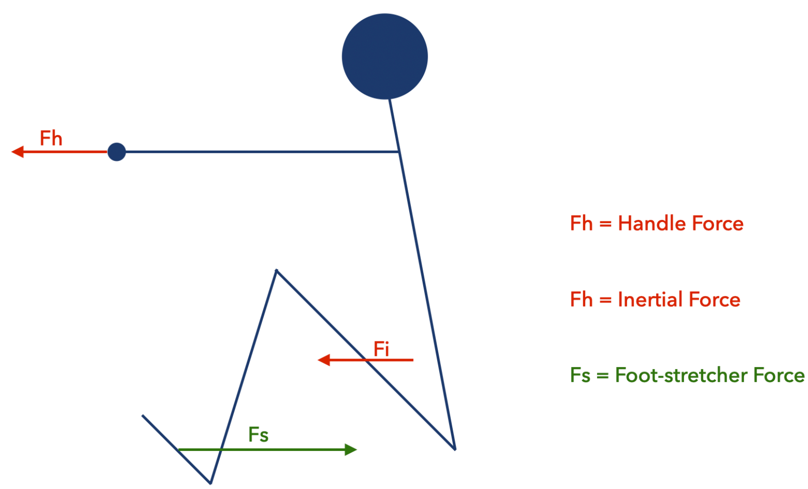
Comparing the Concept2 and the RowPerfect

Even though the fundamentals of the rowing stroke as it is performed on the Concept2 and the RowPerfect are very similar, there are significant differences

(Hooper, 2006). These differences arise from the mechanics of rowing on a fixed versus a free floating power head. The free floating powerhead aims to represent the mechanics of on water rowing by more accurately applying the action-reaction principle of Newton's Third Law. Dudhia (1999) best describes the difference with the following example. If a rower sits at the catch (the point where the propulsive phase begins) on a Concept2 and then pushes her legs down, she will move her body a distance fairly equal to her leg length. However, if the same rower were to perform the same task while sitting in a rowing shell, she would only move her body about 20% of the above length. The rest of the motion would be absorbed by the boat moving away from her. On land, the foot-stretcher against which she pushes is effectively attached to the ground and thus her entire body moves.

Figure B-1

Primary Forces Acting on The Rower



Note. Handle and foot-stretcher forces work in opposite directions during the drive. During the transition from the recovery to the catch, inertial forces (Fi), especially on the Concept2, must be overcome in order for the body to change directions. Fi increases shear forces on the spine during static ergometer rowing compared to dynamic indoor rowing.

On the water, the mass of a single scull is around 17kg compared to the heavier rower. As a result, the reaction force moves the boat a proportional distance farther than the body. Figure B-1 illustrates the different forces acting on the system and thus the difference between static and dynamic designs. The resultant force is what is left of Fh after accounting for the interaction of Fi and Fs. In a static design, forces will be higher. In a dynamic design, forces will be lower.

This difference in perspective is not limited to an external frame of reference. Performing on a static or fixed power head ergometer means the individual is actually performing more work. Not only must the rower accelerate the flywheel, but they must also accelerate their entire actual body weight up and down the slide. The additional mass increases the kinetic energy necessary to move up and down the slide. On the water, as a result of the lighter mass of the scull discussed above, the rower remains relatively stationary and the boat moves. The lighter mass of the shell requires significantly less energy to reach the same effective endpoint. This mass changes with boat class the the weight of the rowers. For example, a coxed pair would have a reaction mass of about 40kg and a single would have a reaction mass of around 14kg (Rekers & Esch, 1993). This is one reason why boats subjectively "feel" different. A conference paper by Hooper (2006) reveals that rowers need to generate up to six times more energy to accelerate and decelerate their body weight on a Concept2 when compared to on water rowing.

In addition to the kinetic differences of each device, researchers have explored the kinematic variations and changes that are associated with using a fixed or a free floating power head. Bernstein, Weber, and Wooledge (2002) investigated the mechanics of each power head design by using a RowPerfect in both a fixed and a dynamic state. They found that rowers on the fixed head machine had strokes that were around 53mm longer than when rowing on the free floating design. The cause was identified as the need to generate more kinetic energy in order to decelerate and accelerate the whole body mass as it moved into the catch position and started the propulsive phase.

