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INVITED COMMENT

THE INCREASING ADOPTION OF CONSUMER GRADE WEARABLES:
COMPARING THE APPLES AND ORANGES OF SPORT SCIENCE

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The increasing adoption of off the shelf wearable technologies by sports scientists is a real sign of the times. It was not so long ago that the thought of using lab based body mounted sensors was new and even treated with suspicion. Today, specialist products for sports science exist and the use of the underlying sensors has been well validated¹ and since that time, have been applied to all manner of sporting applications²,³. Body mounted instruments offer comparable (though sometimes different) method of the quantification of human activity. It has opened the way for consideration of the use of body mounted sensors for a variety of purposes and offered an opportunity to study human movement in relatively unconstrained environments⁴ where considerations such as ecological validity could be removed. Not only outside the lab, but for the first time the performance environment could itself be assessed. In competitive sport the issue of feedback and unfair advantage had to be considered and today GPS sensors are accepted in many forms of team sports during competitive practice.

This change has been driven in no small part to worldwide trends in electronic industries that make this possible. The well-established trend of miniaturisation of electronic components, first proposed by Moore in the 1960’s shows the doubling of complexity every 18 months⁵. The net effect of this is that devices become proportionally smaller and cheaper. This has led to market place convergence of a range of technologies (of which smart phones are a mash up of many components including computer platform, sensors, video camera and web aware telemetry platform). In turn the market responds with a greater demand for these products as they become increasingly useful and inexpensive in the growing consumer sports technology market⁶.

It is here that sports science’s traditional approaches to measurement and instrument is itself subject to digital disruption and the Fitbit is a good example of that⁷. Here we have a consumer product, itself a trickle down by product of the work that has been undertaken in sports science and allied health, that not only have their origins as tools of science creating a market, but also opening up opportunities not possible by these more mature and dedicated products.

Whilst products like the Fitbit and what are used professionally on the surface are measuring the same thing and do so using the same basic sensors,
i.e. accelerometers, each product is driven by its different market segment and achieves its goals through different design decisions. Understanding these, leads to making better decisions when choosing what is the best tool for a particular application.

Lab based technologies (ambulatory or fixed) have a significantly higher cost, both the capital required to purchase and the more hidden cost, that of having a user suitably experienced to use it. Thus they are suited to high accuracy studies of not too many participants. Commercial wearables on the other hand are at least an order of magnitude cheaper to purchase and can be used widely. They represent an opportunity to do larger scale studies of more participants and don’t require a sophisticated operator. These products, driven by the desire for social engagement (consumers like this interaction and are more likely to continue to use and purchase in the future) over data aggregation opportunities across whole communities. Therefore commercially popular devices can possibly be an option for researchers to consider using.

Research quality monitoring platforms, typically use high rate sensors, today in the order of 1000 Hz. In addition they may also have other sensors, modularity and to accommodate for long periods of operation large capacity batteries. All data is collected and stored in raw form with the minimum of filtering, to allow for the most robust of analysis later on8. Fitbits and other commercial wearables need to make substantial compromises to achieve their small form factor and lower cost, so available computational power, sensor sets and batteries all must be substantially smaller. These compromises necessitate much lower sample rates, typically around 10Hz, or interrupt driven footfall events. Raw data is stored in aggregate form, usually in epochs that provide enough accuracy for a user and reduce the required amount to be stored, for example a 1 minute epoch of 10 Hz data is a 600 times reduction in data, but the trade off is resolution and accuracy.

As these consumer products continue to create a market appetite for such technologies, so too the market eventually becomes more sophisticated and the appetite for greater accuracy grows. Coupled with technology trends we will increasingly see products like the Fitbit grow ever closer to their research quality cousins. Consider this, rather than doing studies of $n=20$ for statistical significant that $n=2M$ is well within the realms of possibility…how exciting.

For now though they each have a role and a place. Understanding both of these in conjunction with either accepting an accuracy compromise, or that accuracy is paramount, for a sports scientist. Therefore, the sports scientist has to not only understand his or her objective, but needs to have considerable knowledge in the technology to be able to make an informed choice. In comparing apples with oranges it is perhaps helpful to see them as a fruit salad for the consumption of the discerning fitness professional.

REFERENCES

LITERATURE REVIEW

THE EFFECTS OF RESISTANCE TRAINING ON SPRINT AND ENDURANCE PERFORMANCE IN MASTERS ATHLETES: A NARRATIVE REVIEW

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ABSTRACT

Participation of masters athletes (>30 years) in sprint running (100-400 m) and sprint track cycling (200 m, team sprint, 1-km) has increased significantly over recent decades. With aging, sprint and endurance performance gradually declines. The present review focuses upon the effects of resistance training on sprint and endurance performance and its physiological determinants in masters athletes. The available research demonstrates that resistance training interventions in masters athletes lead to beneficial adaptations in both sprint and endurance athletes. With inclusion of heavy strength training exercises in sprinters’ training regimen, increases muscle mass, size of fast fibres and rapid neural activation capacity along with improvements in maximal, explosive and sprint force production have been observed. In endurance athletes, strength training has been shown to lead to increased maximal and explosive muscle strength levels. The actual event-specific performance changes are typically smaller, but significant (p<0.05), with a 2-4% reduction in sprint running times and 3-6% improvement in endurance cycling and running economy. Taken together, these limited data suggest that resistance training programs produce positive effects on physiological determinants of sprint and endurance performance that result in enhanced sport performance capacity in masters athletes. Further research on these issues is needed to design and deliver optimal training programs to aging athletes.

Keywords: veteran, older athletes, sprint running, cycling, aging, strength training, endurance performance.

INTRODUCTION

Masters athletes are individuals who participate in local, national or international competitive sporting activities specifically designed for middle-aged and older adults.1 Over recent decades there has been a significant increase in the number of masters athletes continuing to train and compete at high performance levels within both individual sports2,3 and multi-sport events.4 The rising popularity of masters sporting competitions can be seen by the increasing numbers of participation in the World Masters Games. For example, the first World Masters Games in Toronto in 1975 had over 8 000 competitors, while in 2009 over 28 000 athletes took part in World Masters Games in Sydney.5 Moreover, participation trends in masters track cycling, are also increasing. In 2005, there were 292 entrants from 20 nations who took part in the Union Cycliste...
Internationale (UCI) track cycling masters world championships and in 2013 this number increased to 400 entrants, from 28 countries. Taken together, these data highlight the increasing participation numbers in competitive masters sporting events.

In track-cycling, the 200 m flying start is the qualifying event for sprint competition, which is considered the most explosive effort amongst high-performance track cycling events. Leading international younger male track-cyclists, compete this event in 10 seconds (females in 12 seconds) with cycling cadences between 150-160 rpm and power outputs of 18 to 22 W/kg. Elite younger male sprint runners complete 100 m event in 10 seconds (females in 11 seconds) with running velocities of up to 12 m/s during maximum speed phase. Such performance requires peak power outputs that approach 18 W/kg. Thus, both sprint cycling and sprint running performance impose high demands on maximal speed-power capacities affected by anaerobic ATP-creatine phosphate and glycolytic systems. Therefore, one important challenge for both researchers and strength and conditioning coaches is to find the most effective training methods that might counteract the well-documented decrements in sprint and endurance performance in masters athletes.

In light of these findings, it might be suggested that the inclusion of a resistance training program into sprint training programs may enhance sprint performance in aging athletes. Indeed, previous research has demonstrated there is a need for masters athletes to engage in resistance training programs to improve sprint performance for three reasons. Firstly, hypertrophy resistance training may offset the age-related decrease in both muscle fibre size and number commonly observed in aging populations. Secondly, high-intensity resistance training stimulates fast-twitch muscle fibres and motor units. Finally, both explosive power weight training exercises and plyometrics maximise coordinated neuromuscular recruitment and elastic behaviour of muscle-tendon complex. The purpose of this narrative review is to examine the effects of resistance training on sprint and endurance running, and cycling performance in masters athletes.

**METHODS**

A literature search was conducted between November and December 2015 using the electronic databases of Ausport, Cochrane, Embase, Scopus, Sportdiscus and Medline. The following search terms of masters athlete OR veteran AND strength training OR resistance training were used. Studies were included in this review if they satisfied all of the following criteria: male, aged 30 years or older and described as masters athletes or veteran, who participated in a resistance training intervention (figure 1). Further restrictions were applied to only include full-text peer reviewed articles, available in English language. An additional perusal of relevant reference lists was also undertaken to further ensure all relevant data has been identified.
### Table 1: Studies investigating the effects of resistance training on sprint and endurance performance in masters athletes

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Training protocol</th>
<th>Outcome Measures</th>
<th>Finding</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piacentini et al. (2013)</td>
<td>16 TMER</td>
<td>44.2 ± 3.9 years</td>
<td></td>
<td>MST Group: 4 x M 2 x F, RT Group: 3 x M 2 x F, C Group: 5 x M 2 x F</td>
<td>6-wk CERS</td>
<td>Significant increase in 1RM LP and RE in the MST group only.</td>
<td>16.3% increase in leg press 1RM LP in MST group. 6.1% increase in RE in MST group</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RT: two times per week, 3x10, 70% 1RM, bench press, lat pulldown, seated row,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cable shoulder press, triceps extension, bicep curl. ½ squat, calf press,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>lunge, eccentric leg extensions on leg press</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MST: 4 x 3-4, 85-90% 1RM, same exercises</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Louis et al. (2012).</td>
<td>9 TMEC</td>
<td>51.5 ± 5.5 years</td>
<td></td>
<td>Gender not specified.</td>
<td>3-wk CER</td>
<td>Significant increase in KE MVC, Tmean and CE.</td>
<td>17.8% increase KE MVC in TMEC. 5.9% increase in KE MVC in TYEC. 6.9% increase in Tmean in TMEC. 3% increase in CE in TMEC.</td>
</tr>
<tr>
<td></td>
<td>8 TYEC</td>
<td>25.6 ± 5.9 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cristea et al (2008)</td>
<td>9 TMS</td>
<td>54.7 ± 5.5 years</td>
<td>males</td>
<td>20-wk CSR RT: two times per week, periodised sets and reps scheme. ST: two s-wk,</td>
<td>10m SV, 60 m ST, 1RM SQ, SJ, TJ</td>
<td>Significant increase in SV/60 mST, 1RM SQ, SJ and TJ performance</td>
<td>4% increase in 10 m SV. 2% increase in 60 m ST. 27% increase in 1RM SQ. 10% in SJ. 4% increase in TJ.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20-60 m track sprint training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaburn and Mackinnon (1996)</td>
<td>12 TMS</td>
<td>54.7 ± 5.5 years</td>
<td>males</td>
<td>8-wk CSR RT: two times per week, 3 x 8-12RM leg extension, leg curl, leg press,</td>
<td>100 m ST, 300 m sprint time, QS MVC, HS MVC, TC</td>
<td>Significant improvement in 100 m sprint performance, TC, QS and HS PT</td>
<td>4% improvement in 100 m sprint time. 1.1% increase in QS PT and HS PT. 1% increase in TC.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>half-squat. ST: 8-wk, two times per week, 100 &amp; 300 meter track sprint training</td>
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</tr>
</tbody>
</table>

