Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 2 (2010) 2555–2561
Procedia Engineering
www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

An Ergometer Based Study of the Role of the Upper Limbs in the Female Rowing Stroke

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Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

Abstract

Optimisation of the rowing technique is of paramount importance in improving performance and minimising injury risks. This report aims to investigate and compare arm kinematics between two commonly used commercial gymnasium rowing ergometers; five female amateur rowers were tested on the Concept2™ and the RowPerfect™. Qualisys™ (Sweden) motion analysis system was used to measure stroke kinematics. Results indicate that subjects on the Concept2™ tended to 'jerk' (impulse load) the handle during the rowing stroke in an attempt to achieve greater power. Arm kinematics indicate that the RowPerfect™ appears to be more effective for recreational users compared to the Concept2™.

Keywords: Rowing; Ergometer; Concept2; RowPerfect; Upper Limbs; Female Rowing Stroke

1. Introduction

Optimisation of the rowing technique is of paramount importance in improving performance and minimising injury risks. Within the sport some research has been undertaken to analyse the rowing stroke, Bull and McGregor (2000)[1], O'Sullivan *et al* (2003)[2] & Steer *et al* (2005)[3]. It should be investigated whether the optimum rowing performance for injury reduction is dictated by a technique that can be replicated.

Although there has been considerable interest in elite level rowing biomechanics, this does not extend to the study of recreational or amateur users of ergometers, as observed in gymnasiums across the UK. Rather than using ergometers to practice and perfect the rowing technique that can be used on water, the majority of recreational users are focused on the fitness aspect. Clearly a significant number of these people have never been out in a racing boat and rely purely on Gym based guidance. Many of the people, who use the ergometers, do so with little or no proper instruction. Also, the everyday user tends to be less conditioned compared to a professional rower. Work has been conducted (Bull and McGregor (2000)[1]) to outline the biomechanics of an "ideal stroke", however, due to the lack

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doi:10.1016/j.proeng.2010.04.031

of water interaction, these phases may not be present for an ergometer. From a definition of a correct rowing procedure it may be possible to analyse a rowing stroke and explore and quantify the deficiencies in that stroke.

The majority of previous work has investigated the back and pelvis of elite rowers. Bull and McGregor (2000)[1] analysed technically incorrect strokes, showing that as fatigue sets in, the lumbo-sacral angle showed greater variation than other rowing techniques, due less control of pelvic rotation. The 'bum shoving technique' held the spine in the neutral upright position; leading to the conclusion that it is more difficult to apply the power through the core.

O'Sullivan *et al* (2003)[2] conducted further work, modelling multivariate biomechanical measurements of the spine during a rowing exercise. They found that rowers with a very sharp (impulse) or heavy catch tend to have a higher probability of Lower Back Pain (LBP). A sharp catch is related to the onset of force applied at the handle; a rower who applies force very quickly may not have the postural control in the trunk to control the transfer of that force from the hands through the kinematic chain to the trunk and then the feet, and thus may develop LBP. This in turn would lead to a lack of boat control. For a non-professional rower a 2000m ergometer session can last for at least 7 minutes, with an average rate of 30 strokes per minute, this means that in each session the subject will undergo approximately 200 strokes. This information highlights the importance of utilising the correct rowing technique; where an incorrect stroke reproduced over many repetitions has a potentially greater risk of injury.

Studies have been conducted to investigate the role of the back and spine in the elite-rowing stroke. However, that is only one part of the kinematic chain that is made up of a number of parameters. This report aims to investigate the role of the arms within that kinematic chain, for amateur subjects that use rowing ergometers. Five female subjects were tested on two of the UK's most commonly used gymnasium based ergometers – Concept2™ and RowPerfect™. This paper provides a direct comparison between the two ergometers and can be used to show bad practice on each. This information can be used to detect possible potential for injury and help in the development of a dynamic model that can be used to improve the stroke.

Work has been conducted in form of an ergometer comparison, Bernstein *et al* (2002)[4] concluded that they 'would expect that changing to a floating power head ergometer would reduce injuries attributable to ergometer training.'[4]

2. Methods

2.1. Equipment

Tests were conducted using one of two types of rowing ergometer; a Concept2™ and a RowPerfect™. Concept2™ is the most common type of ergometer in the UK, it is used in gyms and rowing clubs, by all standards of rower. The RowPerfect™ ergometer is less common than the Concept2™, but it is claimed to be the most advanced available, to emulate 'on-water' rowing. It is not a fixed head ergometer, which means that, the footplate with the head unit (17Kg) and the seat are both mounted on the slide, and thus move independently, the manufacturers claim that this simulates the movement of a boat more closely than any other ergometer[4],[5].

