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The Influence of a Three Week Familiarisation Period on Rowing Mechanics at a New Stretcher Position

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Abstract. The height of the foot plates (stretchers) in rowing have been shown, both theoretically and experimentally, to significantly influence the effectiveness of the rowing stroke. However, the extent to which increasing this height can improve rowing performance, through musculo-skeletal adaptations, is not yet known. The aims of the present investigation were to determine the influence of a three week familiarisation period on rowing performance at a raised stretcher height. Nine male rowers performed a 3.5 minute maximal intensity ergometer trial before and after familiarisation. Mean power per stroke significantly increases during the first, middle and last ten strokes of the trial, post-familiarisation. This increase in mean power per stroke was due to increases in both mean handle force and velocity. The results of the study suggested that a musculo-skeletal adaptation to this new stretcher position had occurred with familiarisation, leading to improved performance. Determination of an ideal stretcher height for maximum mechanical effectiveness was not possible here, as this would be specific to each individual rower, and must take into consideration the balance of the boat and the extra energy required to maintain balance as stretcher height is increased. However, the importance of determining this height is now clearly understood.

Keywords: Rowing Mechanics, Rowing Performance, Stretcher Height.

1. Introduction

The aim in rowing is to maintain a high mean boat velocity in order to complete a race distance, typically of 2000m, in the shortest time possible (Schneider and Hauser, 1981). For this to be achieved, the rower must apply substantial forces to the boat during a complex sequence of movements. During the drive phase of the stroke, when the oar blades are submerged, the rowers powerfully extend their legs, generating a large force at the foot stretchers (Figure 1). Through the maintenance of trunk posture, the horizontal component of this force is transferred to the oar handle which causes the oar shaft to rotate about the oarlock, generating movement of the oar blade through the water, resulting in a fluid force that is used to propel the boat (Figure 2).

There are many positional factors that will influence the effectiveness of transmitting musculo-skeletal forces to the water. These include the position of the rower within the boat, which is influenced by the height differential between the seat and foot stretchers, the position of the oar relative to the boat and rower, which can be changed through adjustment of the inboard and outboard lengths of the oar shaft, the height of the oarlock, and finally the design of oar blade used.

Caplan and Gardner (2005) recently investigated the influence of the height of the foot stretchers relative to the sliding seat in ergometer rowing, since ergometers provide a simple way to replicate the movements seen in on-water rowing (Hagerman, 1984; Lamb, 1989; Nelson and Widule, 1983). It was shown that by increasing the height of the foot stretchers, the rate of fatigue during a three and a half minute maximal effort trial could be reduced. By raising the height of the stretchers, a more mechanically effective position of the lower limbs could be achieved, and the line of force through the stretchers became closer to the horizontal, thus reducing the vertical force component which acts simply to lift the rower away from the seat (Figure 3).

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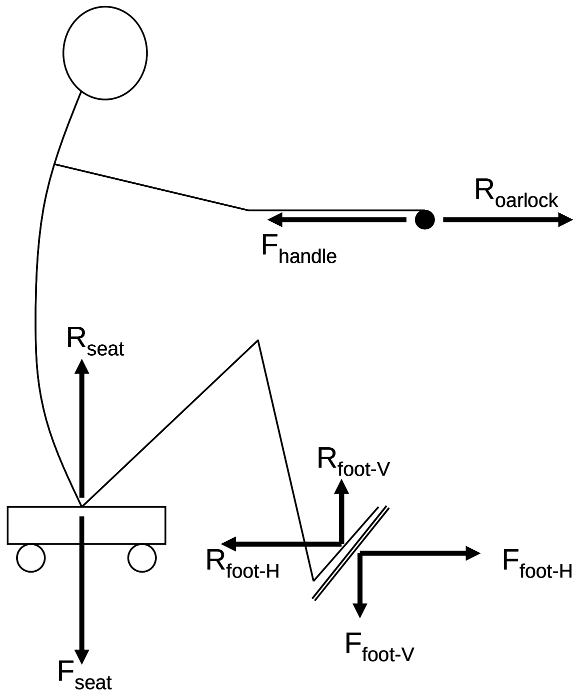

Figure 1. Forces applied to the boat by the rower during the drive phase in rowing and the resulting reaction forces are shown. The horizontal seat forces are ignored, as they are assumed to be negligible, and the handle forces are shown to be horizontal, although in practice a small vertical component of force should be present in on-water and ergometer rowing.