Colloud et al., (2006) demonstrated further proof of the increased inertial forces at the transition from recovery to to propulsive phase. Using force plates on the footstretcher, seat, and handle, the researchers confirmed that rowers on a fixed power head must generate more force to overcome the inertia due to their body weight mass. When rowers are decelerating to zero at the catch in order to take the next stroke, something must absorb the forces. Kleshnev (2008) suggests that passive tissue structures of the knees and lumbar region are the most likely areas. These findings are related to another area of research on rowing machines that is important for development and performance — injury and prevention.

Low back or lumbar pain is a common injury across rowers of all levels and experiences. Over a ten year period, researchers found that 15 to 20% of all elite rowers experience pain at an intensity that requires them to stop training (Hickey, Fricker, & McDonald, 1997). In a training sport, such as rowing, the level of fitness for individual athletes represents a critical component for performance. Injuries or pain reduce training loads and they can also have life-lasting consequences with various spinal issues. The rise of the indoor rowing ergometer created an environment where the rowing stroke could be more accurately measured and studied to explore the causes of lumbar pain and other injuries. During a 60 minute ergometer session, researchers measured the kinematics of spinal motion on a fixed power head ergometer (Holt, Bull, Cashman, & McGregor, 2003). As the session progressed, researchers discovered significant increases in both the lumbar spine range of motion when the rower approached the catch, as well as the total lumbar spine range of motion. Further research demonstrated that additional bodyswing or layback at the finish of the propulsive phase was contributing to an excess of activity in the hip flexors, equivalent to performing prolonged sit-ups (Stallard, 1994)

The combination of research into kinetics and kinematics of rowing on the water, as well as on ergometers, has created a body of research that identifies muscular fatigue and excessive lumbar motion as the primary causes of passive flexion on the spinal area which leads to lumbar or spinal injury. The ubiquity of the fixed power head design means that more rowers are using a device which is known to require more force to overcome the inertia associated with the rower and it is suggested that this is a leading cause of lumbar or spinal injury. The newer free floating design is a more complex machine, requiring more detailed engineering and maintenance, but also more accurately reflects the loading characteristics associated with on water rowing (Reid & McNair, 2000). The dynamic ergometer reduces forces on the lumbar area of the rower, especially at the catch where shear forces are highest on the spine. In addition to this factor, which is likely to help with injury prevention, it also allows the training device to be more task specific. Task specificity is not only relevant for the physiological factors, but also for the skill factor. No study to date has demonstrated that skills learned on the rowing machine specifically transfer to on water rowing. However, even if the current design of free floating power heads does not directly transfer to on water rowing, it does represent a step in the rowing machine design that brings it closer to replicating the physical and neurological components of rowing.

Training to Perform

Kleshnev (2005) investigated the kinematic differences in rowers on fixed versus free floating power head ergometers. His findings concurred with previous research that fixed power heads required more force to overcome inertia and accelerate the body. He also identified that the speed of the leg drive was slower, but doing more work on the static ergometer than on the dynamic ergometer. This finding illustrates one of the challenges with using a machine that attempts to replicate the demands of rowing, without actually rowing. Rate of force development in rowing is known as a key factor in producing speed (Buckeridge et al., 2015). The variance in the rate of force production in each model creates not only physiological differences in how athletes will respond to training, but also neurological differences. The front end of the rowing stroke where the propulsive phase begins has become increasingly investigated. In on-water rowing, the quickness of the blade entry into the water and the time it takes to fully load the blade has been identified as such a critical component of speed, that is now has its own name: M-time (Kleshnev, 2010). If one of the goals of rowing machines is to improve the skill of the athlete, then the coordination of the leg drive with other prime movers during the drive sequence, should as accurately reflect on water rowing as possible. The RowPerfect ergometer is the most accurate representation of this goal presently on the market according to the above research.

The improvement in these designs has created a set of standards across rowing. Elite men are typically required to break the six minute mark for a 2,000m test on a static Concept2. Elite women are typically required to complete the same test in seven minutes or less. Additionally, many countries require athletes to meet these standards in order for them to receive national team invitations, and the opportunity to represent their country at the world championships or Olympic games.