Qualisys™ of Sweden, motion analysis system was used to capture the subjects' movements throughout a number of rowing strokes. The system used in this study utilised passive markers and 8 infrared light emitting cameras. Markers were placed on the test subject and then reproduced digitally. The system was set to record movement at 60 frames per second. After the tests the saved file was processed using Qualisys™ Track Manager (QTM), thus enabling each frame to be viewed individually, each frame displays the markers used for variable calculation (see Table 1). Digital video cameras were also used for a visual record of the different tests.[6]

2.2. Subjects

Five injury free female subjects with informed consent (aged 21 ± 3 years) were tested on both ergometers; their ability level corresponded to that of an amateur user. Both ergometers were set to a consistent resistance for the entire testing period. Each subject had a five-minute warm-up, followed by the main test period, which lasted for four minutes at a continuous stroke rate of 32 strokes per minute. The 20^{th} stroke was measured, and every 10^{th} stroke after that until the 120^{th} stroke. The period between strokes 1-19 gives the subject chance to get used to the ergometer and gain a rhythm. The test subject was prepared by placing reflective markers (Table 1), on numerous bony landmarks and on the ergometer. It is acknowledged that reflective markers applied to the skin move relative to underlying skeletal structures; therefore some of the recorded movement may be subject to skin movement artefacts.

Table 1. The position of the retro-reflective markers used with the Qualisys™ system.

Marker Positions on the Body	
1. Top of the footplate (ergometer)	13. 10th thoracic vertebrae (T10)
2. Bottom of the footplate (ergometer)	14. 12th thoracic vertebrae (T12)
3. Front of the slide (ergometer)	15. 2nd lumbar vertebrae (L2)
4. Rear of the slide (ergometer)	16. 4th lumbar vertebrae (L4)
5. Toe of the Trainer	17. Shoulder Joint
6. Slide of the heel of the trainer	18. Upper Humerus
7. End of ergometer handle	19. Lower Humerus
8. 7th cervical vertebrae (C7)	20. Upper Ulna
9. 2^{nd} thoracic vertebrae (T2)	21. Lower Ulna
10. 4th thoracic vertebrae (T4)	22. Fifth Metacarpal bone
11. 6th thoracic vertebrae (T6)	23. Head
12. 8th thoracic vertebrae (T8)	

The relevant markers were selected and angles and angular velocities were calculated using QTM. These results were then exported to Microsoft™ Excel, where they were graphically analysed and tabulated. The upper arm-torso angle was calculated using the intersect angle between markers 8 & 14 and 18 & 19. The upper arm-forearm angle was calculated using the intersect angle between markers 18 & 19 and 20 & 21. The elbow joint velocity was calculated using marker 20. Each recorded stroke started from the catch phase, passing through the drive phase to the finish and then through recovery back to catch. The catch phase (Figure 1) is the point which represents the blade being placed into the water. The head is held high and the shoulders are positioned over the hips, with the back, elbows and wrists extended. The hips knees and ankles are all flexed. The finish stage (Figure 1) is where the arms are pulled through and the shoulders are behind the hips. The hips, knees, wrists and elbows remain extended along with further extension of the back.[6]

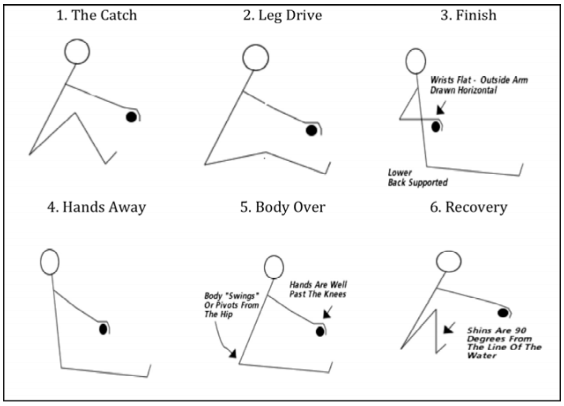

Fig 1. The different phases of the rowing stroke

3. Analysis & Results

3.1. Upper Arm-Torso Angle

As the stroke progresses from the catch through to the finish, the angle between the upper arm and the torso, as seen in Figure 2 (a), decreases before increasing again as the subjects are in the recovery phase. As shown in Figure 2 (a) the curve for the Concept2™ subjects has two troughs at the finish stage (indicated by arrows), and in general the majority of the curve for the RowPerfect™ appears generally smoother.

