Bilateral Strength Comparisons Among Injured and Noninjured Competitive Flatwater Kayakers

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Context: Anecdotal evidence suggests a relationship between strength imbalances and injury incidence.

Objective: To examine the relationship between bilateral strength imbalance and incidence of injury.

Participants and Design: Thirty national- or international-standard flatwater kayakers were classified as noninjured, trunk injured, or upper-limb injured based on the number of days lost from training over the last 6 months. Bilateral strength imbalance was measured using a kayak ergometer, producing data for peak force and force impulse for each side of each stroke. Bilateral strength imbalance was then compared between the noninjured, trunk-injured, and upper-limb-injured groups by means of 2 one-way ANOVAs. No participants reported training days lost through lower-limb injury.

Results: A significantly elevated bilateral peak-force strength imbalance was observed between the upper-limb-injured and the noninjured groups.

Conclusion: These data support the existence of a relationship between strength imbalance and incidence of injury.

Key Words: injury, strength imbalance, kayaking

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For athletes to reach the highest levels in their chosen sports, extensive training regimes have become standard. It is important for athletes to remain injury free so that they are in a position to complete heavy training loads and to train at the required high intensities. Therefore, by examining factors related to sports injury and thus gaining a better understanding of the mechanisms associated with initiating an injury or complicating rehabilitation and return to normal training, it should be possible to reduce the incidence of injury and hasten an athlete's rehabilitation. The results of such evidence-based preventive measures and directed rehabilitation methods could then aid athletes in realizing sporting success.

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There has been much sound research in the areas of preventing and treating sports injuries. One aspect of sports-injury antecedents that appears to have been neglected, however, is that of strength imbalances across the cardinal planes of the body. Sahrmann and White,[1] in discussing this topic, suggest that muscle or strength imbalance is

> The condition arising when forces, both passive and active, exerted by a muscle or muscles contribute to faulty joint alignment, deviations from the ideal path of the axes of joint rotation, or disruption of the ideal recruitment patterns of muscles designated as prime movers and those believed to be accessory contributors. (p 167)

In short, a difference in strength across a joint might result in differential forces being exerted on different aspects of that joint and so causing a disruption in the function of the moving apparatus, thereby overloading certain structures and predisposing them to injury.[2,3] If this imbalance were across a major body plane, characterized by a dynamic series of joints such as the spine, it would be expected that the resulting disruption would be more complex and have extended implications for the body as a whole.[4]

In asymmetrical sports such as tennis and archery, obvious muscle asymmetries arise, and these have been related to injuries, especially impingement syndromes.[3,5,6] This can also be true of symmetrical sports, however; in swimming, shoulder laxity and an imbalance of muscles around the shoulder can cause repeated episodes of subluxation, leading to inflammation within the rotator cuff.[3] Haher et al[7] considered the more global aspect of strength imbalance in swimmers and found there to be a risk of lower back injury resulting from the imbalance between a very strong upper body and a weaker lower body.

To overcome many of these problems, biomechanists are often employed to "examine the sportsperson's activity and estimate the magnitude, direction, and duration of the forces acting on or within the biologic structures with the hope of detecting potential problems in terms of injury recognition and prevention."[8,p58] Although such suggestions regarding strength imbalances as antecedent to injury have been made, little reliable data exist based on research in which this was the primary research question. Therefore, even with the use of complex biomechanical assessment tools, there is little evidence on which to base treatment. The aim of this study was to examine the relationship between strength imbalance and sports injury in the sport of flatwater kayaking, a seemingly symmetrical sport—although asymmetry in both technique and strength has been reported.[9]

Method

Participants

After approval by the University Roehampton Surrey School of Sport Science ethics committee, 30 participants (9 women and 21 men) were recruited (mean age 25 years, SD = 6). All participants trained at least 5 times a week and had done so for at least the last 2 years in a consistent fashion. Because all participants were national- or international-standard flatwater kayakers, all followed similar training regimes consisting of kayaking, running, and weight training. Furthermore, all kept comprehensive training logs as part of their own ongoing monitoring, as suggested by the canoe and kayak sprint-racing Sport Science Support program. In addition, all were free from injury at the time of this investigation.

Design

For this study the classification of *injury* was any aches, pains, or dysfunction experienced that was different from normal "training feelings" and that resulted in missed training. The magnitude of injury was classified by the number of days missed or affected over the period of 6 months prior to testing. This was ascertained through the examination of subjects' training logs.

Participants reporting 5 or more days of missed training in the last 6 months because of injury were classified as either trunk injured (n = 6) or upper-limb injured (n = 12). Participants who had not missed any training over the last 6 months through injury were classified as noninjured (n = 12). No participants in the sample reported any days lost through lower-limb injury. These participant groups were then contrasted on bilateral strength imbalance as measured by the K1 ergometer (Australian Sports Commission).

A questionnaire including informed consent was administered to all participants. This tool gathered demographic data such as age; sex; and information related to frequency and duration of kayak training, competitive standard, and incidence of injury over last 6 months and which body segments these injuries corresponded to.