**TMER** = Trained Masters Endurance Runners; **MST** = Maximum Strength Training; **RT** = Resistance Training, **C** = Control Group; **1RM** = 1 Repetition Maximum; **LP** = Leg Press; **CMJ** = Countermovement Jump; **SQ** = Squat, **SJ** = Squat Jump, **RE** = Running Economy; **TMEC** = Trained Masters Endurance Cyclists; **TYEC** = Trained Younger Endurance Cyclists; **CER** = Concurrent Endurance and Resistance Training Program; **CE** = Cycling Economy; **KE** = Knee Extension; **MVC** = Maximum Voluntary Contraction; **Tmean** = mean torque development; **TMS** = Trained Masters Sprinters; **CSR** = Concurrent Sprint and Resistance Training Program; **SV** = Sprint Velocity; **ST** = Sprint Time; **TJ** = Triple Jump, **QS** = Quadriceps, **HS** = Hamstrings, **PT** = Peak Torque, **TC** = Thigh Circumference, **30WT** = 30 Second Wingate Test, **CSA** = Cross Sectional Area, **IHSMF** = Isometric Half Squat Maximal Force.
RESULTS

A total of four studies met the inclusion criteria and were subsequently included in this review. Of the four articles reviewed, a total of 46 trained masters athletes (37 males and 9 females), with a mean age of 52.2 ± 8.8 years, participated in a resistance training intervention. Intervention components such as the frequency of sessions, the duration of interventions varied. Specifically, duration of interventions ranged from 3 – 20 weeks, while the frequency of interventions ranged from 2-3 sessions per week. Results suggest significant improvements (p<0.05) in 60 m and 100 m sprint time, running economy, cycling economy, knee extension peak torque and 1RM squat and leg press strength. Further details are provided in table 1.

DISCUSSION

The effects of aging on sprint running and sprint cycling performance

This first section reviews research that has investigated the age-related decline in the energetically similar events of 100 m sprint running and 200 m sprint cycling performance.

A number of studies have investigated the decline in sprint running performance with age. For example, Suominen (2011) examined world 100 m sprint running records and reported that running speed declined quite linearly by 6% per decade in men between 20 and 80 years, and in females by 7% per decade between 20 and 75 years. After age 75-80 years, reductions in 100 m record performances become more evident. In a study conducted in European Veterans Athletics Championships, Korhonen et al. (2003) observed that in 100 m finalists, maximum speed declined by 5-6% per decade in men between 20 and 80 years, and in females by 7% per decade between 20 and 75 years. After age 75-80 years, reductions in 100 m record performances become more evident. In another study, researchers investigated the blood lactate concentrations in a group of male and female masters sprint runners (40-88 years) following competitive 100 m, 200 m and 400 m sprint running. The researchers reported blood lactate concentrations were significantly lower in the sprinters aged between 70-88 years. This implies that decreased ability to generate energy from anaerobic glycolysis may be additional factor in the age-related decrease in sprinting ability after 70 years.

Similar age-related declines in metabolic power appear to occur in sprint performance in both veteran runners and veteran cyclists. Metabolic power represents the rate at which energy is generated and it is commonly expressed in relation to body mass (watts/kg). The relative metabolic power in 100 m sprint running performance has been reported to decline by 30% (approximately 10% per decade) from 40 to 70 years in competitive male sprint runners. In veteran cyclists, Balmer et al. (2005) reported in a cross-sectional study of competitive male cyclists aged 30 to 73 years, ramped minute power (watts) measured via air-braked cycle ergometry declines by 2.4 watts per year. More recently, Ampratzis et al. (2011) compared absolute values of both 100 m sprint running and inertial cycle ergometry power in male masters endurance cyclists and 100 m sprint runners aged 40 to 65 years. Their findings suggest a similar decline in both sprint cycling power (25.3% per decade) and 100 m sprint running power (25.4% per decade) between the ages 40 and 65 years.

To date, few studies have examined the age-related decline in sprint cycling performance. Martin et al. (2000) reported that maximal cycling sprint power, as measured during 3-4-s all-out effort using inertial load cycle ergometry, declined by 7.5% per decade in competitive male cyclists aged 30-70 years. The researchers reported the decline in maximal power was reduced to 5% per
decade when scaled to lean thigh volume, suggesting a decrease in muscle mass commonly observed in older athletes \(^9,26,27\) may be a major contributor to age-related declines in track cycling performance. It was also found that with age the pedalling rate at which peak power was attained decreased from 124 to 114 rpm and this was thought to reflect age-related reduction in cross-sectional area occupied by fast type 2 fibres. In addition, Gent & Norton (2012) \(^28\) reported anaerobic peak power measured by 10-s all-out effort using wind-resisted cycle ergometry declined by 8% in both male (n=156) and female (n=17) masters cyclists aged 35-64 years. Taken together, these data suggest cycling peak power declines by 5-8% in masters-cyclists.

We recently examined the current masters 200 m track cycling world records for age-related changes in track cycling performance (see Figure 1). The results suggest 200 m track sprint cycling performance declines by 2.8% and 11.2% per decade in males and female track cyclists, respectively. The data in figure 1 appears to suggest a linear decline in flying 200m performance with increasing age in both male and female masters cyclists. Interestingly, cycling times in the 40-44 year category for males and 45-49 year category for females are slightly faster than the male 35-39 year and female 40-44 categories, faster times in these slightly older cohorts may be a result of improved training practices, track-cycling experience or simply, a more athletic group. Taken together, these competition results are in agreement with previous laboratory-based research which reported that in trained cyclists, the decline in anaerobic performance is magnified from 60 years.\(^25\)

The effect of resistance training on sprint running and sprint cycling performance

In athletes of any age, resistance training programs aim to increase muscular strength, neuromuscular power and sprint performance.\(^29\) For masters athletes, to minimise the age-related decline in physiological function, muscle morphology, and neuromuscular function, resistance training programs should include hypertrophy, strength and power training components for the following three reasons.\(^30\)

Firstly, muscle force production capacity is proportional to muscle size and hypertrophy resistance training is required to offset the age-related decrease in overall muscle size, strength and power.\(^13\) Secondly, heavier resistance training is required to stimulate fast twitch muscle fibres and

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Figure 2: Male and female masters flying 200 m track cycling records
motor units, necessary for the improvement of rapid force production. Thirdly, explosive power resistance training exercises and plyometric exercises are required to maximise neuromuscular stimulation and the utilisation of muscle-tendon elasticity. However, limited research has investigated the effectiveness of resistance training programs in masters athletes. Indeed, no data are currently available on the effect of either resistance training in masters track-cyclists. Nevertheless, it could be hypothesised, that optimal training in middle- and older-aged sprint cyclists, should follow the guidelines of younger athletes and emphasise resistance training along with sport specific sprint cycle training. The aim of the following section is to review the effectiveness of resistance training programs, in improving sprint performance in masters sprint runners, masters endurance cyclists and masters endurance runners.

**Resistance training programs improve sprint performance in masters sprint runners**

To date, only two studies have investigated the effects of resistance training on sprint running performance. Reaburn & Mackinnon (1994) examined the effect of an eight-week hypertrophy training program on 100 m and 300 m sprint run performance, muscular strength and thigh girth (measured anthropometrically) in eight male sprint-trained runners (54.7 ± 5.5 years). Resistance training took place three times per week on alternative days for an eight week period under the supervision of an experienced and qualified trainer. The participants performed three sets of 12, 10 then 8 repetitions at 80% of 1RM with one minute rest between sets. Exercises selected included leg extensions, leg curls, leg press, half squats, bench press, upright row, bicep curl, triceps push down and abdominal crunches. 1RM capacity was measured every two weeks to adjust training loads appropriately. Subjects were instructed to maintain their normal sprint training regime over the period of the study. At the conclusion of the eight-week study, significant improvements were observed in both 100 m (4%) and 300 m (2%) sprint running performance, quadriceps peak torque (10.3%), hamstring peak torque (12%) and thigh circumference (3.4%).

More recently, Cristea et al (2008) investigated the effect of a 20-week combined sprint, strength and power training program on sprint running performance, morphological and neural adaptations in seven sprint-trained masters track athletes (66.0 ± 3.0 years) who had no previous resistance training experience. The resistance strength and power training program was designed to increase explosive power, strength and muscle hypertrophy, while the sprint training was designed to improve acceleration and maximal running speed. Both resistance training and sprint training sessions were performed twice per week on non-consecutive days. The training program was divided into three cycles. The first cycle involved muscular hypertrophy training protocols (3-4 sets, 8-12 repetitions at 50-70% 1RM). The second and third cycles involved combined plyometric, maximal strength and explosive weight training strength exercises used 4-6 repetitions at 70-85% 1RM, explosive exercises (high-load speed strength used 2-3 sets of 4-6 repetitions at 35-60% 1RM), the plyometric exercises (low-load speed strength used 2-3 sets of 3-10 repetitions). Cycle two used similar exercises and repetition ranges as used in cycle one, but with a general increase in intensity through an increase in load and the addition of plyometric and explosive exercises. In cycle 3, reductions in training volume across both sprint running and resistance training exercises occurred to prevent overtraining.

