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The influence of stretcher height on posture in ergometer rowing

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Abstract

The aim of this investigation was to determine the effect on rower posture of raising the stretchers. Nine male university rowers completed a single 30-s trial at each of three stretcher heights on an ergometer, at 30 strokes min^{-1}. The first ten strokes with complete data were averaged and data for four time points during the stroke extracted: catch, mid-drive, finish, and mid-recovery. Ankle angle was shown to increase significantly at all points during the stroke ($P<0.01$) as the stretchers were raised. Knee angle was only significantly increased into a more extended posture at mid-drive ($P<0.05$) and mid-recovery ($P<0.01$) for the higher stretcher positions, hip angle was significantly reduced into a more flexed posture at the catch ($P<0.05$) and at mid-recovery ($P<0.05$), and the trunk was significantly extended at the catch ($P<0.01$), finish ($P<0.01$), and mid-recovery ($P<0.05$) as the stretchers were raised. Our results show that the increase in stretcher height caused the rower's body to rotate posteriorly in the sagittal plane. This we suggest reduced the vertical component of stretcher force, thus achieving a more mechanically effective position, which could have led to the slower rate of fatigue reported previously for the two raised stretcher positions (Caplan & Gardner, 2005). The increased flexion of the hip should not be ignored, however, as this may lead to overstretching of the hip extensors if the stretchers are raised too high. Further research is required to determine the extent to which the stretchers can be raised in on-water rowing.

Keywords: *Rowing, kinematics, posture, stretcher*

Introduction

The rowing stroke involves the application of large forces to the foot stretchers, which are transferred effectively to the oar handle by the rower maintaining a strong posture, such that all body segments move in the direction of handle pull without collapsing. The technique used during the stroke is cyclical in nature with the rower moving back and forth on the seat while performing the four phases of the stroke: the catch, drive, finish, and recovery.

The foot stretcher will typically be below the height of the seat slide by 150 mm ($s=50$) (Sayer, 1996) or 172 mm ($s=15$) (Barrett & Manning, 2004). Herberger (1987) suggested that the height between the lower edge of the foot stretcher and the height of the slide should be minimized optimize the production of power during the stroke. This notion was recently supported by Caplan and Gardner (2005), who confirmed both theoretically and experimentally that stretcher-seat height differential (h_1; see Figure 1) should be minimized, and it was shown that the rate of reduction in mean power per stroke was reduced as the stretchers were raised. It was suggested that the slowing of the rate of reduction in mean power per stroke was due to a reduction in the magnitude of the vertical stretcher force, resulting in a more horizontal force application to the raised stretcher during the drive phase. By reducing the wasted vertical components of force, more of the energy expended by the rower is transmitted directly into propelling the boat. Any vertical force applied during each drive phase of the stroke will act to lower the boat in the water, increasing the wetted surface area of the boat and thus increasing drag. Reductions in the vertical stretcher force will, therefore, also reduce this increase in drag force.

Caplan and Gardner (2005) showed that the mean power generated in each stroke reduced significantly over the course of a fatiguing trial, and that the

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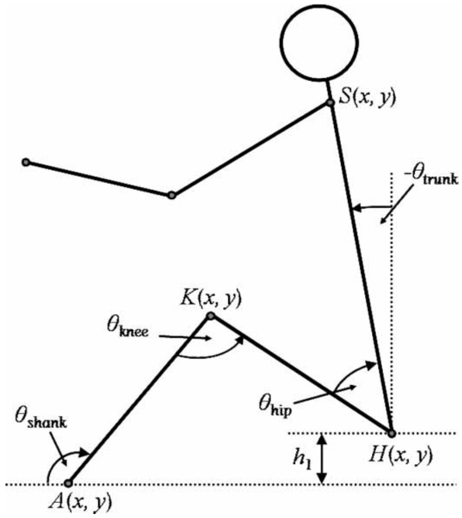

Figure 1. Joint/segment angles are shown along with the joint coordinates recorded in the study. The height differential, h_1, between the foot stretchers and seat is also illustrated. The trunk angle varies over the drive from an anterior angle at the catch to a posterior angle at the finish (i.e. negative to positive).

reduction in power per stroke was at a slower rate as the stretchers were raised. As well as the rate of fatigue, it is expected that the distribution of stresses around the body will also be influenced by the increased stretcher height, due to the inherent changes in body posture. Due to the repetitive loading of the various bone and soft tissue structures of the rower's body, a high incidence of injury has been reported (Hagerman, 1984; Hickey, Fricker, & McDonald, 1997; Howell, 1984; Roy et al., 1990; Shephard, 1998; Stallard, 1980; Teitz, O'Kane, Lind, & Hannafin, 2002). Hickey et al. (1997) reported that the most common chronic injuries in male rowers were to the lumbar spine (19.6%), the wrist (16.1%), the knee (11.1%), and the chest (8.6%).