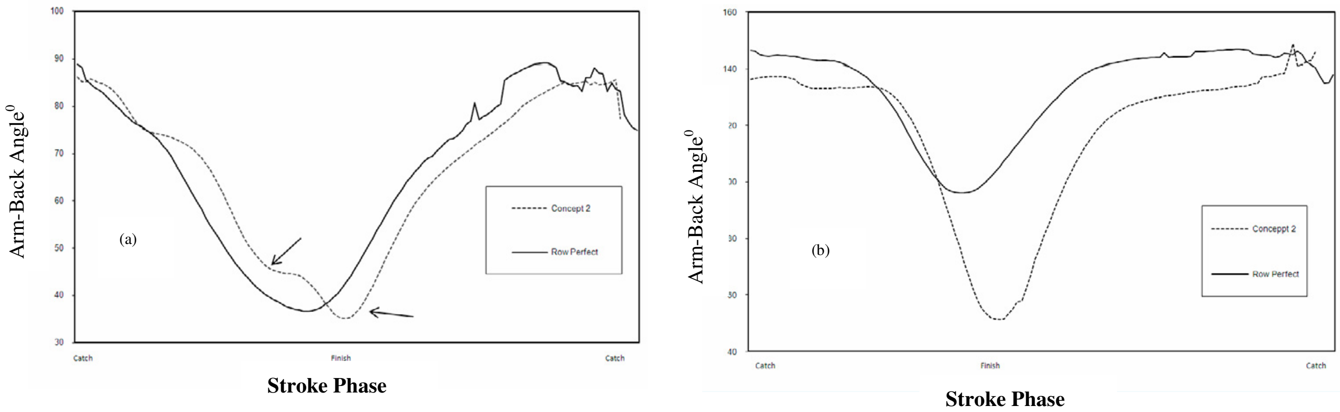

Fig 2. (a) The Results for average upper arm- torso angle (markers 8, 14, 18 & 19) for both the Concept and RowPerfect ergometers; (b) The Results for average upper arm-forearm angle (18, 19, 20 & 21) for both ergometers

3.2. Upper Arm-Forearm Angle

The angle between the upper and lower arm, as seen in Figure 2 (b), decreases as the stroke moves into the finish stage. The Concept2™ tests result in a much more acute angle at the finish stage and the RowPerfect™ gives results with much straighter arms at the catch phase of the stroke. Also, the catch phase seems to be longer on the RowPerfect™, as the point where the angle is lowest continues for longer.

3.3. Elbow Joint Velocity

Individual results, for elbow velocity on the Concept2™ (seen in Figure 3 (a)) are very similar, with an increasing velocity leading to a plateau and then decrease. This, however, is not the case for the RowPerfect™ tests (seen in Figure 3 (b)), there is greater variation between subjects and there is no plateau in velocity, which has a more gradual increase before decrease.