During the first cycle, the sprint runners performed five times 200-250 m runs at 75-85% of maximum sprint running speed. The field sprint sessions were purposefully designed to develop speed endurance with low volumes to accommodate the resistance training program. To develop acceleration, the athletes performed four times 30 m sprints at 80% of maximal effort. During the second and third training cycles, sprint intensity was gradually increased until near maximal speeds were reached. Workouts included two to three repetitions of 30-80 m sprints at 90-98% effort. At the conclusion of the 20-week
training period, significant increases were observed in maximum sprint velocity (4%), ground reaction force in the propulsive phase of contact (8%), 1RM squat strength (27%), squat jump (10%), triple jump (4%) and power of reactive jump test (29%), while 60 m sprint run time was significantly decreased (2%). Significant increases were also noted in the size of fast twitch muscle fibres (20%) and electromyographic activity of leg extensor muscles in squat jump performance (9%).

Examining the effect of resistance training on sprint performance in masters sprinters is limited by very few recent studies, small samples sizes and short intervention periods. Therefore, based on the available literature, these results suggest that resistance training increases muscle mass, fast twitch muscle fibre size and rapid neural activation, thus positively affecting strength, power and sprint performance in masters sprint runners. However, the effects of resistance training on track-cycling performance in masters track-cyclists is not yet known.

**Resistance training programs improve running and cycling performance in masters endurance runners and cyclists**

Limited research has examined resistance training effects in endurance-trained masters runners and cyclists. Previously, Louis et al. (2010) investigated the effect of a 3-week resistance training program on cycling efficiency in nine endurance-trained male masters cyclists (51.5 ± 5.5 years) and eight endurance-trained younger (25.6 ± 5.9 years) cyclists. Before and after the program, participants performed a 15 minute cycling efficiency test that measured the ratio between external power output and energy expenditure. Following the initial testing protocols, participants performed 10 sets of 10 repetitions at approximately 70% of 1RM load three times per week on a pin-loaded knee extension machine with three minutes rest between each set, whilst maintaining their usual endurance training (7 hours per week). Upon completion of the three-week resistance training program, the endurance-trained masters athletes significantly increased both knee extensor maximal voluntary contraction torque (17.8%) and cycling efficiency (3.0%).

Resistance training may also benefit masters endurance runners, by increasing running economy. In their study, Piacentinni et al (2013) investigated the effects of a 6-week resistance training program on running economy in 16 male and female masters endurance runners. Participants were randomly divided into one of three experimental groups, a maximal strength training group (n=6, 4 male and 2 female, 44.2 ± 3.9 years) who performed 4 sets of 3-4 repetitions at 85-90% of 1RM, two times per week, a resistance training group (n=5, 3 male and 2 female, 44.2 ± 3.9 years) who performed 3 sets of 10 repetitions, at 70% of 1RM, two times per week and a control group (n=5, 5 males, 43.2 ± 7.9 years) who continued with their normal endurance training. Upon completion of the six-week training program, only the maximum strength training group made a significant improvement in running economy at marathon pace (6.1%) and dynamic leg strength (16.3%).

Thus, this limited data suggests resistance training programs may produce positive effects on both running and cycling performance in masters endurance runners and masters endurance cyclists. However, research has not yet examined the effects of resistance training on track-cycling performance in masters track cyclists. Therefore we can only speculate that improvements in track cycling performance may result from additional resistance training, which limits the age-related decline in muscle mass, muscle strength and neuromuscular power.

**CONCLUSION**

The present review suggests the addition of a resistance training program to sprint running, endurance running or endurance cycling, may lead to additional benefits in performance for masters athletes. However, no research to date, has examined the effect of resistance training on track cycling performance in masters track cyclists. Therefore, future research examining the effect of resistance training on track-cycling performance in masters track-cyclists is needed.
PRACTICAL APPLICATIONS

- Resistance training may benefit sprint running performance, endurance running and endurance cycling performance in masters athletes.
- The effect of resistance training on track-cycling performance in masters track-cyclists is currently unknown.
- The volume of sprint training may need to be reduced, in order to accommodate for the inclusion of additional resistance training.
- Resistance training programs that incorporate power development, strength development and hypertrophy are recommended.
- Hypertrophy training may be maximised by prescribing loads of 70% of 1RM for 3 sets x 10 repetitions, 2-3 times per week. Strength training may be maximised by prescribing loads of 85-90% of 1RM for 2-4 sets x 4-6 repetitions, for two-sessions per week and finally power training may be maximised by prescribing loads of 35-60% of 1RM for 2-3 sets x 3-10 repetitions, for two-sessions per week.
- Participation in vigorous physical activity such as organised sport or resistance and sprint training poses greater cardiovascular risks to the masters athlete than lower intensity competitive sports, such as golf, billiards and lawn bowling. Therefore strength and conditioning coaches should be aware of the contraindications to exercise before prescribing a resistance and/or sprint training program for a masters athlete.

REFERENCES:


ORIGINAL RESEARCH

VALIDATION OF A SINGLE INERTIAL SENSOR FOR MEASURING RUNNING KINEMATICS OVERGROUND DURING A PROLONGED RUN

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ABSTRACT

Introduction: The purpose of this study was to validate acceleration data from a single inertial sensor containing a tri-axial accelerometer, whilst running overground during a prolonged run against a motion analysis system.

Methods: An inertial sensor was placed on the low back of 10 runners who performed an 8 km run on a treadmill. To provide validation of the sensor, data were collected as runners ran along a runway through a motion analysis system at the beginning and throughout the run.

Results: High levels of agreement between the two systems were found in the craniocaudal and mediolateral acceleration, with anteroposterior having the least agreement with greatest Typical Error of the Estimate (0.66 sample points). Very high to extremely high correlations across all testing times were found in all three directions of accelerations (r=0.75 to 0.95). Heel strike and toe off events were identified in anteroposterior and craniocaudal acceleration, with high levels of agreement and extremely high correlations (r=0.99) between the two systems. Minimal variation and change in agreement and correlation between the data at each testing time were found.

Discussion: This study provides evidence that a single inertial sensor placed on the low back is valid for measuring three-dimensional acceleration in overground running during a prolonged run. Further analysis identified specific events of heel strike and toe off and were comparable between the two systems. The minimal variation and change in agreement between the two systems during the run indicates the adherence method of the inertial sensor was suitable.

Conclusions: The results of this study indicate that data collected from a single inertial sensor is highly correlated with simultaneous data collected using a motion analysis system, and has the capability to identify heel strike and toe off events in overground running throughout a prolonged fatiguing run.

Keywords: accelerometer, sensor, running, motion analysis.

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**INTRODUCTION**

Long distance running is a prolonged repetitive activity and fatigue causes changes in running kinematics\(^1\). To date, the assessment of running kinematics during prolonged runs have typically been conducted on treadmills using motion analysis systems and ground reaction force measurements\(^2,3,4\). While these systems provide accurate measurements they are restricted to laboratories, only providing snippets of information and not allowing for continuous analysis of prolonged running in outdoor overground environments. Furthermore, biomechanical differences between treadmill and overground running have been reported\(^5,6\). Strohrmann et al.\(^1\) reported differences in step frequency and vertical displacement during prolonged treadmill running but not during overground running, while Sinclair et al.\(^5\) found differences in lower limb kinematics between short overground and treadmill steady-state runs. These findings suggest that treadmill running may not be comparable to overground running, and highlights the need to use technology that is capable for the analysis of prolonged running in field conditions. Additionally, due to long distance running being a prolonged repetitive activity, the technology needs to be capable of continuously collecting data over a prolonged time.

The use of inertial sensors are becoming increasingly popular for the analysis of human movement. They small, lightweight and practical, with the capability to collect continuous three-dimensional acceleration data to measure human movement in field conditions\(^6,7,8\). A single inertial sensor placed on the low back provides a simple and effective method to examine movement near the centre of mass (COM)\(^9\). Not only is a low back mounted position the closest external point to the whole body COM, it is the lowest point where a single measuring device can monitor left and right lower limb kinematic data, such as heel strike and toe off. Furthermore, this position would most likely be the best position to measure contralateral changes in gait symmetry\(^9\) that may present in running gait due to variables such as fatigue during prolonged running. Studies have used the COM placement method to assess running kinematics during treadmill running\(^6,7\) and short overground running\(^8\). MacGregor et al.\(^7\) demonstrated that a single inertial sensor placed on the low back was capable of accurately and reliably estimating energy expenditure and running mechanics during treadmill running and found differences between trained and untrained runners. Using the same sensor location Le Bris et al.\(^8\) found increases in mediolateral acceleration data in runners during a short exhaustive overground run indicating alterations in running patterns with fatigue. While these studies demonstrate that a single inertial sensor placed on the low back has the capability to measure human movement near the centre of mass, currently there is a paucity of research using this method to assess kinematics during overground running over a prolong run.

To ensure that inertial sensors provide accurate information in overground running during a prolonged run, validation against a criterion instrument or measure is required\(^10\). Laboratory based three-dimensional motion analysis systems have been used for gait analysis and are a well-established criterion for the analysis of movement\(^11,12,13\). Recent studies have validated the use of an inertial sensor placed on the low back for measuring gait events and vertical acceleration of the COM against a motion analysis system during short treadmill runs\(^9,14\). However, no studies have validated the use of a single inertial sensor against a motion analysis system to assess kinematic variables in overground running during a prolonged run. Such a validation would benefit from further research.

While previous research has validated temporal gait kinematics in running\(^14\), this was not for extended durations. While Lee et al.\(^9\) reported that inertial sensor data alterations in left and right running symmetry with changes in speed, the authors did not report whether fatigue had the same detectable effect on inertial sensor output. Once validated, this may provide unique opportunities for in-field, real environmental assessment of prolonged running gait kinematics that may not be achievable in simulated laboratory conditions.
settings. To determine whether kinematic measures and changes reported in the inertial sensor studies are needed to determine kinematic changes over extended time periods and provide important information about fatigue-related kinematic changes that occur during long distance running. This information can then be utilised to improve understanding of changes that may be detrimental to performance or increase the risk of injury.

If a single inertial sensor placed on the low back is shown to be valid, then more advanced analyses may be obtained. These include heel strike and toe off events in the gait cycle. These gait events can then be used for further analysis for measuring contact time, flight time, stride and step durations. This provides relevant information on a runner’s spatiotemporal characteristics, and provides trainers and runners with relevant information on a runner’s running style under field conditions.