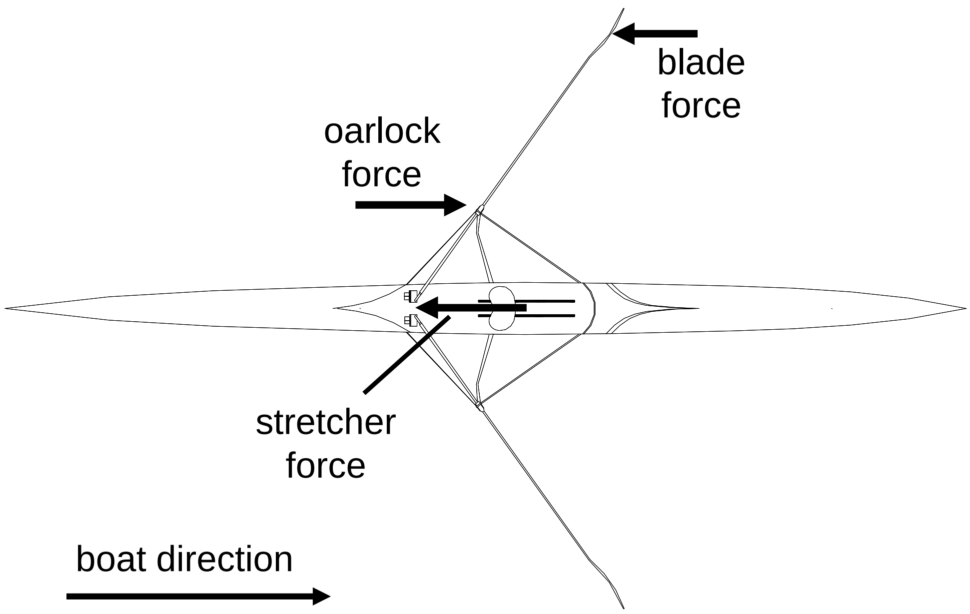

Figure 2. Plan view of a single scull, indicating the kinetic chain used to transfer stretcher force to propulsive force during the drive phase of the stroke.