Spinal injuries, which have been reported to occur in the lumbar region (Hickey et al., 1997; Howell, 1984; Stallard, 1980), have been suggested to be caused by high compressive forces within the lumbar spine during each stroke. Hosea and colleagues (Hosea, Boland, McCarthy, & Kennedy, 1989) reported estimated peak compressive forces in the lumbar region of approximately 6000 N and 5000 N for male and female rowers, respectively. The magnitudes of these compressive forces are well above the magnitude of 4000 N that are believed to cause damage to vertebrae (Dolan, Early, & Adams, 1994).

In a similar fashion to low back injuries, knee injuries commonly result from the repetitive loading on the knee joint caused by the extension–flexion movements employed during the rowing stroke cycle (Shephard, 1998), with the knee joint moving through its full range of motion. Karlson (2000) suggested that rowers often present with patellofemoral pain, due to the magnitude of the load experienced in the knee in the compressed position at the catch (Rumball, Lebrun, Di Ciacca, & Orlando, 2005).

Stallard (1980) and Shephard (1998) both postulated that the increased incidence of injuries in recent years was due to the "modern rowing style", in which the stretchers are raised high in the boat. Despite the suggestion that higher stretchers are the cause of the increased incidence of injuries in rowing, no research has been conducted to determine the influence of raising the stretchers on the kinematics of the rowing stroke.

The aim of the present study, therefore, was to determine the influence of raising the stretchers on the kinematics of the lower limbs and trunk in ergometer rowing, specifically to understand the influence of changing stretcher height on rower posture during the stroke.

Methods

Nine male rowers were recruited from the University of Birmingham rowing club. The rowers had a mean age, height, and body mass of 21.9 years ($s = 1.2$), 1.81 m ($s = 0.07$), and 83.4 kg ($s = 7.8$), respectively. The participants had 5.6 years ($s = 2.8$) of experience in competitive on-water rowing, and used a Concept 2 rowing ergometer as an integral part of their training. The study received approval from the University of Birmingham ethics committee and the rowers provided written informed consent before participating in the study.

A rowing ergometer (Model C, Concept 2, USA) was used in the investigation. The air resistance of the fan that provided a resistance to pull force at the handle was set to 4 for all trials. This setting equated to a drag factor, k, of $1.25 \times 10^{-4}\ \mathrm{N \cdot m \cdot s^{-2}}$, which was calculated by the PM2+ monitor of the ergometer using the equation,

$$k = I\mathrm{d}(1/\omega)/dt$$

where I is the moment of inertia of the flywheel and ω is the angular velocity of the flywheel (Dudhia, 2002). All of the participants were accustomed to training at this drag factor.

The foot stretchers of the ergometer were modified so that as well as the standard ergometer foot height (position 1), two higher foot positions could be provided ($d_1 = 5$ cm – position 2; $d_2 = 10$ cm– position 3; see Figure 2) on the same inclined surface. This meant that the stretchers were, in effect, raised vertically by 3.4 cm between conditions. The heel was positioned 18 cm below the top surface of the seat in position 1, 14.6 cm below the seat in position 2, and 11.2 cm below the seat in

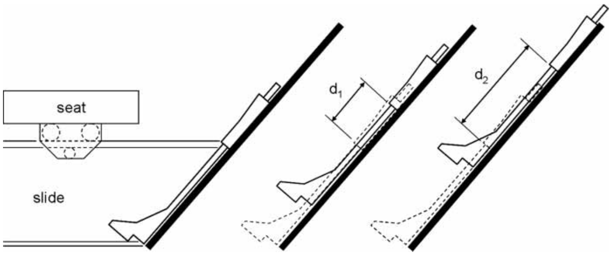

Figure 2. (A) The original Concept 2 foot stretcher position relative to the seat (position 1). (B, C) The two new positions for the foot stretcher, with $d_1 = 5$ cm (position 2) and $d_2 = 10$ cm (position 3).

position 3. In each position, the foot was held in place using the original Concept 2 foot cradle and strap.