Rowing machines are now driving selection and participation in the sport at an increasingly high rate. In order to test the reliability of rowing machines to accurately score individuals across different tests and locations, investigators examined the reliability of repeat tests on the static Concept2 erg (Schabort et al., 1999). Results demonstrated that not only was the Concept2 highly reliable, but also that it was more reliable than the cycling gold standard of the time. The need to accurately monitor individual development in a training sport such as rowing is key for long term growth and performance (Nolte, 2011). Expanding upon this reliability study to include the RowPerfect, Soper & Hume (2004) also reported that the Concept2 was highly reliable in a review article. The RowPerfect was found to be reliable, but not as reliable as the Concept2. Wepeated measures of 2000m and 500m test were conducted, the Concept2 had a percent of mean standard error 1.3% (95% CL 0.9 to 2.9%) and the RowPerfect outcome was 3.3% (95% CL 2.2 to 7.0%). The results show that even if the RowPerfect is more similar to on water rowing as a result of the free floating power head, the Concept2 is a more accurate and better tool for testing physiological progress.

In addition to monitoring performance, the need to develop rowers timing and coordination is a critical one for crewed shells and individual shells. The difference between timing and coordination can be best illustrated by a two people taking the same amount of time to cross a five meter platform, but varying their speed so that they are never side by side except at the beginning and the end. In the same fashion, rowers train to coordinate their power output to create matched symmetries that will increase boat speed. The catch or entry of the blade is the start and the release or finish of the drive is the end. Although blades can enter the water and leave the water at the same time, it does not mean that forces are being applied in the same fashion. Force profiles are increasingly common in the study of rowing, as is their use in developing rowing machines and teaching strategies to increase performance (Warmenhoven, Cobley, Draper, & Smith, 2018).

The use of force profiles and kinematics to investigate timing and coordination was reviewed by Soper & Hume (2004). They agreed with Kleshnev and Kleshnev (1998)that consecutive movements which isolated leg drive first, body swing second, and arm pull third resulted in greater power production. However, when the movements were synchronized, the rower performed a more mechanically efficient stroke. The use of the RowPerfect to evaluate the force profiles (force signature) for athletes could help them find the highest balance of efficiency and power production.

Discussion of Static and Dynamic Ergometers

A recent review explored fifty years of research of force profiles in rowing (Warmenhoven, Cobley, Draper, & Smith, 2018). The review noted that despite 50 years of study, there is no "ideal" force signature. However, there are salient characteristics that should be present. Rate of force production is a significant factor in increasing the amount of work being done at a time where it can contribute to the speed of the boat. Mean to Peak Force Ratio (MPFR) is another metric which looks at how long the individual can sustain the force on the drive series. Consistency and smoothness of the force profile was also associated with better performance and more skill (Hill, 1995). The interplay between these factors led Soper & Hume (2004) to identify all of them as significant developments in understanding rowing performance. For those who do not have access to expensive on-water measuring tools, the indoor rower is the best source of information to develop and improve.

The use of the Concept2 as a testing platform for measuring performance is the standard in the sport and should remain so. The Concept 2 is more reliable than its RowPerfect counterpart and it is also 75% cheaper, which helps rowers of all clubs and backgrounds have better access to the same equipment on which standards for selection are determined. The increase of information related to the potential injuries and other passive stretch mechanisms occurring during extended Concept2 ergometer use also suggests that the RowPerfect has its own place in the sport as an alternative training modality. Rowers using the RowPerfect decrease the shear force on their spine compared to the Concept2 (2003). The literature suggests that this will lead to decreased injury as well as an opportunity to practice a force profile that will more accurately reflect on-water rowing. It could be that further developments in reliability and reductions in cost for the RowPerfect (or another rowing device that functions dynamically) will change the standards. At present the rowing community should continue to embrace the Concept2 for testing performance, but also continue to use the RowPerfect for injury prevention and more accurate study of power application and efficiency to improve the rowing stroke.

Appendix C

IRB Approval Letters

1. Teachers College study one original IRB approval letter — 12/07/2018

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB *Expedited Approval Notification*

To: Nicholas Parker
From: Myra Luna Lucero, Research Compliance Manager
Subject: IRB Approval: 19-070 Protocol
Date: 12/07/2018

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "*Exploring the relationship between instructional cues and indoor rowing performance.* ," under **Expedited Review** (Category **(6) Collection of data from voice, video, digital, or image recordings made for research purposes.**
(7) Research on individual or group characteristics or behavior) on 12/07/2018.

The approval is effective until **12/06/2019**.