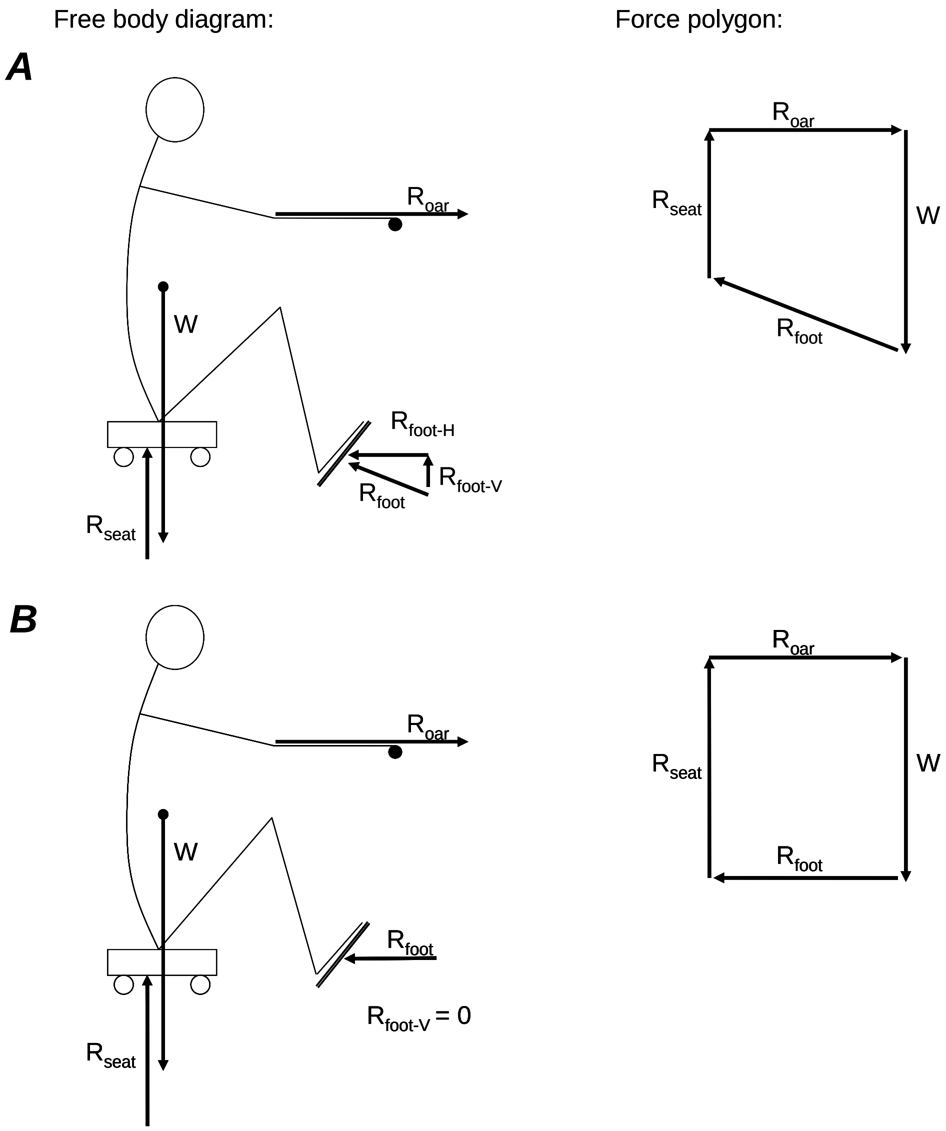

Figure 3. (A) Free body diagram and force polygon for the normal ergometer foot stretcher position, where the height of the stretcher is below that of the seat. This height differential generates a body lifting force of Rfoot-V which is the vertical component of the force Rfoot which is illustrated in the force polygon. (B) Free body diagram and force polygon are shown for an "ideal" stretcher position. The reaction force, Rfoot, at the stretcher is horizontal so no effort is wasted in lifting the body away from the seat (ie. Rfoot-V = 0). More force is therefore available for propelling the boat.

However, Caplan and Gardner (2005) only provided a four minute warm up period was for subjects to familiarise themselves with each new position, which was unlikely to be sufficient to overcome the level of familiarisation of the subjects at the lowest stretcher height, due to their regular training at that height. Taking this into consideration, the significant reduction in the rate of fatigue as stretcher height increased suggested that if subjects were familiar with the new stretcher position, a further improvement of the mechanical effectiveness of the rowing stroke might be achieved. Due to the lack of familiarisation to the new stretcher heights, the previous study was only able to determine the influence of raising the stretchers on the rate of fatigue, and not the overall implications on power production.

The aim of the present investigation was therefore to determine the influence of a familiarisation period on the power generated and rate of fatigue at an increased stretcher height. This would more accurately indicate the potential of increasing the height of the stretchers to improve the mechanical effectiveness of the rowing stroke. With some elite rowing coaches now using raised stretchers with their crews, the results of this study combined with those of the previous investigation (Caplan & Gardner, 2005) could have significant practical implications for rowers and coaches.

2. Method

Nine male senior club rowers, who had a mean (±SD) age, height and mass of 20.2 years (±1.6 years), 1.84 m (±0.05 m) and 83.6 kg (±8.0 kg), respectively, took part in this study. All subjects gave written informed consent, and ethical approval was granted by the local ethics subcommittee. Subjects were accustomed to at least 6 sessions a week of ergometer rowing training, as well as multiple on-water sessions and gym sessions.

A Concept 2 model C rowing ergometer (Concept 2, Morrisville, VT) was used in the investigation. The drag factor, as displayed by the display of the ergometer, remained between 135-138 which the subjects reported as being the range in which they would normally train. Force applied to the handle was measured using a 5 kN axial load cell (F256, Novatech Measurements Ltd., St. Leonards on Sea, UK) which was inserted in series between the handle and the chain of the ergometer. The load cell had a linearity of 0.05% and a hysteresis of 0.05%. Handle velocity was measured using a DC tachometer (263-6005, RS Components, Corby, UK). The tachometer enabled measurement of the rotational velocity of the ergometer chain sprocket, which had a pitch diameter of 0.0283 m, from which linear handle velocity was calculated at a resolution of 0.07%. Both force and velocity signals were sampled at 50 Hz and passed through a 12-bit resolution analogue-to-digital converter (KPCI-3101, Keithley Instruments, Cleveland, OH) and stored on a PC for later analysis.