A motion capture system (Vicon, Oxford Metrics Ltd., UK) was used to examine the motion of the rowers' body segments throughout each stroke. Thirty-five reflective markers (diameter = 0.025 m) were attached to each participant using double-sided adhesive tape, and the location of each marker is described in Table I. The marker positions were selected to enable the calculation of the joint angles shown in Figure 1. Ankle angle was defined as the angle made between the shank and the ground. Knee angle was that between the long axes of the shank and thigh. Hip angle was given by the angle between the long axes of the thigh and trunk segments. Trunk angle was the angle of the trunk segment with respect to a vertical axis. Six infrared cameras (Vicon 8, Oxford Metrics Ltd., UK) detected the position of each marker and the data were sampled at 120 Hz by the Vicon datastation (Vicon 512, Oxford Metrics Ltd., UK) before being stored on a workstation computer for later analysis.

The catch and finish of the stroke were defined by the change in direction of the oar handle. This was determined by a change in the sign of the handle velocity, which was positive during the drive and negative during the finish. Handle velocity was measured using a DC tachometer (263-6005, RS Components, UK). The tachometer enabled measurement of the rotational velocity of the ergometer chain sprocket (pitch diameter = 2.83 cm), from which linear handle velocity could be calculated to a resolution of 0.07%. The analog signals were sampled at 120 Hz and passed to the Vicon Workstation via an analog-to-digital board (Vicon, Oxford Metrics Ltd., UK). The mid-drive and mid-recovery time points were then defined as 50% of the time between the catch and finish, and 50% of the time between the finish and the subsequent catch, respectively.

The participants performed their normal warm-up for a period of 4 min on the rowing ergometer. This period was used to ensure that the participants would settle quickly into their normal technique during subsequent testing, that they were comfortable with the markers attached to them, and that the markers were attached securely. The participants were then asked to row at 30 strokes $\cdot$ min^{-1} for 30 s at each stretcher position, each followed by a 5-min recovery period to avoid any fatigue effects. The 30-s data collection period started once the rowers had reached 30 strokes $\cdot$ min^{-1} to avoid strokes during which the flywheel was being accelerated. The participants were encouraged to maintain their normal rowing style throughout. The test order of stretcher position was systematically varied (participant 1: position 1 → 2 → 3; participant 2: 2 → 3 → 1; participant 3: 3 → 1 → 2, etc.) ensure that non-specified variables such as learning effects did not influence the results.

Marker positions were labelled using the Vicon Workstation software. The data were then reconstructed to convert the two-dimensional (2D) marker coordinates from all six cameras into three-dimensional (3D) coordinates. A cubic spline interpolation was used to fill any gaps in the 3D marker position data of up to 0.1 s caused by markers not being visible to enough cameras. Any strokes that had data missing for more than 0.1 s were discarded.

Only the angles between the longitudinal axes of adjacent body segments were required, and due to the mainly 2D action of rowing, especially for the lower limbs and trunk on an ergometer, these angles were considered as 2D joint/body segment angles.

Table I. Description of marker positions used in the investigation

Marker	Description
LTOE/RTOE	Front top of shoe along centre line of foot
LANK/RANK	Lateral malleolus at the ankle
LHEE/RHEE	Heel of foot, on heel counter of shoe
LSHI/RSHI	Lateral side of lower leg in line with LANK and LKNE (or right)
LKNE/RKNE	Lateral epicondyle of knee
LTHI/RTHI	Lateral thigh in line with LKNE and LASI
LGT/RGT	Greater trochanter
LASI/RASI	Anterior superiliac crest
LPSI/RPSI	Posterior superiliac crest
SCR	Sacrum
C7	C7 vertebra
T10	T10 vertebra
CLAV	Manubrium (top of sternum)
STRN	Xiphoid process (bottom of sternum)
LSHO/RSHO	Acromion at the shoulder joint
LARM/RARM	Lateral edge of upper arm in line with LSHO and LELB
LELB/RELB	Lateral epicondyle at the elbow
LFRM/RFRM	Lateral edge of forearm in line with LELB and LWRA when hand in supinated position
LWRA/RWRA	Styloid process of ulna
LWRB/RWRB	Styloid process of radius

Joint angles for the left and right side of the body were averaged to give a mean angle for each joint. Joint angles for the first ten successful strokes for each participant were analysed at each stretcher position, and subsequently split into drive and recovery phases before being normalized in the time domain to 100 data points. Shank angle with respect to the ground, knee, and hip joint angles, and trunk angle with respect to a vertical axis (Figure 1) at the catch, mid-drive, finish, and mid-recovery were then extracted for further analysis.