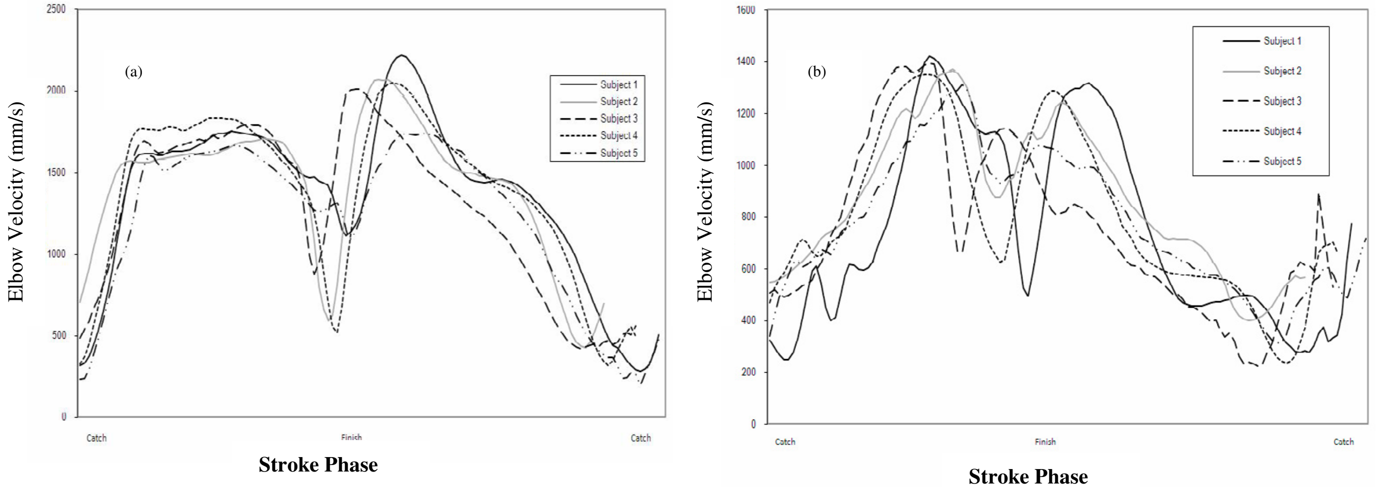

Fig 4. (a) Individual Concept2^{TM} results for elbow joint velocity; (b) Individual RowPerfect^{TM} results for elbow joint velocity

In general, the results shown in Figure 4 would seem to indicate that following the catch phase there is an initial rise in elbow velocity, which plateaus and decreases before reaching the finish stage of the stroke, where the is a decrease in velocity. At the finish stage there is an immediate rise in velocity to a maxima. The velocity then decreases through the recovery stage. The results for the Concept2^{TM} provide higher velocities throughout the stroke and there appears to be greater definition of each of the phases. This is demonstrated where the RowPerfect^{TM} has no plateau, where the speed is constant; the velocity is constantly increasing or decreasing.

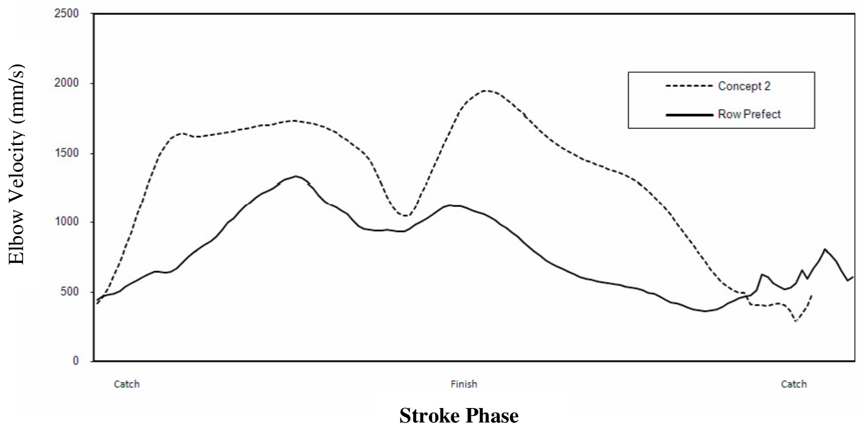

Fig 5. Results for the average elbow joint velocity for both ergometers

4. Discussion

The angle between the upper arm and the back is very similar for both ergometers, but the curve for the Concept2^{TM} does have two troughs at the finish (Figure 2 (a)). This is not just an artefact of averaging the data, as all of the individual subject curves also have two troughs. Suggesting that the arms are being pulled back as normal before an extra pull on the handle to bring the arms tighter in to the body and thus, indicating that the subject is trying to apply extra power to the handle. This 'jerking' (impulse) motion could have a greater injury potential and may be less biomechanically efficient. It has been previously suggested by O'Sullivan *et al* (2003)[2] that a smooth application of power is the best approach. This could attribute to a 'wishing well' technique where the handle is pulled up and over the legs, which aren't fully extended. Additional 'unwanted' effort is more likely to increase the risk of injury. Figure 2 (a) would also suggest that at the catch stage the upper-arms are perpendicular to the torso, analysis of Figure 2 (b) (the upper-lower arm angles) confirms that the upper arm may be perpendicular to the torso, but it appears that the elbow joint is flexed. The fact that the arms are not fully extended may reduce the likelihood of injury; there will be less strain on the arms as the potential range of motion is not achieved. It may also be the case that for 'less-able' rowers, it is easier to apply power with bent arms.

