Time course of changes in bilateral arm power of swimmers during recovery from injury using a swim bench

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Abstract

***Objectives*—There has been little research on the time course of recovery from injury in athletes. This is especially the case for recovery in arm power in injured swimmers. The purpose of this study was to compare the power output of the injured and non-injured arms of swimmers during recovery from injury by use of a maximal exercise test on a computer interfaced isokinetic swim bench.**

***Methods*—Thirteen swimmers (five men and eight women; age 18.8 (3.2) years; stature 1.76 (0.05) m; body mass 61.7 (5.9) kg; mean (SD)) gave written informed consent and were recruited to this study throughout a three year period. All subjects had experienced non-aquatic soft tissue injury to their dominant-side shoulder or upper arm in the three months before participation, but had been allowed to return to swimming training. All of the subjects had injured their dominant arm and the mean time for absence from training was 3.7 (1.1) weeks. At return to training and at four, eight, and twelve weeks thereafter, subjects performed two all-out 30 second tests on the swim bench by simulating the swimming arm action. From these tests, peak power output (PPO), mean power output (MPO), and power decay (PD) for each arm during the 30 seconds of exercise could be determined by averaging the two tests. The differences between return to training and the four, eight, and twelve week periods were analysed using repeated measures analysis of variance with Tukey b post hoc test.**

***Results*—The repeated testing showed 95% confidence intervals of ± 11.4 W for PPO, ± 9.5 W for MPO and ± 0.5 for PD. When the swimmers returned to training the results showed that PPO was 179 (21.9) *v* 111 (18.1) W (P = 0.02), MPO was 122 (9.8) *v* 101 (8.8) W (P = 0.01), and PD was 2.5 (0.6) *v* 5.2 (1.9) (P = 0.001) for non-injured and injured arms respectively (all values mean (SEM)). There were similar differences at four weeks which disappeared after eight weeks, except for that of PPO which was still evident (187.3 (21.9) *v* 156.8 (18.1) W; P = 0.01). At 12 weeks there were no differences between the non-injured and injured arm on any of the indices of arm power (P>0.05).**

***Conclusions*—These results suggest that, using the swim bench power test, differences in bilateral arm power output after injury persist for at least eight weeks after return to swimming training. These findings support the need for prolonged rehabilitation after such injury. This would best include physiotherapy and a training programme within which special consideration is given to the recuperation process.**

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Few studies have investigated the rate of recovery of neuromuscular function in swimmers after injury. Those studies that have reported the time course of recovery from injury are not specific to any particular athletic group and were performed after knee surgery.[1] The main reason for the paucity of data on swimmers seems to be the absence of suitable methods for assessment of arm power. Of course, this would be best performed during swimming, but there are obvious difficulties in making assessments of arm power in the water. This has stimulated the development of dry land techniques using arm cranking,[2] tethered swimming,[3] and especially the isokinetic swim bench.[3–5] However, none of these studies report arm power in swimmers after injury.

Recently, the isokinetic swim bench, which uses pulley ropes, has been interfaced with a microcomputer[6] enabling rapid collection of data during arm pulling, where the swimmer attempts to simulate the front crawl action. The advantage of the computer interfacing, which uses transducers to determine pull force and pull duration, is that it allows the collection of data from the right and left arm. Also, performance of movements that resemble those of the swimming arm action might be more suitable for swimmers than other testing modes. However, power output values from this mode of testing cannot be compared with those from established isokinetic dynamometry.[7] Nevertheless, the computerised swim bench has already been used in swimmers to assess the cardiopulmonary responses to exercise[5 6] and the critical power[8] and might be useful in assessment after injury.

Before this computerised system can be used to assess bilateral arm power it is necessary to establish an appropriate resistance setting (as found on the swim bench) for all-out exercise.

Furthermore, so that the changes between the sequential recovery periods can be evaluated, the expected bilateral differences and the variation in measurement should be determined. The test-retest reproducibility has been reported for the cardiopulmonary responses to exercise on the swim bench[5] but not for maximal intensity arm pulling.

Most studies of the rehabilitation process in sportspersons after injury have used isokinetic dynamometry and have centred upon recuperation from surgery, particularly of the knee.[9] The reported time to "full recovery" is about six weeks, but this end point is usually poorly defined. Indeed, recent studies[1] have shown that the quadriceps can remain weaker than the contralateral side for a period of up to 12 weeks after surgery. However, there are no comparative reports of the recovery pattern for bilateral arm power in swimmers after injury. Therefore the purpose of this study was to determine the time course of recovery of bilateral arm power after injury in swimmers using the computerised swim bench.

Methods

SUBJECTS

Thirteen swimmers (five men and eight women; age 18.8 (3.2) years; stature 1.76 (0.05) m; body mass 61.7 (5.9) kg; mean (SD)) gave written informed consent and were recruited to this study throughout a three year period. All subjects expressed a main preference for front crawl swimming over other strokes. Their mean (SD) best times were: 58.4 (2.7) seconds for 100 m. None was involved in specialised swim bench training programmes, but all subjects had previous experience in the use of the machine.