All variables were checked for normal distribution using a Kolmogarov-Smirnof test. One-way analyses of variance for repeated measures were used to determine whether there were any significant influences of stretcher position on the angles described above, at each of the time points throughout the stroke. If a significant effect was observed, a *post hoc* Tukey test was used to determine where the difference lay. A 95% confidence level was adopted throughout.

Results

All participants successfully completed the study. All variables were found to be normally distributed. Stroke rate was maintained at mean values of 29.9 m $\cdot$ s^{-1} ($s=0.8$), 29.7 m $\cdot$ s^{-1} ($s=0.5$), and 29.6 m $\cdot$ s^{-1} ($s=0.4$) for stretcher position 1, 2, and 3, respectively. Mean stroke distance was shown to be 1.31 m ($s=0.10$), 1.32 m ($s=0.10$), and 1.32 m ($s=0.09$) for stretcher position 1, 2, and 3, respectively. Mean ($\pm$ s) values are shown in Table II for all joint angles at the catch, mid-drive, finish, and mid-recovery.

Shank angle was shown to increase significantly between all stretcher positions at the catch ($F_{2,16}=29.04$, $P<0.01$), mid-drive ($F_{2,16}=51.674$, $P<0.01$), finish ($F_{2,16}=82.908$, $P<0.01$), and mid-recovery ($F_{2,16}=72.397$, $P<0.01$) (Figure 3).

Knee angle was similar at both the catch ($F_{2,16}=0.219$, $P=0.81$) and finish ($F_{2,16}=2.783$, $P=0.09$) between all stretcher heights (Figure 4). An increase in knee angle was observed at mid-drive, however, with this increase being significant between positions 1 and 3 ($F_{2,16}=9.958$, $P<0.01$). A significant increase was also observed at mid-recovery ($F_{2,16}=15.242$, $P<0.05$) between positions 1 and 3 ($P<0.01$) and 2 and 3 ($P<0.01$).

Hip angle was reduced significantly at the catch with increasing stretcher position ($F_{2,16}=24.244$, $P<0.05$) between positions 1 and 2 ($P<0.05$), 2 and 3 ($P<0.01$), and 1 and 3 ($P<0.01$) (Figure 5). No significant influence of stretcher position was observed at mid-drive ($F_{2,16}=3.253$, $P=0.065$) and finish ($F_{2,16}=0.864$, $P=0.435$). At mid-recovery, however, a significant influence of stretcher position was observed ($F_{2,16}=3.748$, $P<0.05$), with hip angle reducing with increased stretcher position between positions 1 and 3 ($P<0.05$).

Significant increases in trunk angle were observed at the catch ($F_{2,16}=8.425$, $P<0.05$) between positions 1 and 3 ($P<0.01$), at the finish ($F_{2,16}=17.238$, $P<0.05$) between positions 1 and 2 ($P<0.05$) and 1 and 3 ($P<0.01$), and at mid-recovery ($F_{2,16}=4.109$, $P<0.05$) between positions 1 and 3 ($P<0.05$) (Figure 6). No significant differences were seen in trunk angle at mid-drive ($F_{2,16}=1.449$, $P=0.266$).

Table II. Joint angles (°) at the catch, mid-drive, finish, and mid-recovery for each of the three stretcher positions 1, 2, and 3 (mean $\pm s$)

	Catch	Mid-drive	Finish	Mid-recovery
Shank				
Position 1	91.6±8.0*	140.4±6.3*	168.5±3.7*	141.2±4.0*
Position 2	95.0±9.2*	144.3±7.2*	171.1±4.0*	144.7±4.2*
Position 3	99.2±10.0*	147.5±6.9*	173.9±4.7*	149.3±2.8*
Knee				
Position 1	41.0±13.5	125.9±15.6	171.2±6.5	127.2±8.6
Position 2	42.1±13.3	128.2±16.8	171.6±6.6	128.9±8.1*
Position 3	41.5±13.7	130.9±16.1*	172.5±7.3	133.2±7.6*
Hip				
Position 1	18.7±8.6*	65.7±6.1	109.1±8.4	51.1±8.2
Position 2	16.4±9.5*	65.7±6.3	109.7±9.3	50.7±8.2
Position 3	13.9±8.3*	63.4±6.2	109.2±9.0	49.5±6.8*
Trunk				
Position 1	−38.1±8.5	−9.4±6.5	16.6±8.3	−24.8±7.2
Position 2	−36.3±9.2	−8.2±7.1	18.7±9.4*	−23.6±7.8
Position 3	−35.1±8.6*	−8.0±6.8	20.3±8.0*	−23.1±6.9

*Significant difference ($P<0.05$).