The IRB Committee must be contacted if there are any changes to the protocol during this period. **Please note:** If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by **11/22/2019** so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is **19-070**. Feel free to contact the IRB Office (212-678-4105 or irb@tc.edu) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp and is attached to this email. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials must include the study's IRB-approved protocol number. You can retrieve a PDF copy of this approval letter as well as the stamped consent(s) and recruitment materials from the IRB Mentor site.

When your study ends, please visit the IRB Mentor site. Go to the Continuing Review tab and select "terminate" from the drop-down menu.

Best wishes for your research work.

Sincerely,
Dr. Myra Luna Lucero
Research Compliance Manager
irb@tc.edu

Attachments:
- Final Rowing Study Informed Consent.pdf

2. Teachers College study one IRB approval renewal letter — 12/07/2019

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB *Continuing Review Approval Notification*

To: Nicholas Parker
From: Myra Luna Lucero Research Compliance Manager
Subject: IRB Approval: 19-070 Protocol
Date: 12/07/2019

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has approved your *continuing* study, entitled "*Exploring the relationship between instructional cues and indoor rowing performance.* " on 12/07/2019.

The approval is effective until **12/06/2020**.

The IRB Committee must be contacted if there are any changes to the protocol during this period. **Please note:** If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by **11/22/2020** so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is **19-070**. Feel free to contact the IRB Office (212-678-4105 or IRB@tc.edu) if you have any questions.

As subject enrollment is complete, no newly stamped copy of the consent form is provided with this continuing approval. You may retrieve a PDF copy of this approval notification from the Mentor site.

As the PI of record for this protocol, you are required to:

- Use current, up-to-date IRB approved documents
- Ensure all study staff and their CITI certifications are on record with the IRB
- Notify the IRB of any changes or modifications to your study procedures
- Alert the IRB of any adverse events

You are also required to respond if the IRB communicates with you directly about any aspect of your protocol. Failure to adhere to your responsibilities as a study PI can result in action by the IRB up to and including suspension of your approval and cessation of your research.

Best wishes for your research work.

Sincerely,
Dr. Myra Luna Lucero
Research Compliance Manager
IRB@tc.edu

3. Teachers College IRB study two approval letter — 02/01/2020

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB	*Expedited Approval Notification*

To: Nicholas Parker
From: Amy Camilleri
Subject: IRB Approval: 20-146 Protocol
Date: 02/01/2020

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "*Instructional Cues and Rowing Performance*," under **Expedited Review** on 02/01/2020: Category (6) Collection of data from voice, video, digital, or image recordings made for research purposes.
(7) Research on individual or group characteristics or behavior

The IRB Committee must be contacted if there are any changes to the protocol during this period. Under the new IRB regulations, continuing review for this study is not required. If you encounter any problems or issues, please contact the IRB office to discuss. When you have completed the study, please terminate using the "Terminate Protocol" button at the top of the view protocol page in Mentor IRB. The IRB number assigned to your protocol is **20-146**. Feel free to contact the IRB Office (212-678-4105 or accamilleri@gmail.com) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp and is attached to this email. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials must include the study's IRB-approved protocol number.

As the PI of record for this protocol, you are required to:

- Use current, up-to-date IRB approved documents
- Ensure all study staff and their CITI certifications are on record with the IRB
- Notify the IRB of any changes or modifications to your study procedures
- Alert the IRB of any adverse events

You are also required to respond if the IRB communicates with you directly about any aspect of your protocol. Failure to adhere to your responsibilities as a study PI can result in action by the IRB up to and including suspension of your approval and cessation of your research.

You can retrieve a PDF copy of this approval letter from Mentor IRB.

When your study ends, please visit the IRB Mentor site. Go to the view protocol page and click on the "Terminate Protocol" button at the top.

Best wishes for your research work.

Sincerely,
Amy Camilleri
IRB Administrator
IRB@tc.edu

Appendix D

Consent Forms

1. Study One Informed Consent

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

Protocol Title: Exploring the relationship between instructional cues and rowing performance on a RowPerfect indoor rowing machine.
Principal Investigator: Nicholas Lee Parker, MS, Teachers College
212-854-4872, n.parker@columbia.edu

INTRODUCTION

You are being invited to participate in this research study called "Instructional Cues and Rowing Performance." You may qualify to take part in this research study because you are actively engaged in regular rowing practice and you have rowed for a period of less than one year or two plus years. Approximately fifty people will participate in this study and it will take 30 minutes of your time to complete.

