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Invited Review

Injury prevention, performance and return to sport: How can science help?

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The margins in elite sport are becoming increasingly smaller particularly in timed sporting events forcing the limits of performance to be pushed further. Although traditionally only the physiological and physical attributes of performance were considered, there is growing awareness of a range of factors including but not limited to; the performance culture including the team environment, athlete coach relationship, facilities etc; specific physical attributes and skills for each sports; mental skills such as confidence, resilience, motivation etc; technical skills including agility, coordination; tactical skills and finally lifestyle skills including nutrition, well-being, and recovery.

In sports medicine there is a growing need to understand the relationship between training load, injury, fitness and performance.[1] For an individual an injury can be devastating, however if that individual is performing in a team the impact goes beyond the individual affecting the whole team. Since timed races are frequently decided by tenths and hundredths of a second, athlete's training loads are increasing and injury has the potential to become a probability rather than a risk.

Rowing is a highly competitive and popular sport in the United Kingdom, although historically the injury rate was thought to be low compared to other sports, especially contact sports such as football,[2,3] more recent findings have suggested that elite international rowers are at a higher risk of injury.[4] Understanding injury in sport is complex and dependent on how injury is defined and recorded. Wilson et al[4] used a definition adapted from the Rugby Injury and Performance Project[5] where injury was recorded if the athlete had:

- Missed at least one competition OR
- At least two training sessions OR
- Required at least one visit to a health professional for treatment.

The final category thereby accounting for athletes attending visits to the physiotherapist, which are often used by athletes to “keep a problem under control”. This classification of injury was in fact the most revealing, as the authors noted that many athletes actually train for longer when injured. However, the inclusion of this final category is likely to account for the high injury rates recorded, similar rises in injury rates are likely in other sports if this additional definition of injury is used. Both past and current studies agree that in the sport of rowing the region that is most frequently injured is the lumbar spine, accounting for 31% of all injuries in Wilson et al's[4] work and between 15 and 25% in Hickey et al's[2] study.

There has been considerable speculation as to why such rowing injuries occur, Wilson's work[4] highlighted that injuries occurred predominately during training rather than competition and linked this to high volumes of ergometer training. Newlands et al[6] also attributed injury rates to training load, noting that many were overuse injuries. Past research has also attributed a rise in spinal issues to ergometers, as well as poor rowing technique, inadequate warm up, stretching and flexibility, changing in equipment e.g. Blades, and poor weight training skills.[7–13]

For the past 16 years we have focused on the biomechanics of rowing technique, and the interaction of the rower with the rowing ergometer. While the ideal would be “on-water” measures of the rower, the rowing shell, and oar research has been limited. Recent work has attempted to redress this including Wilson et al's work[14] into spinal movement during “on-water” rowing the interpretation of which is constrained by technological limitations. On-water measures also require parameters of the environment to be measured or controlled for including wind speed, water stream, and temperature. Not surprising a far greater body of work has been conducted on a rowing ergometer with a focus on intrinsic injury risk factors e.g. biomechanics, conditioning, physiology etc.

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This approach has however led to a very biomedical/biomechanical model of injury.[15]

While the initial focus of our research was to understand how the rower moved and interacted with the equipment with a view to understanding injury, our work has also translated to performance which is inherently linked to injury. An advantage of the sport of rowing is the repetitive and cyclical rowing stroke which lends itself to detailed biomechanical assessments. The rowing stroke is commonly described as comprising of the "drive phase" where the rower applies pressure to the oars (or ergometer handle) thereby pulling the boat through the water and "the recovery" where the oar is removed from the water and the rower returns to the start position which is commonly referred to as "the catch". Different rowing associations have attempted to define the perfect rowing stroke with clear depictions of each stage [https://www.britishrowing.org/upload/files/CoachingTraining/PerfectStrokePoster.pdf, accessed June 2016].