The foot stretchers of the ergometer were modified such that they were raised by 0.1 m on the same inclined surface as the original stretcher (Figure 5), as done previously (Caplan and Gardner, 2005). This meant that the stretchers were, in effect, raised vertically by 0.068 m. The foot was held in place using the original Concept 2 foot cradle and strap.

Each subject was required to attend an initial pre-familiarisation testing session, followed by six familiarisation sessions spread out evenly over three weeks, during which time they were instructed not to alter their normal training. They were then asked to attend a final post-familiarisation testing session. Stretcher height was in the raised position for both experimental trials and all familiarisation sessions. At the start of each testing session, subjects performed a 4 minute warm up, in which they rowed at 18 strokes.minute^{-1}. Three 5 second bursts of higher intensity effort were performed during the last minute of the warm up period. During the next four minutes, subjects performed static stretching. Subjects were then instructed to row with maximal effort for a period of 3 minutes 30 seconds at 30 strokes.minute^{-1} as used previously by Caplan and Gardner (2005), during which time handle force and velocity data were collected.

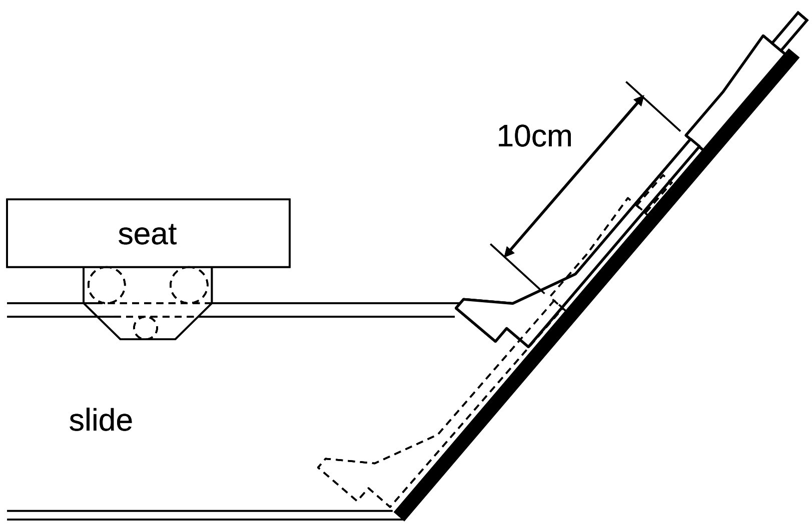

Figure 4. The position of the foot stretcher is shown relative to the original ergometer stretcher position. The stretcher was raised 0.1m on the same plane as the original stretcher.

Handle force and velocity outputs were sampled continuously throughout each trial, and stroke rate was indicated to subjects by the PM2+ display of the ergometer. Subjects were verbally encouraged to maintain both maximal effort and the requested stroke rate throughout each of the pre and post familiarisation trials, and all were blind to the purpose of the investigation. During the familiarisation period, subjects rowed at the new stretcher position for a duration of 15 minutes on each visit, at a stroke rate of 20 strokes.minute^{-1}.

Subjects were not required to row with maximal effort during these sessions and handle force and velocity were not recorded. All subjects reported that the volume of rowing required during the familiarisation sessions was much less than their normal volume and frequency of training, and they indicated that the required stroke rate used was similar to that they often used during regular training.

Power, P_{rower}, applied by the rowers to the handle during each testing session was calculated by,

$$P_{rower} = P_{handle} \times V_{handle} \tag{5}$$

where F_{handle} is the force applied to the oar handle and V_{handle} is the velocity of the oar handle. Mean power per stroke was then given as the mean of the power data during the drive phase of each stroke.

The last 100 strokes of each trial were identified for data analysis. This allowed an initial 10 second period for subjects to reach the required stroke rate. Two subjects stopped just before the end of the trial duration. Therefore, the last three strokes were also discarded from all trials to avoid any erroneous influence these two subjects might have on the outcome of the study. Three analysis periods during the remaining strokes identified for each trial were defined (the first ten strokes; the middle ten strokes; the last ten strokes), and the mean power per stroke was calculated for each of the three analysis periods. A 2 condition (time) x 3 interval (analysis period) two-way analysis of variance with repeated measures was performed to determine whether a significant interaction was present between time (pre-/post-familiarisation) and analysis period for mean power per stroke, mean handle force per stroke, and mean handle velocity per stroke. If a significant interaction was observed between variables, simple analysis of variance with repeated measures, post hoc *Tukey*, were carried out to identify where these significances occurred. A 95% confidence level was used throughout.