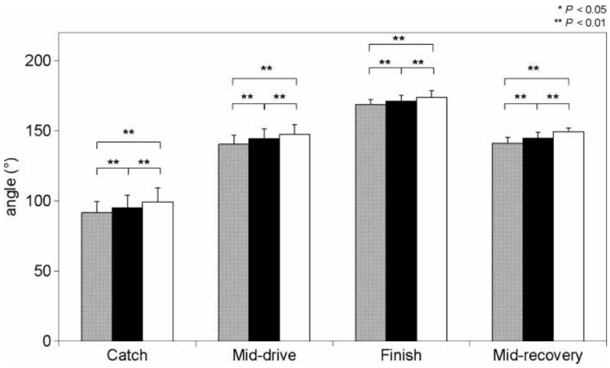

Figure 3. Shank angle (mean $\pm s$) at the catch, mid-drive, finish, and mid-recovery for stretcher position 1 (hatched bars), 2 (solid bars), and 3 (open bars). Significant differences between stretcher positions are indicated by square brackets: $^{*}P<0.05$, $^{**}P<0.01$.

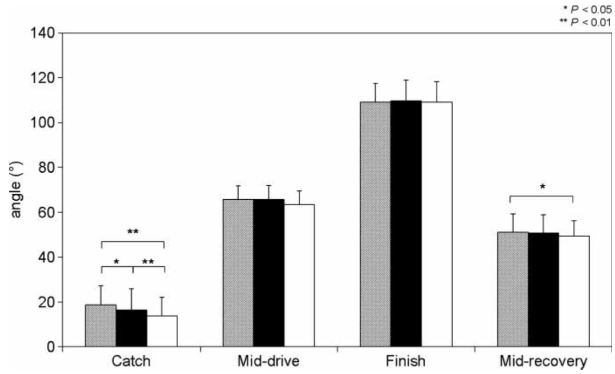

Figure 5. Hip angle (mean $\pm s$) at the catch, mid-drive, finish, and mid-recovery for stretcher position 1 (hatched bars), 2 (solid bars), and 3 (open bars). Significant differences between stretcher positions are indicated by square brackets: $^{*}P<0.05$, $^{**}P<0.01$.

Discussion

The aim of the present study was to determine the influence of stretcher height on rower posture, specifically the lower limbs and trunk, in ergometer rowing. As previously suggested, the knee is prone to soft tissue injury (Hickey et al., 1997), due to the compressed posture at the catch. The lack of difference in knee angle at the catch as stretcher position was raised might suggest that there would be no change in the risk of knee injury caused by the compressed catch position (Figure 5). To confirm this, future research should identify, through kinetic analysis, whether there is any change to the moment arm between the stretcher force and the knee, and examine changes to the loading of the knee joint. Although the degree of knee flexion seen at the catch was well within the normal range for knee flexion as reported by Borms and Van Roy (1996) for young male physical education students (25–50°), it was not possible to conclude from the present data whether the rowers were able to efficiently absorb the compression loads at the angles observed. The degree of knee extension at the finish was also within the normal range (160–187°).

Due to the increase in foot position as the stretchers are raised, and with the knee angle remaining the same, the angle of the thigh to the horizontal will be increased. To maintain trunk posture as stretcher height is raised, the hip will have to compensate through increased flexion. This was confirmed by the present data, with a significant decrease in hip angle (increased flexion) seen at the catch as stretcher height increased (Figure 6). Flexibility of the hip extensors might play a key role in the determination of optimal stretcher height, as if hip angle continues to reduce as the stretchers are raised, the hip flexors could become over-stretched, thus increasing the likelihood of injury.