The ability for sensors to remain in place on the trunk with movement has been suggested to contribute to errors in acceleration data. During a prolonged run, there is increased opportunity for alteration in the position of the sensor compared to a short run, leading to an increased risk of error in the acceleration data. Again highlighting the need to validate inertial sensor data capture during a prolonged run.

Therefore, the aims of this study were to: 1) compare acceleration data collected using an inertial sensor with a laboratory motion analysis system in overground running during a prolonged run, and 2) determine whether specific events in the running gait cycle (heel strike and toe off) were identified consistently by both data collection methods.

**METHODS**

**Participants**

Ten (six male; four female) recreational runners (27.5 ± 9.5 years, 175.8 ± 8.1 cm, 69.5 ± 11.8 kg) were recruited. Participants were included if they ran at least 30 km per week (average 52.5 ± 12.75 km/week), were injury free at time of testing, and had no lower extremity abnormalities that affected their gait. The study was approved by the James Cook University Human Research Ethics Committee (H5217).

**Procedures**

Participants wore clothing that allowed their lower back to be exposed. The sensor was adhered using double-sided tape directly to the skin of the runner’s low back, and secured with an elastic bandage that was wrapped over the sensor and around the waist. Reflective markers were adhered with double-sided tape on the sensor and on the midpoint of the rear foot (calcaneal) and the forefoot (distally on the 1st metatarsal) of the participant’s shoes. A sport specific inertial sensor was used and calibrated using software from a custom toolbox.

The inertial sensor (52 x 33 x 10 mm, mass 21 g) comprised of a tri-axial accelerometer (sampling at 100 Hz, saturation at 8g) and an antero-posterior (Z) axis. The three-dimensional axes of the sensor were manually orientated with the anatomical (orthogonal) axes of the craniocaudal (X), mediolateral (Y) and anteroposterior (Z) directions with the participant standing in a static position.

The kinematic three dimensional positioning data of the reflective markers were recorded using a 12 infrared camera motion analysis system and supporting software (NEXUS v1.8, Vicon Motion Systems Ltd. UK) operating at 100 Hz. Calibration of the system and capture zone was carried out using the calibration wand as per the manufacturer’s instructions.

**Running Preparation**

Prior to commencing the running protocol, participants were familiarised with running on the treadmill, how to safely dismount the treadmill and run along the runway of the motion analysis laboratory. Participants completed a five minute warm-up on the treadmill prior to commencement of data collection.

**Running Protocol**

The treadmill gradient was fixed at 1% to compensate known variances between treadmill and overground running and ensure energy expenditure...
was close to the participant’s experience when running on level surfaces. Following warm-up, participants ran along the 50 m runway of the motion analysis laboratory. This was repeated on the return run. Overground running data were collected during this run using a 10 m long infrared camera capture field situated mid-way along the runway. Participants then mounted the treadmill to begin the 8 km run, and instructed to run at a self-selected pace typical of their aerobic training for the entire 8 km. Participants dismounted the treadmill after 2 km, 4 km, 6 km, and 8 km to run along the runway. Participants were only off the treadmill for a short period of time to run through the runway once and then remounted the treadmill to continue the prolonged run. During each runway run, overground data within the infrared capture field was collected simultaneously via the inertial sensor and the motion analysis system.

**Synchronisation of Measurements**

Synchronisation of the inertial sensor and motion analysis system data were achieved using first contact with the ground within the infrared camera motion analysis system’s capture field. Both systems’ recording commenced before participants entered the camera capture field. Strides were counted from the commencement of the run to the first contact within the marked boundary of the capture field. From these synchronised data points acceleration changes at any given point in any plane was compared for agreement between the two systems.

**Signal Processing**

Heel strike and toe off events were identified in raw sensor data to ensure no loss or timing shift from filtering. All three channels were used to identify both events. Heel strike was identified at the point where the Z acceleration began increasing towards its large impact peak (Figure 1). For toe off, an algorithm detected the zero acceleration crossover in the X acceleration data. The same events in the motion analysis system were identified in the system’s signal processing function prior to differentiation and filtering. For the motion analysis system, heel strike was deemed as the lowest vertical displacement of the calcaneal positioned marker and toe off was the first vertical displacement of the 1st metatarsal marker. All participants were identified during the warm up as heel strikers.

The motion analysis system data were collected as displacement relative to the global origin. Double derivative calculation was performed to convert it to acceleration and allow direct comparison to the sensor acceleration data and reflective marker positioned on the low back. Inertial sensor data were recorded as millivolts and were calibrated to produce gravitational (g) scale output. All data were trimmed to synchronisation points.

The inertial sensors recorded acceleration data from the three orthogonal axes.

The effect of gravity acting on the sensor was obtained by low pass filtering the data at 0.5 Hz. This vector was then removed from the raw data. A 10 Hz low pass Hamming Filter was applied removing high frequency noise in line with frequency calculation methods previously reported. The primary purpose was to filter noise and impact peaks in order for comparisons to be made with the infrared camera system comparison. The infrared camera system was filtered using the system’s dynamic gait filtering within its processing capabilities. The synchronisation points allowed for both systems’ data to be aligned for comparisons of acceleration magnitudes of the sensor and reflective marker. From this, measures of agreement and correlation were calculated. Additionally, overlay plots of the trimmed data sets were generated, providing visual demonstrations of outputs.

**Statistical Analysis**

Agreement between the inertial sensor data and motion analysis system data were conducted using the Typical Error of the Estimate (TEE). The error of the estimate is the amount by which the sensor differed from the motion analysis system. A TEE analysis uses the units of the dependent variable, in this case sample points. The closer to parallel and the narrower the spread of data,
indicates how well the inertial sensor data aligns with the motion analysis system. The TEE and bias results were interpreted using the Hopkins modified Cohen scale: <0.20, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large. Confidence limits were set at 95%. Residuals were used to describe the spread of data between the upper and lower confidence limits. The smaller the residual, the closer the agreement between both systems and the greater confidence of accuracy of the relationships. The TEE plots were used to visually display the data differences between the systems.

Correlation analyses were performed to determine the relationship between acceleration and motion analysis data using Pearson’s R correlation. The correlation classifications were interpreted using the Hopkins scale: 0.01-0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, high; 0.7-0.9, very high; 0.90-<1.0, extremely high; 1, perfect.

**RESULTS**

The TEE and correlations have been presented for each acceleration direction and motion analysis system data (Table I). Comparisons were on all data sample points (n=6163) detected inside the infrared capture field.

**Craniocaudal Acceleration**

The correlation was extremely high, averaging 0.95 across all testing times. The average TEE across all captures was small at 0.31 sample point. The TEE plot highlights the strong agreement
between both systems (Figure 2). The comparison prior to commencing the treadmill run (0 km) showed the least error (0.28 sample point). The error was also small at 2 km, 4 km, 6 km and 8 km comparison and correlation very high.

### Table 1: Typical Error of the Estimate and correlation between inertial sensor acceleration data and infrared camera system data. Residual data is the difference between the upper and lower confidence limits (CL). Typical Error of the Estimate units of measure are sample points.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Typical Error of the Estimate</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TEE</td>
<td>Upper CL</td>
</tr>
<tr>
<td>Craniocaudal Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 km</td>
<td>0.28</td>
<td>0.29</td>
</tr>
<tr>
<td>2 km</td>
<td>0.32</td>
<td>0.33</td>
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<tr>
<td>4 km</td>
<td>0.32</td>
<td>0.33</td>
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<tr>
<td>6 km</td>
<td>0.31</td>
<td>0.33</td>
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<tr>
<td>8 km</td>
<td>0.30</td>
<td>0.31</td>
</tr>
<tr>
<td>All runs</td>
<td>0.31</td>
<td>0.31</td>
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<tr>
<td>Mediolateral Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 km</td>
<td>0.55</td>
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<tr>
<td>4 km</td>
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<tr>
<td>8 km</td>
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<tr>
<td>All runs</td>
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<tr>
<td>Anteroposterior Acceleration</td>
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<tr>
<td>2 km</td>
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<tr>
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<tr>
<td>All runs</td>
<td>0.66</td>
<td>0.67</td>
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</tbody>
</table>

**Mediolateral Acceleration**

The correlation was high, averaging 0.87 across all testing times, and average TEE across all captures was small at 0.50 sample point. The TEE plot highlights a high level of agreement (Figure 3). The comparison at the end of the 8 km run showed a very high correlation (r=0.90) and least error (0.44 sample point).
Anteroposterior Acceleration

The correlation was high averaging 0.75 across all testing times. Anteroposterior acceleration had the greatest error, however it was at the lower end of moderate (0.66 sample point). The comparison at 0 km and 4 km the end of the 8 km run showed the highest correlation ($r=0.77$) and least error (0.64 sample point).

The TEE plot shows the lower agreement between the two systems (Figure 4).

Gait events

Heel strike and toe off were primarily identified in the raw data in the anteroposterior and craniocaudal acceleration data, respectively (Figure 1). Heel trike corresponded to commencing the upward climb in the anteroposterior acceleration data, and toe off corresponded to the crossing of the craniocaudal acceleration at zero of the downward curve. Average variation in the heel strike event between both systems were shown to be 0.15 sample point, which is equivalent to 0.002 seconds (s), or less than the capture rate (100 Hz). Average variation in the toe off event were shown to be 0.013 s (1.3 sample points). The range of the differences were between -0.04 s and 0.05 s. The TEE was shown to be trivial at 0.08 sample point for both heel strike and toe off. The correlation was very high ($r = 0.99$) for both gait events.

DISCUSSION

The study’s aim was to compare acceleration data collected from a single inertial sensor with a motion analysis system during overground running under fatigue conditions, and determine whether specific events in the running gait cycle were identified consistently by both data collection methods. This study provides evidence that a single tri-axial inertial sensor placed on the low back is valid for measuring three-dimensional acceleration and identifying specific events in overground running during a prolonged fatiguing run. Craniocaudal and mediolateral acceleration data demonstrated the best accuracy of running kinematics with high levels of agreement and correlations between data.
from both systems. Anteroposterior acceleration displayed less agreement between both, however a high level of correlation indicates a relationship between the two systems of measure. Specific events of heel strike and toe off were comparable and identifiable using anteroposterior and craniocaudal acceleration data, respectively.