3. Results

Seven of the nine subjects completed the study successfully, with two withdrawing for personal reasons. Mean stroke rate for all subjects was maintained at 30.5 ± 0.9 strokes.min^{-1} and 30.7 ± 0.2 strokes.min^{-1} for the pre- and post-familiarisation conditions, respectively.

Mean (± *SD*) values for mean power per stroke, mean handle force per stroke, and mean handle velocity per stroke are shown in Table 1. A significant interaction was observed between time (pre-/post-familiarisation) and analysis period ($F(2,68) = 8.159$, $p = 0.000$). Post hoc tests revealed that the subjects were shown to have fatigued in both experimental trials as indicated by a significant reduction in mean power per stroke between the first and last analysis periods for both pre-familiarisation ($p < 0.01$) and post-familiarisation ($p < 0.01$).

Table 1. Mean (± *SD*) values for mean power per stroke, mean force per stroke and mean velocity per stroke, for all subjects during each analysis period.

	Pre-familiarisation	Post-familiarisation
Mean power (W)		
First 10 strokes	751.8 ± 7.7	815.8 ± 12.5
Middle 10 strokes	592.4 ± 18.0	683.4 ± 10.5
Last 10 strokes	535.8 ± 10.5	624.8 ± 6.7
Mean force (N)		
First 10 strokes	373.2 ± 4.0	403.0 ± 5.4
Middle 10 strokes	322.3 ± 8.0	358.7 ± 4.0
Last 10 strokes	303.4 ± 5.3	338.3 ± 2.8
Mean velocity (m.s^{-1})		
First 10 strokes	1.472 ± 0.007	1.524 ± 0.008
Middle 10 strokes	1.420 ± 0.009	1.501 ± 0.003
Last 10 strokes	1.409 ± 0.004	1.476 ±0.005

Figure 6 clearly illustrates this significant reduction in mean power per stroke throughout both trials. It can also be seen that a higher mean power per stroke was achieved throughout the entire duration of the trial after three weeks of familiarisation. Post hoc analysis showed this increase to be significant in the first ($p < 0.01$), middle ($p < 0.01$) and last ($p < 0.01$) analysis periods.

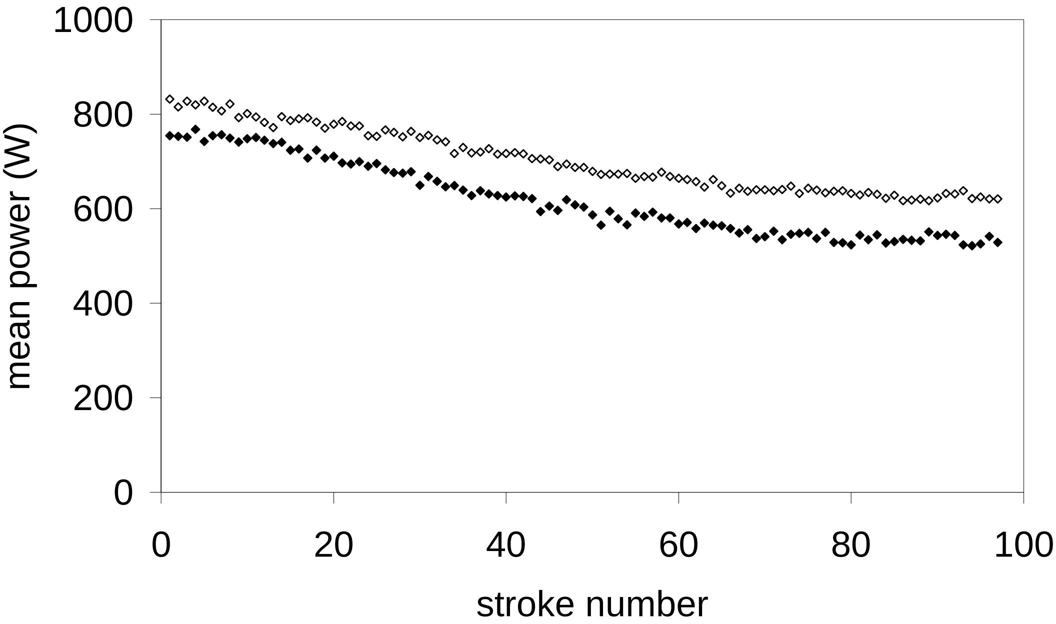

Figure 5. Mean power per stroke for all subjects is shown for pre- (♦) and post-familiarisation (◊) conditions.