Throughout the entire stroke the RowPerfect™ comparatively produces straighter arms than the Concept2™ (Figure 2 (b)). This would indicate that the arm is being pulled back further, thus giving an increased range of motion. The arms for the Concept2™ do not fully extend, indicating that like the RowPerfect™ the arms are not being used to their full potential, this is less so for the Concept2™, which produces a wider range of motion. As before moving the arms more than necessary is more likely to increase the risk of injury. Following the catch phase, there is an initial rise in elbow velocity (Figure 4). This demonstrates the catch and leg drive phases of the stroke. The velocity then begins to decrease towards the finish stage, where the arms are at their tightest. The increase that follows is due to the arms accelerating away from the body, before decelerating through the recovery stage to the catch. The Concept2™ has a very sharp initial velocity followed by an area of constant velocity before decreasing at the finish stage, where as the RowPerfect™ gives a continuous increase in velocity. Before the decrease there is no area of constant velocity. Therefore it can be suggested that on the Concept2™ there is a sharp (impulse) tug on the handle, following the catch, before being pulled smoothly through to the finish stage. This means that there is no constant smooth application of power, which goes against the rational of an ideal stroke, O'Sullivan *et al* (2003)[2]. This also conforms to the 'jerking' action on the Concept2™ (where there is a more rapid acceleration), which does increase the potential for injury to the arms and back. However, the fast increase in the elbow velocity may also be attributed to the greater slip of the chain over the flywheel axis on the concept2 ergometer at the beginning of the catch in combination with a higher amount of inertia forces acting on the athletes body. Compared to the RowPerfect™, the Concept2™ produces much higher velocities throughout the stroke; this may not necessarily be an advantage. Higher arm velocities may mean that the stroke is less co-ordinated and controlled leading to a technically poor stroke. The RowPerfect™ has a more constant velocity throughout, indicating greater coordination and control and it can be argued that for amateurs this is a very important first step as opposed to being the fastest. It should also be remembered that the ergometers have different inertial loading characteristics, only the Concept2™ is a fixed head ergometer. The floating head unit may make it harder to have straighter arms on the RowPerfect™. The individual elbow joint velocities for the Concept2™ across the five subjects indicate that the Concept2™ allows for easier stroke repetition for different people. The RowPerfect™ has a more varied range of results, indicating that it may be more difficult to implement the same stroke repeatedly.

5. Conclusions

From the study, the results suggest that on the Concept2™ the subjects are 'jerking' the handle back prior to the finish stage, in an attempt to gain greater power. This produces a greater chance of injury and is actually less efficient. The amateur rower needs careful instruction to highlight the importance of achieving a repeatable stroke, which will maximise their effort and ultimately build their power output, as opposed to initially maximising their power output in a manner that could be both inefficient and injurious. One of the main problems identified was the fact that the subjects were not straightening their arms as much as they could have. This confirms that 'jerking' was produced and also suggests that there is potentially a greater rotation at the shoulder joint than is required. It may be the case that the injury potential is reduced due to less arm movement, any unwanted movement or over extension of the arm, may increase the chance of injury, due to the further ranges of motion achieved.

The sharp increase in velocity for the Concept2™ can be used to indicate that the subjects are applying a sharp (impulsive) tug on the handle, following the catch, before being pulled smoothly through to the finish stage. This means that there is no constant smooth application of power. Higher arm velocities may mean that the stroke is less co-ordinated and controlled, leading to a technically poor stroke, which has a greater injury potential. This is the case for the Concept2™ over the RowPerfect™.

Recreational use of ergometers across the country is increasing and it is imperative that the correct technique is taught and implemented. The RowPerfect™ appears to provide results, for arms, that would be more effective than the Concept2™, backing up the theory of Bernstein *et al* (2002)[4], that 'a floating power head ergometer would reduce injuries attributable to ergometer training.'[4]. However, as with previous work, this paper concentrates solely on one parameter and a true judgement cannot be made until the whole kinematic chain has been investigated.

Acknowledgements

We would like to thank Dr. Alison McGregor of Imperial collage London; who provided feedback throughout the project, and suggested possible research areas. Also to Barry Lovern; who demonstrated the use of the motion analysis system and to Penny Challens who was always willing to give advice on rowing technique and procedure.

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