The craniocaudal acceleration data were found to have the lowest error and very high correlations at all testing times, therefore strong agreement between the two systems can be reported. This concurs with previous research that reported similar outcomes when using a low back mounted sensor comparing craniocaudal acceleration to a motion analysis system during treadmill running. The comparisons in the mediolateral direction had slightly higher error than the craniocaudal acceleration. However, differences were small when referenced to the modified Cohen scale, and very high correlations between comparison data were found across all testing times. This is supported by the narrow spread of the data (Figure 2), indicating high levels of agreement between the two systems in mediolateral acceleration. Research by Lee, Mellifont and Burkett validated mediolateral data for identification between left and right steps when identifying spatiotemporal kinematics during treadmill running. Clear positive and negative peak signals in the mediolateral acceleration data were detected that occurred just following heel strike. Outcomes reported here and that found in previous research indicate that craniocaudal and mediolateral directional motions had cyclically repeating accelerations with clear peaks which may explain the increased validity in these directions. Another possibility for variation is that acceleration of forward movement is less than gravity, which inertial sensors simultaneously measure, while the infrared camera system is not. While gravity is not measured in the anteroposterior direction, it affects the forward movement readings. Therefore, the effect of gravity should be removed before comparative agreement assessments. Although the process used to remove gravitational data was not perfect (due to the dynamics attributed to the movement), it was the best known method. It involved low pass filtering to find an approximate orientation with respect to gravity acting on the sensor. The result provides the constant gravity vector relative to the sensor. This vector is then removed from the raw data. This technique is constant and very low frequency accelerations not attributable to gravity are also removed, resulting in difficulties removing gravity effects without affecting kinematic accelerations smaller than 1 g.

While agreement was least in anteroposterior acceleration data, the very high correlations found indicates a relationship between the anteroposterior data collected by the two systems. Therefore, data collected by the sensor in this direction may still be considered an acceptable measurement of overground running kinematics.
The identification of gait events using the inertial sensors were found in the raw data of anteroposterior and craniocaudal acceleration and demonstrated very high correlation with the motion analysis system. Heel strike corresponded to the beginning of the upward peak in anteroposterior acceleration, and toe off was identified when craniocaudal acceleration crossed at zero of the downward curve. This is similar to Auvinet et al. who identified heel strike and toe off in these acceleration channels in short duration overground runs using an accelerometric sensor attached to the low back. Auvinet et al. used filtered data to identify the gait events, while this current study found clearer points in the raw data. The differences between studies using filtered and raw data may be due to the system used that the events were compared to. Auvinet et al. compared sensor data to a video camera analysis, while this study used a motion analysis system, and this may have accounted for the differences in the acceleration data used. Future research using a similar method as in this current study will use the raw data for gait event analysis as the study findings indicate that a low back mounted sensor has the capability to identify heel strike and toe off gait events during overground running during a prolonged run. While there were variations between data from the three channels of capture, an important finding was that little change in agreement occurred between both systems at each testing session during the 8 km run. This indicates that the adherence method used in this study allowed the inertial sensor to remain in place throughout the prolonged run. It has been suggested that sensor movement may contribute to error, however, this was not the case in this study.

A limitation of this study was that data were collected while running along a short runway. Although, there was agreement between the two systems, the running kinematics on such a runway may not entirely replicate kinematics of prolonged overground running.

CONCLUSIONS

Three-dimensional acceleration data collected from an inertial sensor in overground running during a prolonged run is highly correlated with simultaneous data collected using a motion analysis system. To the authors’ knowledge, no researchers have validated inertial sensors in this context. Furthermore, specific events of heel strike and toe off in the gait cycle are clearly identifiable from the inertial sensor in the anteroposterior and craniocaudal acceleration data. Little change in variation between the inertial sensor and motion analysis data throughout the prolonged run indicates a suitable method of adherence of the sensor. This study supports future use of a single inertial sensor positioned at the low back to assess kinematics during prolonged overground running.

PRACTICAL APPLICATIONS

A single inertial sensor placed on the low back can be used to assess three-dimensional acceleration data during overground running under fatigue conditions.

Further analysis of the data can be used to identify heel strike and toe off events in the gait cycle during overground running.

REFERENCES


CASE STUDY

SAFETY ALERT FOR TREADMILLS IN HEALTH & FITNESS FACILITIES IN AUSTRALIA: RESULTS FROM A PILOT STUDY OF AN OBSERVATIONAL AUDIT TOOL

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ABSTRACT

Introduction: Design of a health/fitness facility is a crucial element in managing risks to its operators, users and others. Improper location of treadmills not compliant with industry recommendations can increase the risk of injuries, adverse events and subsequent legal liability for health/fitness facility operators. The aim of our study was to analyse the location (spacing and placement) of treadmills in health/fitness facilities in Australia.

Methods: An on-site observational audit was conducted at regional and metropolitan health/fitness facilities (n = 11) in New South Wales, South Australia, Victoria and Queensland. The spacing surrounding the treadmills was measured in centimetres (cm). Placement was assessed by the objects within two metres behind the treadmills.

Results: In all health/fitness facilities the distances surrounding the treadmills on the sides, and behind were less than the recommended minimum distances (0.5 - 1m on the sides, 2m behind) by the manufacturers. In most of the health/fitness facilities there was other equipment (60%, n = 6) within two metres behind the treadmills.

Discussion: The findings suggest that most of the health/fitness facilities audited in this study do not comply with industry minimum recommendations on location of treadmills necessary for safe operation.

Conclusion: Health/fitness facility operators in Australia should be trained to increase their awareness about the risks associated with improper location of treadmills to take appropriate preventive measures.

Key words: risk management, health/fitness industry, facility design, safety, injury, liability

Sources of funding: The Australian Fitness Industry Risk Management (AFIRM) Project was funded by an Australian Research Council Linkage Project Grant (LP120100275) in conjunction with Fitness Australia (FA) and Sports Medicine Australia (SMA). Caroline F. Finch was supported by a National Health and Medical Research Council Principal Fellowship (ID: 1058737).
INTRODUCTION

Treadmills are one of the most common cardiovascular machines present in health/fitness facilities. Despite the health benefits associated with their use they can contribute to many of the equipment-related injuries.\(^1,2,3\) The Australian Competition and Consumer Commission (ACCC) has prompted the regulation of the supply of treadmills guided by the high risk of injuries (e.g. friction burns) for young children caused by, for example, home users not realising their kids behind or kids trying to climb on a running treadmill.\(^4,5\) However, this regulation only applies to people selling, exchanging, leasing, or hiring out treadmills and is limited to the mandatory provision of a permanent warning label on all treadmills stating: “WARNING: keep young children away from this machine at all times. Contact with the moving surface may result in severe friction burns.”

An analysis of case law in the United States of America (USA) has shown that improper spacing, placement, maintenance and installation of treadmills that does not conform to the published industry standards or manufacturer’s guidelines can increase the risk of untoward events such as musculoskeletal injuries or even head traumas resulting in death and subsequent legal liability for health/fitness facility operators.\(^6\) In the case of Xu v. Gay\(^7\) in the Michigan Court of Appeals, the plaintiff fell off the treadmill resulting in a severe head injury and his death approximately a month later. The representative for the plaintiff contended that when Xu tripped while running, the treadmill throw him back into the wall or the window ledge behind him and that there was only 75cm clearance behind the treadmills. An expert witness in this case testified that according to the industry’s standard for duty of care there should be a minimum of 1.5 metres safety clearance behind treadmills. Henceforth, the industry standard for treadmills was revised in 2012 and currently requires minimum 2 metres safety clearance at the back of treadmills.\(^8\)

There are no published industry standards in Australia relevant to the location (spacing and placement) of treadmills in health/fitness facilities. However, the standard of care (duty of care) for safe operation of treadmills in health/fitness facilities can be established by the courts according to the industry/manufacturer’s guidelines. The aim of our study was to analyse the location (i.e., spacing and placement) of treadmills in health/fitness facilities in Australia measured against relevant manufacturers’ guidelines (see Table 1).

METHODS

This study was approved by the University Human Research Ethics Committee (RO: 1676). As part of the Australian Fitness Industry Risk Management (AFIRM) Project (LP120100275) an on-site observational audit tool (AFIRM-OAT) was developed to explore information as to current safety practices relating to the layout, operating procedures and conditions of fitness facilities\(^9\). The items in the AFIRM-OAT were developed based on review of literature, the American College of Sports Medicine’s (ACSM) fitness facility standards and guidelines\(^10\) and Australian work health and safety (WHS) and fitness industry codes of practice.

Content and face validity of the AFIRM-OAT were ensured by a multidisciplinary panel.
comprising of experts in injury prevention, risk management, legal liability, occupational health and safety, and sports science. The final AFIRM-OAT contained 81 items under six main sections:

- Environment
  - Entry to facility (3 items)
  - General facility environment (19 items)
- Cardiovascular/motorised equipment (19 items)
- Weight/pin-loaded machines (14 items)
- Free/plate-loaded weights (14 items)
- Emergency situations (8 items)
- Procedures (4 items)

Opportunity sampling was used to recruit 11 fitness facilities, based on the research team members’ locations across Australia, to conduct the pilot audits. These 11 facilities extended across seven metropolitan and regional Australian cities in New South Wales, Queensland, South Australia and Victoria.

The AFIRM-OAT items related to treadmills under the ‘cardiovascular/motorised equipment’ section were included in this study. One of the health/fitness facilities audited did not have treadmills and was excluded from this study. All data collected were de-identified as to the specific facility. The minimum spacing around a treadmill in a facility was measured using a tape measure and recorded in centimetres. The placement of treadmills was assessed according to what was within two metres behind the treadmills.

Following measurement of all treadmills in each facility, the treadmill with the least spacing at each facility (n = 10) was selected and recorded for the study. Due to the geographical spread of the facilities, seven different people conducted the audits. One auditor was present at every audit across each facility and six other trained auditors assisted during the data collection process throughout the country.

The AFIRM-OAT results were entered into SPSS 20 and descriptive statistics were used to calculate Mean and range values of the spacing measurements.

### RESULTS

The mean distances surrounding the treadmills (n = 10) were 12.1cm (range = 4cm - 25cm) on the left, 12.4cm (range = 3cm - 31cm) on the right, 74.3cm (range = 3.2cm - 156cm) at the front and 105.1cm (range = 45cm - 171.5cm) behind.