Coaching the perfect rowing technique has to date been a "craft" profession that relies on a coaches eye and the anaesthetic of technique and the ability of the crew to win races. However, in the desire to understand injury our work sought to explore the kinematics and kinetics of the rowing stroke. Through this we felt we could address some of the theories speculated to be behind the large volume of injuries recorded. Such theories include the generations of large compressive forces and moments acting on the spine;[16] the repetitive impact on these high forces on the visco-elastic structures of the spine;[17,18] and the risk of high spinal bending of the spine as a result of fatigue in the back muscles.[19]

The initial step was to define the movement of the rower's spine during the rowing stroke which was performed on a rowing ergometer (Concept 2 Model C, Concept Inc, USA). The movement of the lumbar spine, pelvis and thigh was assessed using a commercial electromagnetic motion analysis device, the Flock of Birds (Ascension Technology, USA), with the position of the sensor on the thigh used to characterise the start and end of the rowing stroke.[20] This permitted an understanding of the characteristics of the rowing stroke and was able to define common technical errors in rowing technique. However, it was clear that we needed a more robust approach to defining the start of the rowing stroke, and the need to quantify the force generated at the handle was identified. Subsequently a load cell was embedded in the handle of the rowing ergometer and synchronised with the Flock of Birds motion analysis system. This then permitted the identification of the start of the rowing stroke from the initiation of force on the handle at the catch phase of the rowing stroke.[21] Data was collected and then normalised with the catch being defined as the start of the stroke at 0% and the return to this position as 100%. An averaging technique was then applied for each rower and each data set. An example of the resultant average data for one rowing is provided in Fig. 1.

Concurrent work examined the spinal posture of rowers at different stages of the rowing stroke in an upright open MRI scanner (General Electric Signa SP10 Interventional MRI scanner, Milwaukee, USA).[22] This scanner had an open configuration consisting of two connected but opposing ring "doughnut" magnets with a gap between then of 56 cm which generated a uniform field of 0.5 T which was sufficient to gain an insight into spinal posture. The position of the rower in the scanner was simulated using a wooden rowing jig capable of recreating the start and end of the stroke. This work revealed how posture influenced how the rowing position was achieved and emphasised the concept of lumbo-pelvic motion. Fig. 2 shows how at the catch the position can either be achieved through anterior rotation of the pelvis with minimal lumbar flexion or through pronounced forced lumbar flexion, the latter being a potential factor in the high rates of low back pain. Subsequent work into the kinematics of technique therefore considered both pelvic rotation and lumbar flexion separately (Fig. 3).

Since we had a tool to define rowing technique we could now explore a series of factors that have been speculated to impact on this technique including performance level/ability; prior injury; fatigue; stroke rating; and test environment – including the type of ergometer used. The work of Holt et al's[21] work demonstrated that rowing technique deteriorated over time and demonstrated a marked increase in lumbar flexion of the spine at the catch and finish phases of the stroke with fatigue. However, technological restraints at the time meant that data could not be collected continuously and when this work was repeated in 2009 and the protocol was repeated on international athletes with continuous data collection, the impact of duration on technique was not observed.[23] Instead it was observed that it took up to 10 mins for

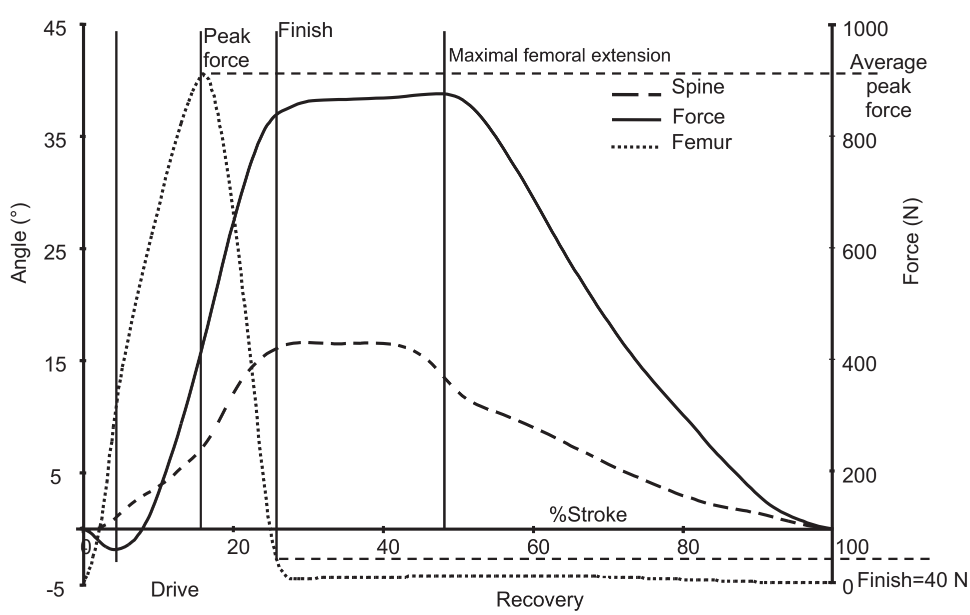

Fig. 1. An example of an averaged rowing stroke and the identification of key phases of the rowing stroke. (Adapted from Holt PJ, Bull AM, Cashman PM, et al. Kinematics of spinal motion during prolonged rowing. Int J Sports Med. 2003;24:597-602).