WHY IS THIS STUDY BEING DONE?

This study is being done to determine if instructional cues affect performance on an indoor rowing machine.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY?

If you decide to participate, you will be asked to choose a time that is convenient for you to meet with the investigators in the Rowing Training Room or a Squash Court in the Dodge Fitness Center to complete the 30 minute process. An investigator will inform you of your rights as a participant. If you agree to continue, you will be guided by the investigator through the rowing portion of the study. Randomly selected participants will be video-recorded. Video files will be stored on a hard drive in the NeuroRehabilitationLab at Teacher's College. After the video is analyzed, it will be deleted. If you do not wish to be video-recorded, you may not participate. You will be asked to fill out a questionnaire upon completing the rowing portion of the study. This will take a total of 30 minutes to complete.

Study tasks specific to the rowing portion start with a. five minute warm up on the rowing machine at a self-selected pace. After the warm up, three trials lasting 45 seconds with three minutes of rest will be conducted. During each trial, the investigator will provide you with a different set of instructions. You are free to withdraw from the study at anytime, including during the trials.

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine physical or psychological examinations as part of your normal rowing routine. Knowledge or your performance scores will not be visible during the trial, nor will they be available to you or any other participant for this study at any time.

However, there are some risks to consider. The principal investigator is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a deidentified code on all materials instead of your name and keeping all information in RedCap, a password protected and encrypted server.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

There is no direct benefit to you for participating in this study. Participation may benefit the field of rowing and coaching education, helping rowers and coaches improve their performance using instructional cues.

The primary investigator is also the head coach of men's lightweight rowing for Columbia University. Participation in this study does not entitle you to any current or future benefits pertaining to tryouts or participation on the men's lightweight rowing team or any other rowing teams or organizations to which the investigator belongs. If you choose (or do not choose) to be in this study, your current student status or role in athletics will not be impacted in any way.

WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid to participate. There are no costs to you for taking part in this study.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS?

The study is over when you have completed the interview and filled out the questionnaire. However, you can leave the study at any time even if you haven't finished.

PROTECTION OF YOUR CONFIDENTIALITY

The investigator will keep all written materials locked in a file cabinet in a locked office. Any electronic or digital information (including audio recordings) will be stored on a computer that is password protected. What is on the video-recording will be analyzed and then the video will be deleted. There will be no record matching your real name with your

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

deidentified code. The master list for the codes will be kept separate from all other information on a password protected computer and destroyed after analysis is complete.

For quality assurance, the study team, the study sponsor (grant agency), and/or members of the Teachers College Office of Sponsored Programs may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

HOW WILL THE RESULTS BE USED?
The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational purposes. This study is being conducted as part of the dissertation of the principal investigator.

CONSENT FOR AUDIO AND OR VIDEO RECORDING
Video-recording is part of this research study. You can choose whether to give permission to be recorded. If you decide that you don't wish to be recorded, you will not be able to participate in this research study.

_____I give my consent to be recorded ____
Signature

_____I **do not** consent to be recorded ____
Signature

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 19-070
Consent Form Approved Until: 12/06/2019

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

WHO MAY VIEW MY PARTICIPATION IN THIS STUDY
(Choose the appropriate description below)

___I consent to allow written, video and/or audio taped materials viewed at an educational setting or at a conference outside of Teachers College ______________________________________
Signature

___I **do not** consent to allow written, video and/or audio taped materials viewed outside of Teachers College Columbia University ____
Signature

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?
If you have any questions about taking part in this research study, you should contact the principal investigator, Nicholas Lee Parker, at 212-854-4872 or at n.parker@columbia.edu. You can also contact the faculty advisor, Dr. Lori Quinn at 212-678-3424.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu. Or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 1002. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

PARTICIPANT'S RIGHTS

- I have read and discussed the informed consent with the researcher. I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.
- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty.
- The researcher may withdraw me from the research at his or her professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the investigator will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- Identifiers may be removed from the data. De-identifiable data may be used for future research studies, or distributed to another investigator for future research without additional informed consent from the subject or the representative
- I should receive a copy of the Informed Consent document.