In most of the health/fitness facilities there was a walkway (60%, n = 6) and/or other equipment (60%, n = 6) within two metres behind the treadmills. Other common items behind the treadmills were an electric outlet (40%, n = 4) and/or a wall (30%, n = 3) (see Table 2).

### DISCUSSION

The findings of this pilot study indicate that health/fitness facilities in Australia are not meeting the minimum criteria for space allocations and placement of treadmills recommended by leading international and national treadmill manufacturers. In all health/fitness facilities the distances surrounding the treadmills on the sides and behind were less than the recommended minimum distances (0.5 - 1m on the sides, 2m behind). While the treadmill manufacturers warn to keep the treadmill clear of any obstructions, including walls, furniture and other equipment, in most of the health/fitness facilities there was other equipment

<table>
<thead>
<tr>
<th>What is behind the treadmills (within 2 metres)?</th>
<th>%</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walkway</td>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>Other equipment</td>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>Electrical outlet</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>Wall</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Railing</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Mirror</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. There can be more than one item that describes the placement of a treadmill in a health/fitness facility.
(60%, n = 6), an electric outlet (40%, n = 4), wall (30%, n = 3) or mirror (10%, n = 1) within two metres behind the treadmills.

These results are worrisome as inappropriate location of treadmills can result in serious injuries with severe consequences including incapacitation from daily activities and/or work and death of exercise participants and subsequent legal liability. Research shows that one of the most common causes of treadmill injuries is “trip and fall” that can result in dislocated joints, fractures, head trauma and even death. This is because when a person falls off on a running treadmill, they usually get thrown off the treadmill hitting their vital body parts including face and head against the machine, floor, and other objects or wall behind. Trip and fall on a treadmill may occur due to the negligence of a user such as wearing improper or loose shoes, closing their eyes while using the treadmill, or using electronic mobile devices such as cell phones that can cause distraction and loss of balance. A person may also fall off a treadmill if, for example, the treadmill suddenly stops while running due to a product defect or a lack of preventive maintenance, or the running speed was inappropriately prescribed by a fitness instructor. However, no matter what the root cause of a trip and fall injury may be, a health/fitness facility operator can be found liable for negligently increasing the level of risk of injury by not following the industry/manufacturer’s guidelines on location (spacing and placement) of treadmills and failing to satisfy the standard of care.

CONCLUSIONS

Treadmills are an important part of services provided by health/fitness facilities to satisfy the health and fitness needs of their clients. However, improper location of treadmills can result in severe injuries and adverse events. Therefore, it is crucial for health/fitness facility operators, managers and staff to be trained in risk management specific for the context of the health/fitness industry. This can increase their awareness about the hazards and risks associated with treadmills in order to implement appropriate control measures as part of a preventive maintenance program to protect the safety of their clients.

The main limitations to this pilot study were time and budget that limited the number of facilities that could have been recruited for a more representative sample. Nevertheless, this study highlights the importance of further nationwide more comprehensive research (i.e., auditing of all treadmills in a facility for more validity) on this topic across the fitness industry.

PRACTICAL APPLICATIONS

Health/fitness facility operators and/or managers should check the location of the treadmills to identify hazards and allocate enough and clear space around the treadmills according to the manufacturer’s guidelines for safe operation. If it is not sustainable or practicable for the health/fitness facility to allocate enough and clear space around the treadmills, treadmills should be replaced with alternative cardiovascular fitness equipment that occupies less space such as elliptical trainers or bikes.

All new users should be given an orientation on how to safely operate the treadmills including use of emergency break keys and clips that can stop the treadmill from running to minimise the risk of fall related injuries.

All users should be informed about how to safely operate the treadmills by permanent signage that is easy to see and read.

The cardiovascular training area in the facility should be regularly inspected for hazards and constantly supervised to avoid equipment misuse and ensure that users do not disembark a treadmill until it reaches a full stop.

REFERENCES


ORIGINAL RESEARCH

THE DEVELOPMENT AND APPLICATION OF AN OBSERVATIONAL AUDIT TOOL FOR USE IN AUSTRALIAN FITNESS FACILITIES

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ABSTRACT

Introduction: To ensure a minimal chance of injury, it is important for fitness facilities to provide users with a safe environment. The aim of this study was to pilot an observational audit tool (OAT) developed specifically for fitness facilities across Australia.

Methods: An OAT was designed, trialled and amended to ensure objective components. Audits were conducted at 11 regional and metropolitan fitness facilities across four Australian states. Face and content validity of the tool was assessed.

Results: The OAT was found to have high face and content validity. The median recorded temperature in each activity area was above the American College of Sports Medicine (ACSM) recommended level; however, the median illuminance of each area was below these levels. The median distance behind treadmills was found to be less than the minimum distance recommended by manufacturers. In the majority of facilities, walkways were clear of obstacles (eight facilities) and most floor surfaces were in good condition (ten facilities). Only five facilities were supervised at all times, and only six clearly displayed their rules and etiquette. Free weights equipment was observed laying on floors (not in dedicated storage areas) in seven facilities.

Conclusions: Fitness facility operators are advised to conduct regular risk assessments to ensure that rules and behaviour policies are easily seen and followed. It is desirable to have a systematic risk management program that is standardised throughout Australia to ensure the risk of injuries associated with poor risk management, as well as the likelihood of consequent legal liability, are reduced.

Practical applications: Observational safety audits that are regularly conducted in fitness facilities are an important tool that can help to identify potential injury-causing hazards so that they may be controlled.

Keywords: safety; risk management; injury; fitness centre; audit

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INTRODUCTION

An audit is a “systematic, independent and documented verification process of objectively obtaining and evaluating evidence to determine whether specified criteria are met”. Audits are useful to maintain the integrity of regulatory systems, to ensure credible and robust regulation, and to improve compliance with these. Observational audits are a valuable and important activity that can be undertaken to assess the safety of any physical environment. Observational audits can identify unsafe practices and point the way toward improvements.

Observational audits are often conducted with the aid of a checklist or form. Questions or topics within them are designed to document the characteristics of an environment objectively, enabling the features of the environment to be observed consistently and recorded transparently. Observational audit tools have been used for a variety of applications, including documenting the use of non-sterile gloves in acute hospital settings, assessing pilot performance, and determining the safety of environments for sport and physical activity.

By their nature, fitness facilities can contain numerous injury hazards. They house heavy equipment for the purpose of physical exercise, some of which is motorised, heavy free weights, pin-loaded weight machines, wet areas (such as showers), steps and stairs, and high-traffic areas such as group exercise areas. There are many opportunities for adverse incidents leading to injury to occur. Some examples include facility users falling (in the course of their exercise regime or walking throughout the facility), experiencing body contact with other users or with equipment, and misusing equipment.

Safety is an important issue that needs to be considered by the operators and staff of a fitness facility and its users to ensure minimal risk of injury or adverse health effects. A high proportion of fitness facility users surveyed in one Australian study believed that responsibility for their own safety lay with them rather than with facility management. Three other studies, however, have identified that staff training in safety and risk management is vital to ensure minimal risk of injury. It is in the best interests of fitness facilities, to implement a safe and well-maintained environment to ensure the safety of its users.

Australia currently has no nationwide standards or guidelines for setting up and operating fitness facilities. However, under the Work Health and Safety (WHS) legislation, fitness facilities have a duty to provide a safe and healthy environment for their users and employees. These WHS regulations require employers to identify hazards and assess and control identified risks through process-based standards that rely on documentation requirements. There are general WHS codes of practice providing practical guidance to achieving WHS requirements (e.g. How to Manage Work Health and Safety Risks, Managing the Risk of Falls at Workplaces, First Aid in the Workplace). However there are no specific WHS codes of practice targeting WHS risks in the fitness industry. When there is no regulation, ministerial notice or code of practice about a risk, the WHS framework requires a person to take reasonable precautions, and exercise proper diligence to manage exposure to risks in the best possible way. The various voluntary or mandatory state and territory fitness industry codes of practice across Australia only provide relatively limited guidance about health and safety risks. Accordingly, an observational health and safety audit tool designed specifically for fitness facilities and implemented in those facilities has the potential to help improve the physical environments. This, in turn, should help reduce the risk of injury or adverse health effects to people who use those facilities and hence also the legal liability risks to facility businesses associated with adverse events.

The primary aim of this research was to develop and pilot an observational audit tool for use in Australian fitness facilities. A secondary aim was to pilot this tool to assess the health and safety conditions of 11 fitness facilities sampled across Australia.
METHODS

Observational audit tool development

The Australian Fitness Industry Risk Management (AFIRM) Project was designed to determine how Australian regulation currently controls risk management in the fitness industry.15 As part of this project, it was considered important to observe and record information as to current safety practices, relating to the layout, operating procedures and conditions of a sample of fitness facilities.

The items in the observational audit tool (AFIRM-OAT) were developed based on peer-reviewed and grey literature,14,16-18 example audits of similar facility types,19,20 the American College of Sports Medicine’s (ACSM) fitness facility standards and guidelines21-23 and Australian WHS and fitness industry codes of practice. This tool was designed to ensure that all major areas of typical fitness facilities were covered.

Based on the literature, 81 potential items were developed which were then divided into the main physical or operational areas of a fitness facility: environment, cardiovascular equipment, weight machines, free weights, group exercise studios, stretching areas, emergency situations and procedures. The audit tool was reviewed and checked by the co-authors, who come from diverse but complementary disciplines.

The AFIRM-OAT comprised a set of sequential questions enabling an auditor to record a binary response, a direct measurement (e.g. distance between equipment), or to select from several options. Depending on the question, multiple answers could be selected. For example, the question “is entry/exit to the facility suitable for disabled access” could only be answered with a yes or no response. At different locations around the facility (for example in the free weights area) temperature, humidity and levels of brightness required measuring with standard equipment, to a specified level of precision. Minimum gap measurements between common pieces of cardiovascular equipment (behind, front, left and right) were taken using the measuring tape. For the question “what is behind the treadmills (within 2 metres)” the response options included “free space”, “railing”, “other equipment” or “pillar”.