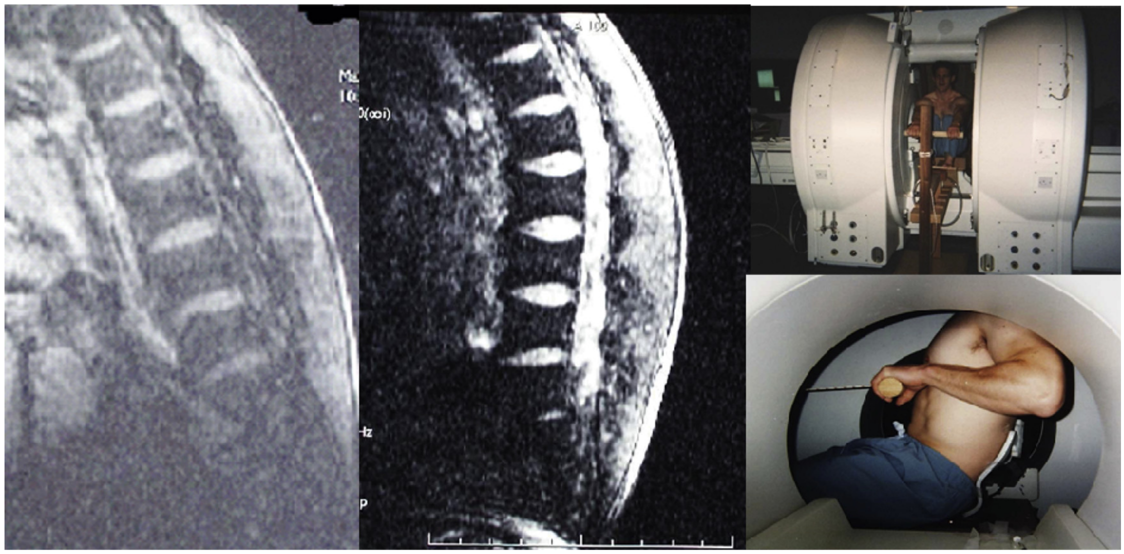

Fig. 2. Far left rowing "catch" posture achieved through anterior rotation of the pelvic compared to middle image where the position is achieved through lumbar flexion predominately at the thoraco-lumbar junction. Far right portrays rowing simulations with scanner. (Cited from McGregor A, Anderton L, Gedroyc W. The assessment of intersegmental motion and pelvic tilt in elite oarsmen. Med Sci Sports Exerc. 2002;34:1143-1149).

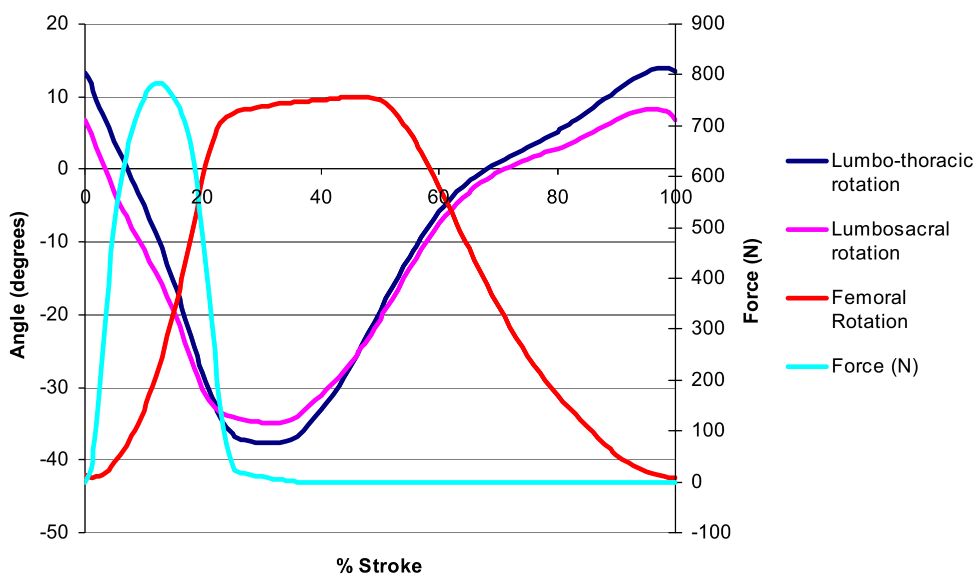

Fig. 3. An averaged rowing stroke considering motion at the pelvis (lumbosacral rotation) and lumbar spine (lumbo-thoracic) independently.