INJURIES

All subjects had experienced non-aquatic soft tissue injury to the dominant-side shoulder or upper arm in the three months before participation, but had been allowed to return to swimming training. Seven of the subjects had experienced acute trauma (impact blow) with rupture to the biceps, triceps, or deltoid. The other six had experienced acute trauma (impact blow) injuries to upper arm or shoulder tendons. None was experiencing chronic overuse injury to these regions. The mean length of time spent out of the water was 3.7 (1.1) weeks.

THE SWIM BENCH

The swim bench (H and M Engineering, Blaina, Gwent, Wales) consisted of two pulley resistance devices mounted on a steel bench, on to which the swimmer laid prone. The swimmers placed their hands into hand paddles attached to pulley ropes that operated the resistance devices and attempted to simulate the front crawl swimming arm action. A detailed description of this swim bench has been given previously.[5] The resistance devices consisted of two rotating drums around which the pulley ropes were wound. As tension was applied to the pulley rope, it rotated the drum which applied a braking force through friction pads. Resistance to the application of tension was such that the pull rope paid out at a velocity that ranged up to a preset maximum. This has been termed maximal pull velocity (MPV).[10] The resistance unit offered seven MPV settings (0–6) on a continuous scale.

The tensile force developed through the pull rope was measured using transducers attached to the swim bench chassis, through which the pull ropes passed. The applied tensile force and movement distance of each hand paddle was logged at 100 Hz by the transducers during stroking. The tensile force, pull rope distance, and duration of force as shown on the read out from the transducers can be easily calibrated by the suspension of known weights from the pull ropes. Mean power output for each stroke was computed by a microprocessor using pull force, distance, and duration as logged throughout each arm pull.

Subjects adopted a prone position and pulled on the hand paddles with alternating arms, thereby simulating the front crawl stroke. The subject was secured to the bench by a suitably mounted strap around the torso. Each individual was instructed to perform stroking in a similar fashion to that adopted in the swimming pool, maintaining maximal stroke length at all times.

DETERMINATION OF THE OPTIMUM PULL VELOCITY SETTING

Before the all-out testing it was necessary to determine an appropriate resistance setting for the isokinetic swim bench. This was administered using a separate group of swimmers (n = 12) who performed four ten second all-out tests at different resistance settings (MPVs). These resistance settings gave MPV of 3.1, 2.75, 2.6, and 2.45 m/s. These four tests were administered in a randomised order and were performed on subsequent days. The optimum value was determined by quadratic curve fitting procedures which allowed identification of the MPV that corresponded to highest peak power output (PPO).

VARIATION IN BILATERAL ARM POWER VALUES USING THE SWIM BENCH TEST

In this study the differences in bilateral arm power and test-retest variation in arm power values for non-injured swimmers was also determined. These were essential for comparison with those values recorded during recovery from injury. This was administered in the same subjects who performed the optimisation procedure (n = 12). All of these individuals performed two 30 second all-out tests on the computerised swim bench on subsequent days, 24 hours apart.

MAXIMAL EXERCISE TEST

All subjects performed two all-out 30 second exercise tests on each of four separate occasions. After being secured to the swim bench the swimmers were instructed to warm up by performing arm pulling at 25 W for two minutes. At the end of this period they were advised to extend both forearms so that their pulling could commence without the need for

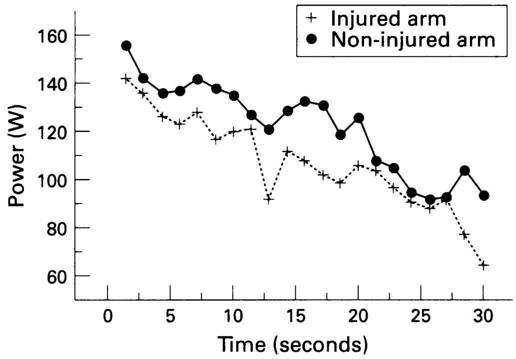

Figure 1 Example of the power output profile for injured and non-injured arms during an all-out 30 second swim bench test.

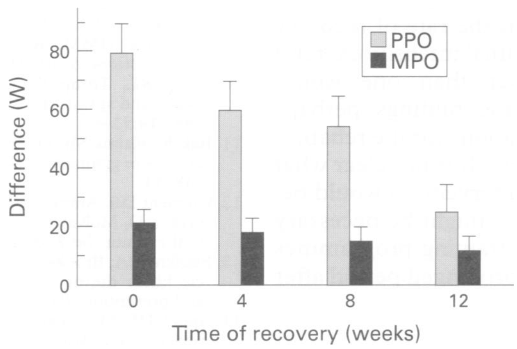

Figure 2 Mean differences in peak power output (PPO) and mean power output (MPO) for bilateral arm power at entry to the study and after four, eight, and twelve weeks of recovery from injury. Error bars represent SEM.

an initial recovery action. The subjects were prepared for the commencement of the test with the commands "ready, steady" and the exercise test began on the command "go". They were given verbal time references after 15, 20, and 25 seconds, then instructed to stop after 30 seconds had been completed.