The AFIRM-OAT then underwent review by a multidisciplinary panel of experts to ensure its content validity. This panel comprised expertise in injury prevention, legal liability, occupational health and safety, and sports science. The final paper-based AFIRM-OAT, which contained 81 items, was divided into the following sections:

• Environment
  ◦ Entry to facility (3 items)
  ◦ General facility environment (19 items)
• Cardiovascular/motorised equipment (19 items)
• Weight/selectorised machines (14 items)
• Free/plate-loaded weights (14 items)
• Emergency situations (8 items)
• Procedures (4 items).

The multidisciplinary panel of experts also revised some questions to ensure that they were well-aligned with the specific aims of the AFIRM project and key findings from its nationwide survey of the Australian fitness industry.11 Surveyed fitness professionals indicated that they wished to be more informed of emergency situations and procedures, therefore 12 of the 81 items in the AFIRM-OAT were devoted to this. A copy of the AFIRM-OAT is available upon request from the authors. Ethics approval was granted by a recognised ethics committee.

Conducting the audits

Equipment required to conduct these audits was intentionally kept to a minimum and included a measuring tape, a thermometer, hygrometer and light meter. Rather than using three separate meters, a multi-function environment meter (Digitel QM1594), which is capable of measuring temperature, humidity and light intensity, was used alongside the measuring tape. The same equipment was used for all audits.

Opportunistic sampling was used to recruit 11 fitness facilities to undergo observational audits. These were selected based on the research team’s connections and location across Australia, however there were no conflicts of interest or other connections between auditors and facilities. These
11 facilities spanned seven Australian cities across New South Wales, Queensland, South Australia and Victoria. Given the geographical spread of the facilities, seven different research team members conducted the audits. All were trained and supervised by the same person on how to use the tool and equipment, to ensure its consistent use.

At the end of the study, written feedback from each auditor regarding the OAT and its use was also obtained, collated and summarised by the lead author in order to further refine the AFIRM-OAT where necessary for future studies.

**Analysis**

All data collected were de-identified as to the specific facility. The AFIRM-OAT results were entered into SPSS, and descriptive frequencies were generated to determine the risk management status conditions of the eleven facilities.

**RESULTS**

Feedback from the auditors demonstrated that the AFIRM-OAT was well set out, straightforward and easy to use. On this basis, it was considered to be adequate for the purpose of assessing the health and safety conditions of different areas of fitness facilities that were relevant to the AFIRM project. The items were considered to have met the project’s objectives by providing the information that the tool was aiming to provide.

Physical measurements using the multi-function environment meter, (i.e. temperature, humidity and illuminance) were recorded for each of the activity areas (cardiovascular equipment, weight machines and free weights). Table 1 displays the minimum, maximum, mean, and median for each area and measurement, as well as the ACSM guidelines for comparison given the absence of specified Australian guidelines.

All facilities had separated activity areas. Table 2 shows the descriptive statistics of the distances around common items of cardiovascular equipment.

Table 3 shows the number of facilities with observed negative risk management characteristics.

**DISCUSSION**

Observational audits are a valuable tool for the assessment of health and safety risks in the physical environment of fitness facilities. It is known that injuries occur at fitness facilities and, in light of the literature on injury causation, we believe that many injuries could be prevented through the development of management techniques and procedures grounded in the data that can be generated by such audit tools. Having an

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**Table 1**: The descriptive statistics for temperature, humidity and illuminance of each activity area across eleven fitness facilities and the ACSM guidelines.

<table>
<thead>
<tr>
<th>Area</th>
<th>temperature (°C)</th>
<th>humidity (%)</th>
<th>illuminance (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>mean ± SD</td>
</tr>
<tr>
<td>Cardiovascular equipment</td>
<td>21.6</td>
<td>26.0</td>
<td>23.4 ± 1.1</td>
</tr>
<tr>
<td>Weight machine area</td>
<td>20.7</td>
<td>26.0</td>
<td>23.5 ± 1.4</td>
</tr>
<tr>
<td>Free weight area</td>
<td>20.7</td>
<td>25.6</td>
<td>23.4 ± 1.5</td>
</tr>
<tr>
<td>ACSM recommended</td>
<td>68-72°F (20-22.2°C)</td>
<td>≤60%</td>
<td>≥50 foot candles (538.2Lux)</td>
</tr>
</tbody>
</table>

Note. “min” and “max” are the minimum and maximum observed across all facilities. One facility did not have a free weights area.
Table 2: The minimum, maximum, mean and median distances (to the nearest centimetre) around common pieces of cardiovascular equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>minimum (cm)</th>
<th>maximum (cm)</th>
<th>mean (cm)</th>
<th>median (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treadmills</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>45</td>
<td>172</td>
<td>105 ± 42</td>
<td>94</td>
</tr>
<tr>
<td>front</td>
<td>3</td>
<td>156</td>
<td>74 ± 51</td>
<td>78</td>
</tr>
<tr>
<td>left</td>
<td>4</td>
<td>140</td>
<td>25 ± 41</td>
<td>11</td>
</tr>
<tr>
<td>right</td>
<td>3</td>
<td>31</td>
<td>12 ± 9</td>
<td>11</td>
</tr>
<tr>
<td><strong>Elliptical trainers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>41</td>
<td>247</td>
<td>112 ± 66</td>
<td>104</td>
</tr>
<tr>
<td>front</td>
<td>35</td>
<td>168</td>
<td>104 ± 48</td>
<td>102</td>
</tr>
<tr>
<td>left</td>
<td>10</td>
<td>110</td>
<td>45 ± 35</td>
<td>30</td>
</tr>
<tr>
<td>right</td>
<td>12</td>
<td>110</td>
<td>43 ± 36</td>
<td>27</td>
</tr>
<tr>
<td><strong>Rowing machines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>106</td>
<td>800</td>
<td>218 ± 209</td>
<td>146</td>
</tr>
<tr>
<td>front</td>
<td>24</td>
<td>147</td>
<td>70 ± 48</td>
<td>46</td>
</tr>
<tr>
<td>left</td>
<td>27</td>
<td>80</td>
<td>54 ± 21</td>
<td>58</td>
</tr>
<tr>
<td>right</td>
<td>27</td>
<td>93</td>
<td>59 ± 26</td>
<td>62</td>
</tr>
<tr>
<td><strong>Exercise bikes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>39</td>
<td>800</td>
<td>202 ± 217</td>
<td>141</td>
</tr>
<tr>
<td>front</td>
<td>20</td>
<td>153</td>
<td>67 ± 40</td>
<td>64</td>
</tr>
<tr>
<td>left</td>
<td>21</td>
<td>72</td>
<td>44 ± 17</td>
<td>40</td>
</tr>
<tr>
<td>right</td>
<td>29</td>
<td>65</td>
<td>43 ± 11</td>
<td>44</td>
</tr>
<tr>
<td><strong>Recumbent bikes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>24</td>
<td>250</td>
<td>91 ± 64</td>
<td>81</td>
</tr>
<tr>
<td>front</td>
<td>20</td>
<td>173</td>
<td>78 ± 49</td>
<td>71</td>
</tr>
<tr>
<td>left</td>
<td>15</td>
<td>192</td>
<td>49 ± 52</td>
<td>33</td>
</tr>
<tr>
<td>right</td>
<td>19</td>
<td>41</td>
<td>31 ± 7</td>
<td>32</td>
</tr>
<tr>
<td><strong>Stair climbers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>56</td>
<td>194</td>
<td>104 ± 45</td>
<td>110</td>
</tr>
<tr>
<td>front</td>
<td>10</td>
<td>781</td>
<td>188 ± 266</td>
<td>92</td>
</tr>
<tr>
<td>left</td>
<td>7</td>
<td>195</td>
<td>42 ± 68</td>
<td>16</td>
</tr>
<tr>
<td>right</td>
<td>7</td>
<td>93</td>
<td>31 ± 31</td>
<td>18</td>
</tr>
<tr>
<td><strong>Steppers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>behind</td>
<td>20</td>
<td>280</td>
<td>111 ± 84</td>
<td>89</td>
</tr>
<tr>
<td>front</td>
<td>0</td>
<td>150</td>
<td>56 ± 51</td>
<td>62</td>
</tr>
<tr>
<td>left</td>
<td>10</td>
<td>90</td>
<td>38 ± 28</td>
<td>31</td>
</tr>
<tr>
<td>right</td>
<td>10</td>
<td>240</td>
<td>78 ± 72</td>
<td>64</td>
</tr>
</tbody>
</table>
observational audit tool specifically designed for fitness facilities would enable the safety of their physical environment to be improved, leading to reduced risk of injury or adverse health effects.

The physical environment of the 11 fitness facilities audited in this study was assessed using the specifically developed AFIRM-OAT. The face validity of the AFIRM-OAT was evaluated during pilot testing, and found to be successful in covering the areas that it aimed to measure. Feedback from auditors was that the AFIRM-OAT was straightforward and easy to use. The questions were generally deemed to be clear and concise. The auditors felt that some questions with binary responses could be limiting, however. The consensus was that for many of the binary responses a ‘not applicable’ option should be added, as not all items were relevant to all facilities. For example, auditing a facility in relation to changes in elevation (e.g. ramps, stairs) and whether this change is clearly identifiable is not applicable when a facility is all on one level. For questions relating to supervision, many auditors felt that the level of supervision should be provided as opposed to only a yes/no that supervision is provided. They suggested that the supervision questions could be answered on a Likert scale, ranging from ‘never’ to ‘always’. Without time guidelines for each option, and the time to observe the level of supervision, this could introduce an element of subjectivity that would require pre-application testing. Additionally, determining the degree of supervision may be limiting and not necessary for the OAT if its aim is to be used at all fitness facilities. For example, fitness facilities that never close are unsupervised the majority of the time, and therefore it is meaningless to require auditors to record this. Therefore, for future versions of the OAT the item related to supervision could be removed, and instead, individual fitness facilities could address their operational practices themselves, which includes supervision.