In summary, the independent variable for this investigation was subjects' injury classification (noninjured, trunk injured or upper-limb injured). The dependent measures assessed bilateral strength imbalance: bilateral peak-force imbalance and bilateral force-impulse imbalance.

Apparatus and Procedure

Bilateral strength imbalances were assessed via a K1 kayak ergometer. The K1 ergometer is an air-braked ergometer, with an interface for downloading relevant work/power data to a laptop computer. Currently this ergometer is considered by athletes to most closely simulate the kayaking movement, although there is nothing in the scientific literature to support this belief. Kinesiological analysis of the kayak stroke has highlighted a significant recruitment of muscles on the side of the body performing the stroke.[10] Based on this, the force profiles for left and right strokes were used as direct measures of sport-specific strength of the right and left sides of the

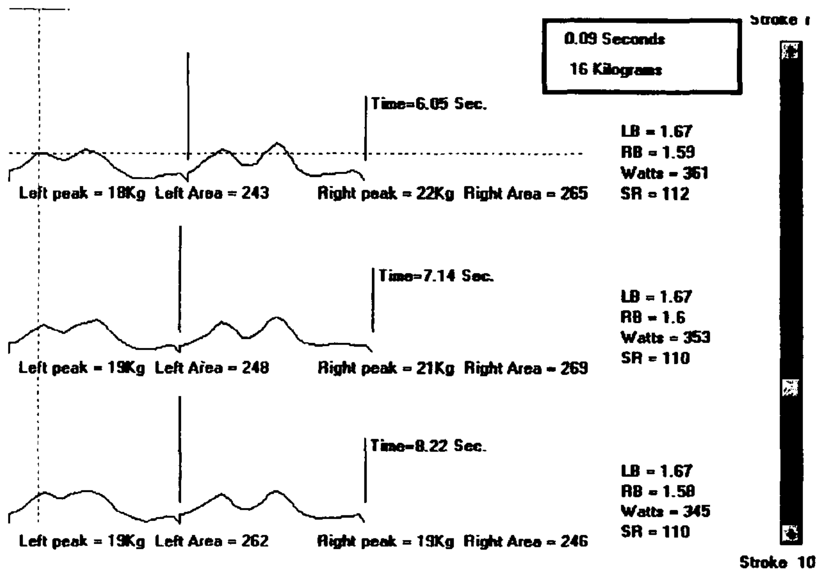

Figure 1 An example of the time/force profiles output from the K1 ergometer software.

body. These data were then used to calculate muscle imbalance or asymmetry (see Figure 1).

Subjects fulfilling the prerequisites for frequency and duration of training were recruited for individual assessment of bilateral strength imbalance via the K1 ergometer. After adjustment of the distance from seat to footplate on the ergometer to fit the participant, each was asked to perform his or her normal warm-up. A further explanation of what was required was given, any additional stretching needed was completed, and any further questions were answered. There then followed 5 extra minutes of paddling on the ergometer at a steady warm-up intensity. Participants were asked to paddle at 60 rpm, and when they indicated they were ready, a 5-4-3-2-1 countdown was given before the maximal effort was commenced. The duration of the effort was 10 seconds—short enough to allow a maximal effort. Two of these 10-second efforts were conducted, with a rest between of more than 20 minutes; this was to check that the data were reliable (Cronbach alpha coefficients of .96 and .93 were observed for peak force and force impulse, respectively). A cool-down period was then encouraged, with participants debriefed regarding their role in the experiment.

Data Analysis

Bilateral strength imbalance was calculated for each participant in terms of the dependent measures of peak-force imbalance and force-impulse imbalance. These imbalances were calculated by subtracting each subject's left-side average scores over the 2 trials from their averages for the right. These scores were then converted to absolute imbalance scores. One-way analyses of variance (ANOVAs) were then conducted on both the peak-force and the force-impulse data, with a post hoc Tukey HSD test where appropriate.

Results

The mean (± SD) days lost through injury over the previous 6 months for injured and noninjured groups are shown in Table 1. No subjects reported missing any training in the previous 6 months as a result of lower-limb injury; thus this variable was omitted from any further analysis.

As shown in Table 1 and Figure 2, there was a trend of higher imbalances for both the injured groups than for the noninjured group. Statistical analysis demonstrated a significant group effect for the peak-force variable, $F_{2,29} = 3.77$, $P < .05$, with post hoc Tukey honestly significant difference results showing the noninjured group and the upper-limb-injured group to be significantly different. For the injured group, the absolute bilateral strength imbalance for this variable represented 28% of that group's average maximum force. For the force-impulse variable, 1-way ANOVA did not show the trend of increased imbalance for injury groups to be significant, $F_{2,29} = 2.31$, $P = .118$.

In short, the kayakers classified as injured demonstrated the greater strength imbalances, with the peak-force data providing the greatest differences, showing a significant difference between the noninjured group and the upper-limb-injured group.