The hip angles recorded at all three stretcher heights were less than those reported by Barrett and Manning (2004) for on-water rowing, which were notably less than the normal range of 35–75° for hip flexion (Borms & Van Roy, 1996). This could be attributed to differences in the inertial

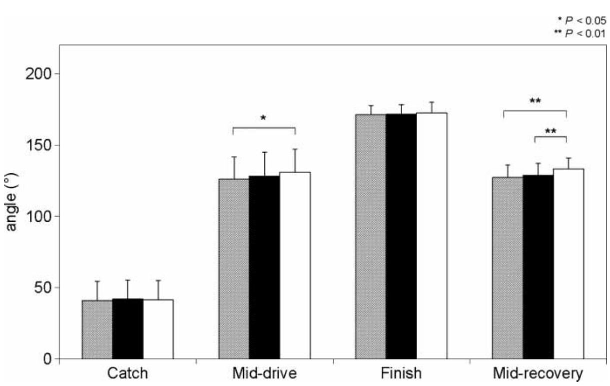

Figure 4. Knee angle (mean $\pm s$) at the catch, mid-drive, finish, and mid-recovery for stretcher position 1 (hatched bars), 2 (solid bars), and 3 (open bars). Significant differences between stretcher positions are indicated by square brackets: $^{*}P<0.05$, $^{**}P<0.01$.

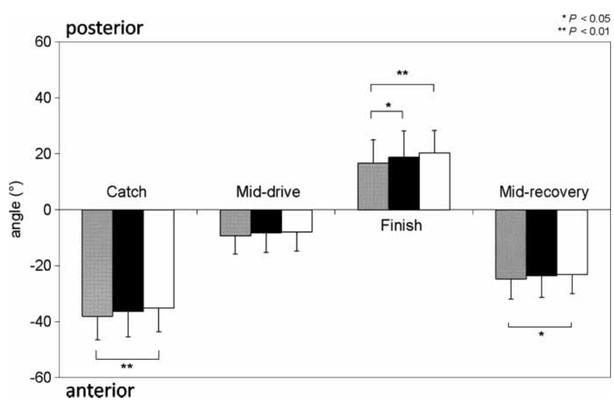

Figure 6. Trunk angle (mean $\pm s$) at the catch, mid-drive, finish, and mid-recovery for stretcher position 1 (hatched bars), 2 (solid bars), and 3 (open bars). Significant differences between stretcher positions are indicated by square brackets: $^{*}P<0.05$, $^{**}P<0.01$.

characteristics between ergometer and on-water rowing. In ergometer rowing, the rower has to overcome the momentum of the body moving forwards, which increases the load placed on the legs as the body accelerates forward during the recovery. It was noted for one of the rowers that as he approached the catch, the hips were abducted, creating space for the arms to pass between the knees. This could be a mechanism used to reduce stress on the hip and pelvic region as stretcher height is increased, also affecting the force exerted on the stretcher. As the hip joint moments were not measured here, further comment is not justified.

At the catch, the trunk is rotated anteriorly towards the handle. As the stretchers were raised, the amount of forward lean was reduced, and this was significant between stretcher positions 1 and 3 (Figure 6). This alone, however, would act to reduce stroke length. Stroke length was similar between stretcher heights, which was attributed to a significant increase in posterior (positive) trunk angle at the finish to compensate for the decreased anterior (negative) angle at the catch.

The findings of the present study suggest that as stretcher height increases, the entire body of the rower is rotated posteriorly in the sagittal plane. This rotation of the body would reduce the angle of force application through the legs to the stretcher. As such, the line of action of force applied to the stretcher would move closer to being in line with the direction of handle force, and could explain the previously reported reduction in the rate of fatigue as the stretchers are raised, through a more effective application of force (Caplan & Gardner, 2005).

Conclusions

It was shown that by raising the height of the stretchers in rowing on an ergometer, the kinematics of the rower remain similar, although the entire body is rotated posteriorly in the sagittal plane. Hip angle was reduced at the catch, presumably in an attempt to maintain forward reach and hence the length of the stroke. The changes in posture observed here were suggested as causing a reduction in the vertical component of stretcher force, which does not contribute to propulsion. As the stretchers were raised, the hip became more flexed. This change has the potential to lead to soft tissue injury of the hip flexors if they become overstretched. To relate the findings of this study to on-water rowing, further work is needed. Raising the stretchers will raise the centre of mass, which will influence balance of the boat, and the change in posture may require adjustments to the rigging of the oars to ensure optimal oar blade force production.

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