The significant increase in mean power per stroke observed between pre- and post-familiarisation conditions (Figure 6) was shown to be due to significant increases in both the mean force per stroke applied to the oar handle at the start ($p < 0.01$), middle ($p < 0.01$) and end ($p < 0.01$) of the trial (Figure 7) and the linear velocity of the oar handle at the start ($p < 0.01$), middle ($p < 0.01$) and end ($p < 0.01$) of the trial (Figure 8).

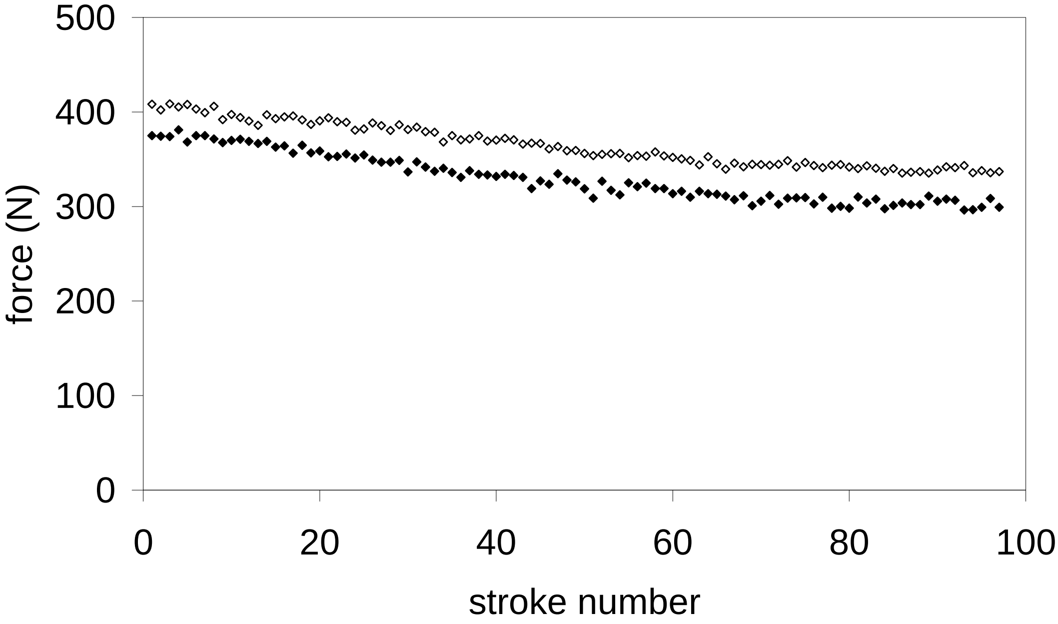

Figure 6. Mean force per stroke applied to the oar handle for all subjects is shown for pre- (♦) and post-familiarisation (◊) conditions.