My signature means that I agree to participate in this study

Print name: ______________________________ **Date**: ____________

Signature: ____

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 19-070
Consent Form Approved Until: 12/06/2019

2. Study Two Informed Consent

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

INFORMED CONSENT

Protocol Title: Instructional Cues and Rowing Performance.
Principal Researcher: Nicholas Lee Parker, MS, Teachers College
212-854-4872, n.parker@columbia.edu

INTRODUCTION
You are being invited to participate in this research study called "Instructional Cues and Rowing Performance." You may qualify to take part in this research study because you are actively engaged in regular rowing practice. Approximately fifty people will participate in this study and it will take 30 minutes of your time to complete.

WHY IS THIS STUDY BEING DONE?
This study is being done to determine if instructional cues affect performance on an indoor rowing machine.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY?
If you decide to participate, you will be asked to choose a time that is convenient for you to meet with the investigators in the Rowing Training Room or a Squash Court in the Dodge Fitness Center to complete the 30 minute process. An investigator will inform you of your rights as a participant. If you agree to continue, you will be guided by the investigator through the rowing portion of the study. Randomly selected participants will be video-recorded. Video files will be stored on a hard drive in the NeuroRehabilitationLab at Teacher's College. After the video is analyzed, it will be deleted. If you do not wish to be video-recorded, you may still participate. You will be asked to fill out a questionnaire upon completing the rowing portion of the study. This will take a total of 30 minutes to complete.

Study tasks specific to the rowing portion start with a. five minute warm up on the rowing machine at a self-selected pace. After the warm up, three trials lasting 45 seconds with three minutes of rest will be conducted. During each trial, the investigator will provide you with a different set of instructions. You are free to withdraw from the study at anytime, including during the trials.

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine physical or psychological examinations as part of your normal rowing routine. Knowledge or your performance scores will not be visible during the trial, nor will they be available to you or any other participant for this study at any time. The data will be kept for the minimum three year period after the study concludes.

However, there are some risks to consider. The principal investigator is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a deidentified code on all materials instead of your name and keeping all information in RedCap, a password protected and encrypted server.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?
There is no direct benefit to you for participating in this study. Participation may benefit the field of rowing and coaching education, helping rowers and coaches improve their performance using instructional cues.

The primary investigator is also the head coach of men's lightweight rowing for Columbia University. Participation in this study does not entitle you to any current or future benefits pertaining to tryouts or participation on the men's lightweight rowing team or any other rowing teams or organizations to which the investigator belongs. If you choose or do not choose to be in this study, your current student status or role in athletics will not be impacted in any way.

WILL I BE PAID FOR BEING IN THIS STUDY?
You will not be paid to participate. There are no costs to you for taking part in this study.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS?
The study is over when you have completed the post-study questionnaire. However, you can leave the study at any time even if you haven't finished.

PROTECTION OF YOUR CONFIDENTIALITY
The investigator will keep all written materials locked in a file cabinet in a locked office. Any electronic or digital information (including audio recordings) will be stored on a computer that is password protected. What is on the video-recording will be analyzed and then the video will be deleted. There will be no record matching your real name with your deidentified code. The master list for the codes will be kept separate from all other information on a password protected computer and destroyed after analysis is complete.

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

For quality assurance, the study team, the study sponsor (grant agency), and/or members of the Teachers College Office of Sponsored Programs may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

HOW WILL THE RESULTS BE USED?

The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational purposes. This study is being conducted as part of the dissertation of the principal investigator.

CONSENT FOR AUDIO AND OR VIDEO

Video-recording is part of this research study. You can choose whether to give permission to be recorded. If you decide that you don't wish to be recorded, you will still be able to participate in this research study.

______I give my consent to be recorded ____
Signature

______I **do not** consent to be recorded ____
Signature

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

WHO MAY VIEW MY PARTICIPATION IN THIS STUDY

___I consent to allow written, video and/or audio-recorded materials viewed at an educational setting or at a conference outside of Teachers College, Columbia University

____
Signature

___I **do not** consent to allow written, video and/or audio-recorded materials viewed outside of Teachers College, Columbia University

____
Signature

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?

If you have any questions about taking part in this research study, you should contact the principal investigator, Nicholas Lee Parker, at 212-854-4872 or at n.parker@columbia.edu. You can also contact the faculty advisor, Dr. Lori Quinn at 212-678-3424.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu. Or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 1002. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
525 West 120th St. New York, NY 10027
212-678-3000 | www.tc.columbia.edu

PARTICIPANT'S RIGHTS

- I have read and discussed the informed consent with the researcher. I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.
- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty.
- The researcher may withdraw me from the research at his or her professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the investigator will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- Identifiers may be removed from the data. De-identifiable data may be used for future research studies, or distributed to another investigator for future research without additional informed consent from the subject or the representative
- I should receive a copy of the Informed Consent document.