THE TIME COURSE

All subjects were assessed twice on each of four separate occasions. They underwent the repeated testing 24 hours apart at entry to the study and at four, eight, and twelve weeks thereafter. All of these tests were performed at the same time of day and swimmers were asked to refrain from training on the day before testing. A light meal was consumed no later than two hours before testing.

STATISTICAL ANALYSIS

For analysis of repeated tests, analysis of variance was performed with Tukey b post hoc test. The variation in measurement of arm power values was expressed as the 95% confidence interval. A comparison of bilateral arm power in non-injured swimmers was made using Student's *t* test.

Table 1 Mean (SEM) percentage differences in bilateral arm power values at intervals throughout recovery from injury

	Percentage differences			
	0 weeks	*4 weeks*	*8 weeks*	*12 weeks*
PPO	51 (6.2)	34 (3.9)	22 (2.4)	11 (2.6)
MPO	27 (4.1)	16 (2.7)	8 (2.8)	3 (3.1)
PD	26 (5.3)	23 (3.6)	14 (3.1)	6 (2.7)

PPO, peak power output; MPO, mean power output; PD, power decay.

Results

The PPO values for the different MPV settings showed that the highest was achieved at 2.75 m/s. The differences in bilateral arm power values for non-injured swimmers were 13.1 (2.40) W for PPO, 11.7 (2.2) W for mean power output (MPO) and 0.6 (0.1) for power decay (PD) (all values are mean (SEM)). None of these differences were significant (P>0.05). A similar pattern emerged from the repeated tests with none of the arm power values being significantly different from one test to the other (P>0.05). The test-retest variation in measurement of arm power was ±11.4 W for PPO, ±9.5 W for MPO and ±0.5 for PD.

At return to training the arm power values for non-injured and injured arms respectively were as follows; PPO was 179 (21.9) *v* 111 (18.1) W (P = 0.02), MPO was 122 (9.8) *v* 101 (8.8) W (P = 0.01), and PD was 2.5 (0.6) *v* 5.2 (1.9) (P = 0.001) (all values mean (SEM)). There were similar differences at four weeks. However, at eight weeks only PPO was higher (187.3 (21.9) *v* 156.8 (18.1) W; P = 0.01). At 12 weeks the differences between the injured and non-injured arm were not significant on any of the indices (P>0.05). Figure 1 gives an example of the power output recording for injured versus non-injured arms, and fig 2 is a representation of the mean differences in arm power at the stated periods throughout recovery. Table 1 gives these differences as percentages.

Discussion

The time course of the recovery in arm power for swimmers has not been reported previously. Comparison can only be made with studies that have investigated the time course of recovery in bilateral leg power after knee surgery.[1] After such surgery athletes are reported to be able to walk within three days and resume athletic training within two to four weeks.[9] However, more recent comparisons of the time course of recovery of quadriceps peak torque has shown that muscle weakness can persist for up to 12 weeks after surgery.

Other studies have shown various times for recovery. The time to recovery after injury during training in gymnasts was about 30 days.[11] However, 22% of the injuries had a recovery period greater than six months. In 71 athletes with exercise induced injuries to the femur, the average time to recovery was reported to be 10.4 weeks,[12] whereas the recovery time was much shorter (30 days) after injury induced by eccentric muscle activity.[13] These reports appear to compare quite favourably with the results of the present study when the severity of the injury is taken into account.

The suggested explanations for the prolonged imbalance of power probably relate to loss of neural function, muscle atrophy, and reduced metabolic function.[14] These aspects of neuromuscular function are known to be the consequence of immobilisation or disuse after injury. The reported course of decreases in muscle strength involves rapid losses in the first week, and thereafter the decreases are attenuated. The atrophy experienced after injury is characterised by reduced protein synthesis and increased protein breakdown. Furthermore mitochondrial size and number are known to be affected soon after injury.[14] There are also reports that suggest that gains in these aspects of muscular function as an adaptative response to training follow a similar pattern.[15]

In summary, the results of this study suggest that there are significant differences in arm power up to eight weeks after injury of the dominant arm in swimmers. This impairment appears to persist even though these swimmers were allowed to return to regular exercise. These results suggest that the rate of recovery in arm power during maximal intensity exercise is probably much slower than one would expect. Furthermore these findings perhaps have their greatest implications for the rehabilitation process of swimmers. It is not clear what the effect of therapeutic intervention would be. However, it appears that it might be necessary to continue to adapt the training programmes of these individuals for a prolonged period after injury.

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