rowing technique to become stabile suggesting the importance of an adequate warm up. This finding has impact not only in terms of injury prevention but also in relation to performance testing.

This was not the only testing that indicated an impact of rowing experience and performance status. Rowing technique at a range of testing intensities was assessed in collegiate rowers, which revealed limitations in power output, poor timing of the stroke and compromised stroke biomechanics in terms of the rower's kinematics all of which deteriorated as rowing intensity increased, similarly statistical modelling has been used to differentiate between elite international and competitive national athletes.[24] The implications of these differences in technique with respect to injury, is less clear but suggest that elite performances have evolved a more proficient and mechanically advantageous technique. More detailed interrogation using the statistical model developed by O'Sullivan et al[24] did indicate difference between those with and without a history of low back pain. At this time however the model did not provide any clinical insight to either cause or management, however with the growth of novel analytical approaches this does require further investigation.

The concept of rowing stroke deteriorating was explored further during a routine physiological step test in elite international athletes.[25] This incremental test comprised of 5 four minute steps performed on a rowing ergometer with the first step conducted at 18 strokes per minute and subsequent steps at 20, 22, 24, and 26 strokes per minute followed by a minute at maximal effort. Force output increased significantly as the intensity increased, and while stroke length remained consistent across steps it was observed to shorten during maximal testing. Marked differences were also seen in relation to lumbo-pelvic motion. At the start of the stroke there was a marked trend of reduced anterior pelvic rotation associated with increased lumbar flexion as the rating increased this was marked during final maximal effort test. Similarly at the finish of the stroke there was a loss of pelvic control and a resultant slumped posture again more marked during the maximal effort test. This inability to maintain technique at maximal effort may arise from a number of factors including muscle strength and body coordination.

Concurrent studies exploring aspects of strength in rowers, primarily focuses on the spine and lower limb. Initial studies looking at asymmetries in leg strength and back function in collegiate rowers, noted that rowers did not present with significant asymmetries in strength in the legs, but that whilst their legs strength was markedly greater than a control population there was not a reciprocal different in the back muscles.[26] This finding was explored further in elite rowers, while isometric and isokinetic back strength was greater in the athletes, this was more prominent in the later stages of range, and greater inequalities in strength were observed in the extensors compared to the flexor influencing trunk flexor-extensor ratios.[27] Of more interest was the marked fatigue observed in both rowers and controls, which is of interest given the high levels of endurance training required in rowing. These high levels of fatigue and inequalities in strength through range and between trunk muscles groups all have potential implications to the low back pain and indeed the loss of a strong biomechanical rowing technique observed at high race intensities. As such training programmes for trunk were revised.

Whilst no evaluation of this intervention was performed, however, 7 or the original 12 athletes who had their technique evaluated using our biomechanical system has this repeated after a year's training under the new training regime. This repeat testing revealed significant improvement in peak force output and stroke length were observed for the same physiological workload. Associated with these changes were improvements in their lumbopelvic control more specifically an improved use of pelvic rotation at the catch and finish with less reliance on lumbar motion to achieve the extremes of range required during rowing.[25,28] Whilst this work suggests that as a result of changes in coaching and training athletes were able to become more biomechanically efficient for the same physiological work which has a direct impact on performance, we also believe that this change will have an impact on spinal health – this remains to be elucidated fully. However, early biomechanically modelling of the rowing action does suggest that these changes in technique have implications in relation to compressive and shear loads to the spine.[29]

The next stage of this work is to see how we can translate message to the wider rowing community, but also how we can use this knowledge to prevent injury. The system has the capability of real time feedback which has shown potential for engaging rowers in behavioural change and requires further development and exploration. It is also important to explore whether regular markers of biomechanical performance have a role in injury prediction however in elite sport this is limited by numbers. However, more importantly is how such approaches could be used to understand other musculoskeletal injuries and diseases and work in on-going to achieve this.

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