My signature means that I agree to participate in this study:

Print name: ______________________________ **Date**: ____________

Signature: ____

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 20-146
Consent Form Approved Until: No Expiration Date

Appendix E

Demographics and Questionnaire

Confidential

Rowing Instructions Study Demographics

Please complete the survey below.

Thank you!

1) Identifier (Investigator Use Only)

____
(Please Print)

2) Date of Birth (MM/DD/YY)

____

3) The pronouns I use are:

☐ he/his
☐ she/her
☐ they/their
☐ Other

4) I identify my ethnicity as:
(Select all that apply)

☐ Asian
☐ Black/African
☐ Caucasian
☐ Hispanic/Latino
☐ Native American
☐ Pacific Islander
☐ Prefer not to answer
☐ Other

5) Total Height in CM

____
(Researcher can assist with all height measurements)

6) Height from Floor to Knee

____

7) Height from Floor to Hip

____

8) Weight in KG

____

9) Choose the answer that best describes how long you have been regularly participating in rowing?

◯ 6 Months or Less
◯ 6 Month to 1 Year
◯ 1 to 2 Years
◯ 2 to 4 Years
◯ 4 to 6 Years
◯ 6 to 10 Years
◯ 10+ Years

10) Briefly describe your rowing experience in one or two sentences.

____
(i.e. Physical Education Rowing Class, Novice Rowing on a University Team, Club Rowing, National Team Rowing, etc.)

11) How many hours a week do you typically spend exercising? (Include rowing and any other physical activity you do).

◯ 0-2 Hours
◯ 2-4 Hours
◯ 4-6 Hours
◯ 6+ Hours

12) What is the highest level of athletic competition you have achieved in any sport or athletic activity?

◯ Do not know/Do not compete
◯ High School Junior Varsity Team
◯ High School Varsity Team
◯ High School District Champion
◯ High School State Champion
◯ High School National Champion
◯ Junior National Team
◯ Elite (World Championships/Olympics) Competition
◯ World or Olympic Medalist

13) What is the highest level of athletic competition you have achieved in rowing?

◯ Do not know/Do not compete
◯ High School Junior Varsity Team
◯ High School Varsity Team
◯ High School District Champion
◯ High School State Champion
◯ High School National Champion
◯ Junior National Team
◯ Elite (World Championships/Olympics) Competition
◯ World or Olympic Medalist

14) I have reviewed the Informed Consent document with the investigator and agreed to participate of my own volition. I understand that I may withdraw from the study at anytime without penalty.

◯ Yes
◯ No

15) Sign below to verify that the above information is accurate to the best of your knowledge.

____

Confidential

Rowing Instructions Study Post-Test Questionnaire

Please complete the survey below.

Thank you!

1) Identifier (Investigator Use Only)

____
(Please Print)

2) On a scale of 1 to 10, with 1 being easy and 10 being hard, how challenging did you find the physical component of the study?

◯ 0 - Nothing at all
◯ 1 - Very light
◯ 2 - Fairly light
◯ 3 - Moderate
◯ 4 - Somewhat hard
◯ 5 - Hard
◯ 6
◯ 7 - Very hard
◯ 8 -
◯ 9 -
◯ 10 - Very, very hard (Maximal)

3) Were you able to focus on your legs when asked to for one of the trials?

◯ Yes ◯ No

4) Were you able to focus on the flywheel when asked to for one of the trials?

◯ Yes ◯ No

5) On what did you focus during the trial where you were not provided a specific focus?

____

6) On a scale from 1 to 10, with 1 being easy and 10 being hard, how challenging was it to row between 24 and 26SPM during the trials?

◯ 0 - Very, very easy
◯ 1 - Very easy
◯ 2 - Fairly easy
◯ 3 - Moderate
◯ 4 - Somewhat hard
◯ 5 - Hard
◯ 6
◯ 7 - Very hard
◯ 8 -
◯ 9 -
◯ 10 - Very, very hard (Maximal)

7) Is there any information you feel the investigators should know concerning your participation or experience during the study?

____

8) Thank you! Please sign to verify the above answers are correct to the best of your knowledge and recall.

____