Discussion

There was a distinct trend of higher asymmetry in muscle strength in injured groups than in the noninjured group. Although both the dependent

Table 1 Data for Each Participant Group, Means (SDs)

Participant group	Number of days lost through injury	Peak-force imbalance (N)	Force-impulse imbalance (N · s)
Noninjured	0	1.97 (1.30)	269.7 (222.5)
Upper-limb injured	29.8 (17.0)	5.89 (4.11)	504.4 (322.4)
Trunk injured	66.7 (31.4)	4.84 (5.28)	341.8 (243.8)

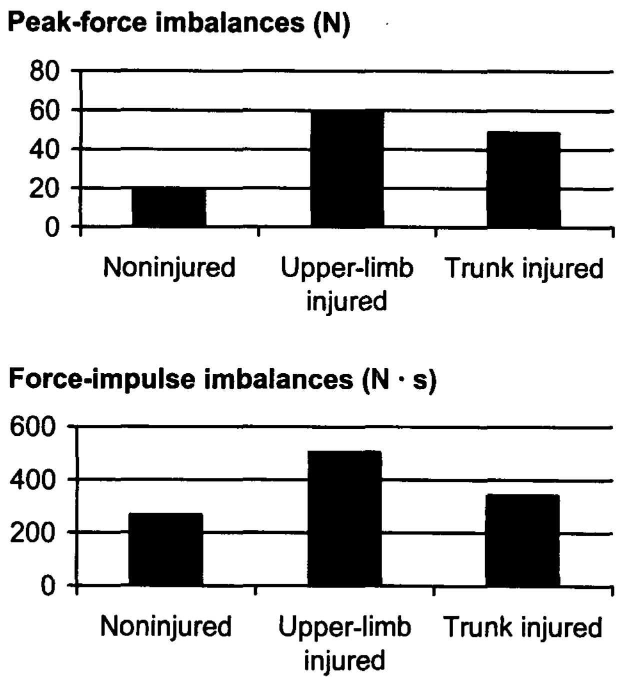

Figure 2 Strength imbalances of the injured and noninjured groups.

strength-imbalance variables—peak force and force impulse—demonstrated this trend, the peak-force variable was the more sensitive, showing greater differences. In fact, it was the results of the peak-force data that were significant.

With regard to the different classifications of injury origin, it was interesting to observe that none of the athletes in this sample reported any training interruption as a result of lower-limb injury, despite research suggesting that kayaking is a complete body action.[10] In terms of the remaining classifications of origin of injury, the upper-limb-injured group demonstrated greater bilateral strength imbalances.

There would appear to be 2 major points of interest that evolve from these data. First, What body segment is the most sensitive to injury-related bilateral strength imbalance in flatwater kayakers? Second, strength imbalance appears to be related to injury incidence. With reference to the first point, the presence of a significant difference in peak-force imbalance between the noninjured and the upper-limb-injured groups suggests that the upper limb is the body segment most sensitive to injuries related to bilateral strength imbalance in flatwater kayakers. Again, this might appear to be surprising; a sensible prediction would have been that large differentials in forces generated from left to right would cause injuries to be prevalent around the spine. One would expect that the distortion and disruption of the spine's alignment overload such structures and predispose them to injury.[2,3]

Another possible interpretation of these findings could be that the upper limbs are in fact more tolerant of strength imbalances than is the trunk in relation to kayaking. If this were so, one could expect to see larger imbalances in athletes with upper-limb injury, because the imbalance might not have reached a critical value that would cause catastrophic malfunction of the relatively more robust related joints and structures of the upper limbs. Because of the possible robustness of related upper-limb structure, such individuals would still be continuing with training and participation in such a study as this, despite their strength imbalances. However, if the trunk region were much more sensitive to strength imbalance, sizable imbalances could not develop, because the condition would cause structural damage and resulting pain that might stop training activities that would further the imbalance. If this were true, one would expect to see more kayakers classified as trunk injured than as upper-limb injured. Because this was not the case, another possible explanation of the data could be that the upper limbs (including shoulders) were disrupted through the distortion of the spine and related musculature, almost akin to a secondary or related injury, such as in Wadsworth and Bullock-Saxton's[11] finding that swimmers with unilateral injuries presented with bilateral muscle-function deficits.

Another explanation of why the upper limbs might be at a greater risk of injury through bilateral strength imbalance than is the trunk was offered by Parkhurst and Burnett.[12] After examining back injuries, they concluded that patients might use postures and movement patterns that, although maybe detrimental themselves, protect against more major pathologies. These maladaptive modified movement patterns then present symptoms of injuries secondary to the major injury or disposition.

Still another explanation, of course, might be that participants misperceived their trunk injuries as upper-limb injuries, this misdiagnosis being caused the secondary symptoms of the upper limbs, caused by the trunk's incorrect alignment, being the most "feelable" and distressing. To produce a more exact and confirmed explanation of our results, more research in this area is needed.

The second major point of these results is that the observed data do appear to give further support to the suggestion that strength imbalance is an important factor in sports injury occurrence even in seemingly "symmetrical" sports such as flatwater kayaking. However, although such measures of strength imbalance as those employed in this investigation may well act as warning signals to sport therapists, potentially alerting all involved of an increased risk of injury, the question of causality is still unanswered. This must be an important question for investigators in this field: Do strength imbalances cause injuries or vice versa? Until a well-developed answer to this question is produced, preventive and remedial physiotherapy will still strive for truly evidence-based practice.

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