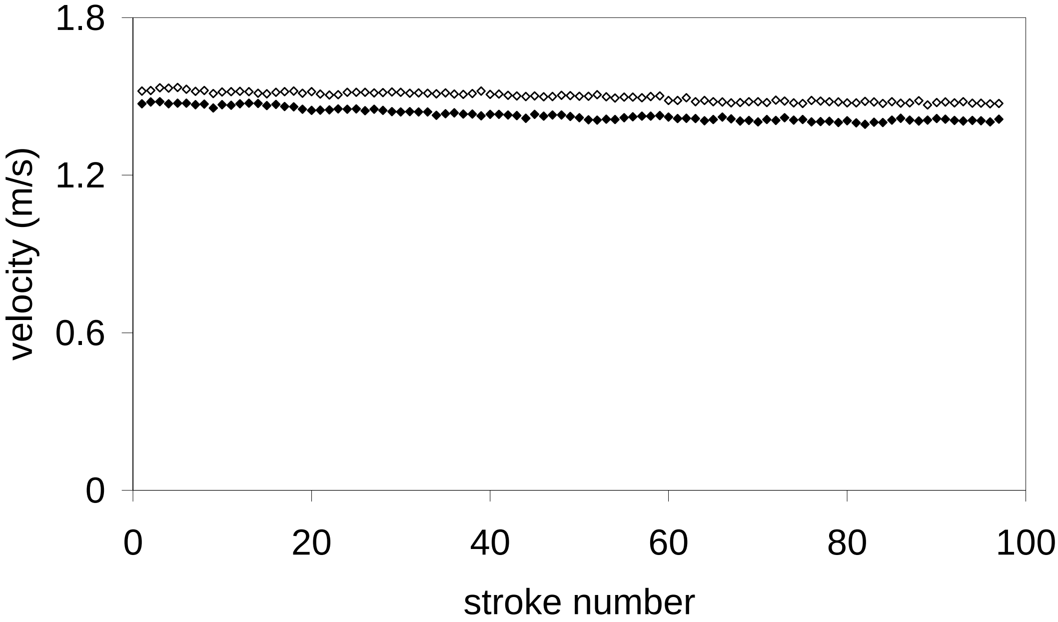

Figure 7. Mean handle velocity per stroke for all subjects is shown for pre- (♦) and post-familiarisation (◊) conditions.

4. Discussion

The aim of the present investigation was to determine the influence of a three week familiarisation period on the power generated each stroke during ergometer rowing and on the rate of fatigue at an increased stretcher height.

Caplan and Gardner (2005) previously showed a reduction in the rate of fatigue as stretcher height was increased. The mechanism behind this reduction in the rate of fatigue was theorised to be a change in the direction of the resultant musculo-skeletal force applied to the foot stretcher acting through the ankles and hips. In the present investigation, a significant increase in mean power per stroke was observed with familiarisation, despite the line of musculo-skeletal force remaining constant. Through a simple process of elimination, it is suggested that this increase must be due to physiological adaptations that influence the forces applied by the legs to the stretchers. By raising the foot stretchers, the relative lengths of the flexor and extensor muscles of the hips, knees and ankles will change. For an efficient stroke, a musculo-skeletal adaptation to the new stretcher position would, therefore, be required before the full potential of this new position could be determined. This adaptation took place over the three week training period, as shown by the significant increase in mean power per stroke with familiarisation, with the increase in mean handle force and velocity per stroke indicating that the muscles of the legs were able to extend at a higher velocity and with greater force after familiarisation had occurred.

Subjects were asked not to alter their normal training during the study, so it is unlikely that their fitness would have changed significantly between the two experimental trials. However, even if the fitness of the subjects had improved over the duration of the study, the rate of fatigue would be expected to reduce post-familiarisation. The similar rate of fatigue in both trials suggested that the subjects' normal training over the three week period had this effect.

The increase in mean power per stroke post-familiarisation could also be due to subjects familiarising themselves with the requirements of the experimental trials. However, this is unlikely due to the extended duration between the pre- and post- familiarisation trials. A learning effect of the fatigue trial would also not be expected to influence the mean power per stroke during the first ten strokes, as the subjects were not fatigued and are used to exerting maximum effort. It is only when the subjects begin to fatigue that any learning effect would become apparent, and would be indicated by a reduction in the rate of fatigue. The rate of fatigue in the present trials was similar between trials and the increase in mean power per stroke was observed throughout the entire trial.

The results of the present investigation suggest that stretcher height should be raised above that which is normally used in ergometer rowing in order to maximise the musculo-skeletal effectiveness of the rowing stroke. The investigation was unable to indicate the size of this increase in stretcher height for maximum effectiveness and, as discussed previously (Caplan and Gardner, 2005), this would depend upon the anthropometric and musculo-skeletal characteristics of individual rowers and could only be determined on an individual rower basis. It must also be remembered that by raising the height of the foot stretchers, and hence the legs, the centre of buoyancy will also be raised within the boat in on-water rowing, thus influencing the balance of the boat (Dudhia, 2002), and the energy required to maintain a stable boat position in the water.

In summary, the present investigation aimed to determine the influence of familiarisation on the mechanical effectiveness of the rowing stroke at a new stretcher position. The results of the study suggested that a musculo-skeletal adaptation to this new stretcher position had occurred with three weeks of training, as shown by the significant increase in mean power per stroke throughout the duration of the trial. Determination of an ideal stretcher height for maximum mechanical effectiveness was not possible. It was suggested that, whilst the stretchers should be raised as close to the height of the seat as possible, their most mechanically effective position would be specific to each individual rower, and must take into consideration the balance of the boat and the extra energy required to maintain balance as stretcher height is increased.

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