Overall, the trial results showed that the extent of observable risk management practices and the level of maintenance and upkeep varied considerably among facilities. As noted above, currently, there are no Australian standards or guidelines specifically for the physical environment of a fitness facility (aside from the WHS

### Table 3: Examples of AFIRM-OAT findings that demonstrate negative risk management characteristics and the number of facilities observed with each condition

<table>
<thead>
<tr>
<th>no. facilities with this condition</th>
<th>condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Signs informing users to turn off equipment</td>
</tr>
<tr>
<td>1</td>
<td>Rips/tears/splinters/protruding nails in its floor</td>
</tr>
<tr>
<td>1</td>
<td>Cardiovascular machine was broken and not sign posted</td>
</tr>
<tr>
<td>2</td>
<td>Uneven floors (excluding defined steps and ramps)</td>
</tr>
<tr>
<td>3</td>
<td>Not suitable for movement of disabled throughout the facility</td>
</tr>
<tr>
<td>3*</td>
<td>Non-functioning lights</td>
</tr>
<tr>
<td>3*</td>
<td>No signs instructing users to put weights away after use</td>
</tr>
<tr>
<td>3*</td>
<td>No appropriate storage for all equipment</td>
</tr>
<tr>
<td>4</td>
<td>No signs asking for users to wipe down weight machines after use</td>
</tr>
<tr>
<td>5</td>
<td>No sign enforcing the use of a towel</td>
</tr>
<tr>
<td>5</td>
<td>No rules or etiquette displayed</td>
</tr>
<tr>
<td>6</td>
<td>Facility floor unsupervised at all times</td>
</tr>
<tr>
<td>6</td>
<td>No visible evacuation plan</td>
</tr>
<tr>
<td>6</td>
<td>No signs asking for users to wipe down cardiovascular equipment</td>
</tr>
<tr>
<td>6</td>
<td>Not all weight machines had instructions on how to use them</td>
</tr>
<tr>
<td>7*</td>
<td>Equipment lying on the floor (not in storage)</td>
</tr>
<tr>
<td>8</td>
<td>No emergency response plan displayed</td>
</tr>
<tr>
<td>8</td>
<td>Visible electrical cords or wiring (with no attempt to hide)</td>
</tr>
</tbody>
</table>

*Note. * denotes that number given is from 10 facilities not the full 11 due to incomplete audits.*
framework), therefore international standards and guidelines and recommendations from those who work in the industry can be used for comparison of results.

Accordingly, given the lack of specific Australian standards or guidelines for the temperature, humidity and illumination of facilities, measurements were compared with ACSM guidelines. Observed temperatures were higher than recommended in all activity areas. This could be due to insufficient air conditioning or air circulation in the observed facilities. It is possible that given Australia is an overall warmer climate than the United States, the population is capable of tolerating warmer ambient temperatures for physical activity and temperatures can be marginally higher. No studies were found comparing these, however Australia recommends particular levels of caution at overall higher temperatures than the United States. The mean humidity for each activity area was within the ACSM's guidelines. Sports Medicine Australia has published ‘Hot Weather Guidelines’ that provide information on adverse health effects should overheating occur due to high temperature and humidity (such as dizziness, nausea and loss of consciousness). These effects could be particularly dangerous should the facility user be lifting weights or using motorised equipment when overheating occurs. Given that the ACSM guidelines provided the recommended illumination in foot candles (≥50 foot candles), this was converted to the SI unit of Lux (538.2 Lux). Illumination in all areas was on average much lower than the ACSM recommended level. This could be due to poor facility set-up by management (e.g. equipment obstructing lights), all lights may not have been switched on, or lights may not have been fully functional. Poor lighting could not only strain eyes, but make it more difficult to see and avoid hazards. Our auditing identified that illumination was generally lower in the free weights area than both the cardiovascular equipment and weight machine areas, which were bright enough at some facilities. Considering that exercise with free weights is technique-based, illumination should be higher in these areas to enable participants to see sufficient detail. For all measurements, there were facilities that did not meet the recommended ACSM levels.

The minimum distance behind a treadmill was 45cm. Therefore, if a user is thrown off the back due to a fall or inability to keep up it could result in severe injury, including death, especially if there is contact with other equipment or a wall. Treadmill use/misuse is often reported to result in one of the highest level of injuries of all equipment in fitness facilities. An unpublished study by Sekendiz et al used the data from this AFIRM-OAT to compare Australian practices with international industry standards and manufacturer guidelines for treadmill clearances (which differ depending on the manufacturer), and found that none of the 11 audited facilities complied with all of these. Failure to comply with industry standards and manufacturer guidelines could be due to: (a) the insufficient size of the facility compared to the number of users and the amount of equipment it contains to meet demand; (b) poor layout of the facility; (c) a lack of awareness about the risk of treadmill injuries; or (d) a lack of published industry standards in Australia. However, manufacturers’ guidelines can still be used by courts to determine standards of fitness facility layout design and use. Failure to comply with these guidelines can lead to breaches of WHS requirements and successful liability claims by injured patrons for breach of a duty of care. The large variation in distances behind treadmills and around other pieces of equipment, as well as the variation in the recommended treadmill manufacturer guidelines, highlights the need for future research into safe equipment clearances.

Attention should also be given to the items where more than half of the facilities failed to exhibit each condition (see Table 3). Lack of supervision in a facility can lead to heightened injury risk, particularly if patrons engage in dangerous training practices when qualified fitness professionals are not available to advise or to assist. A lack of visible emergency response and evacuation plans, especially with no staff available to assist, could lead to adverse events. Objects lying on the floor and not in storage could signify poor
housekeeping practices or poor safety culture in the facility, which reflects negatively on users and management. It is important that fitness facilities both display and enforce safety practices and rules. These findings further justify the need to develop Australian standards and guidelines to improve the safety of fitness facilities for both staff members and users.

The main factors that limited the scope of this pilot testing of the AFIRM-OAT were time and budget. The AFIRM project was only able to transport one trained auditor to each of the 11 facilities. Moreover, this pilot application of the AFIRM-OAT was not able to assess inter-rater reliability (degree of agreement between auditors) of the tool. Nonetheless, its application across the country gives us some confidence as to its broad usefulness and relevance across the fitness sector.

Information regarding the type and size (based on membership and floor space) of the audited facilities was not recorded within the AFIRM-OAT. It is possible that these factors could help to explain the sometimes large variation in results. It will be important to record this information in future versions of the AFIRM-OAT.

For future application of the AFIRM-OAT within fitness facilities by their local staff, there is a need for development of a training manual. Providing an extensive accompanying manual to the AFIRM-OAT would be a good reference resource for those trained to conduct audits, as well as provide the information required for a non-trained person should they need to conduct an audit. On the basis of this study, an example of the content areas that would need to be included in such a manual is:

- an introduction to why the observational audits should be performed
- what the OAT aims to do
- equipment required to conduct the audit
- definitions of equipment (including pictures of each piece so that there is no confusion if different manufacturers refer to the same equipment under different names)
- instructions on how to take measurements
- definitions of terms used in questions
- Australian codes of practice (as the OAT was designed for use in Australian facilities)
- International standards (for comparison, and since these are more extensive)
- question justification
- references
- examples of hazards
- examples of signage

Until Australian fitness facility standards and guidelines for their environment and operation are developed, that are relevant to the Australian context, reference points to international standards should be provided in the AFIRM-OAT manual alongside relevant questions to determine if fitness facilities are meeting minimum industry standards or recommendations for safe operation. Therefore, the AFIRM-OAT could serve as both an observational audit tool to assess the equipment and environment, as well as a risk assessment form that provides control measures to minimise the risks. More extensive research into the application of the AFIRM-OAT and its reference manual is required. This should include inter-rater reliability studies to determine the objectivity of the tool, as well as its usability among untrained fitness facility operators, as well as the potential to include a scoring system to determine a facility’s degree of compliance.

CONCLUSION

The AFIRM-OAT risk management audit tool successfully evaluated the health and safety of the physical environment of fitness facilities, and highlighted areas of the fitness facilities that required improvement. Observational audits to identify hazards should be conducted regularly by fitness facilities. Australia-wide processes and guidelines need to be developed specific to the Australian fitness industry, so that the results of the observational audits may be compared with standards for a high quality of risk management in fitness facilities in the Australian context.
PRACTICAL APPLICATION

• Australia has no standards and guidelines specific to fitness facilities for setting up and operating their businesses, this study highlights the need for their development
• An observational audit tool specific to the fitness industry that is capable of identifying hazards or other areas of fitness facilities that require improvement can help managers implement more stringent risk management policies
• Having more robust risk management strategies, such as an observational audit tool, will help to ensure that the risk of injury or adverse health outcomes is minimal

CONFLICTS

The authors declare that there are no conflicting interests.

REFERENCES


ORIGINAL RESEARCH

HIGH INTENSITY INTERVAL CYCLING IMPROVES PHYSICAL FITNESS IN TRAINED ADULTS

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ABSTRACT

Introduction: High intensity interval training (HIIT) is a specific type of vigorous intensity exercise characterised by periods of work over 85% maximum heart rate (HRmax). Numerous past studies have documented significant cardiovascular, metabolic, musculoskeletal, and body composition improvements with this type of training, traditionally with cycling Wingate tests. However, popular HIIT sessions outside of research typically incorporate weight-bearing impact, which limits large segments of the population from participating. Thus, a low-impact alternative in a practical format with parallel benefits is an imperative option that requires testing.

Methods: Thirty-six trained adults were randomly assigned to one of two groups: Group HIIT or Group FIT. Group HIIT participants replaced a single 60-minute cardiovascular training session with 2, 30-minute high intensity indoor cycling sessions for 6 weeks. Group FIT maintained their current training routine. We measured blood pressure, peak oxygen consumption, fasting blood profile, body composition, and leg strength.

Results: The HIIT intervention significantly improved all variables (p<0.05) except HDL cholesterol. Peak oxygen consumption and leg strength increased significantly for the HIIT group (+9.7% and 11.9% respectively) but not the FIT group. There were significant decreases in the HIIT group for blood pressure (-9.9%), fasting blood glucose (-7.0%), total cholesterol (-6.0%), LDL cholesterol (-7.8%), triglycerides (-16.3%) and fat mass (-1.1%).

Conclusion: Adding high intensity interval cycling to the routine of trained adults improved physical fitness. Our results suggest that replacing one bout of moderate intensity exercise with two 30-minute bouts of cycling HIIT is an effective, low impact option to improve cardiovascular, metabolic and musculoskeletal fitness, as well as body composition.

Keywords: exercise, intervention, cardiovascular, metabolic, musculoskeletal
INTRODUCTION

Vigorous intensity exercise lowers cardiovascular disease risk and can even extend lifespan by 22% in men and 31% in women\(^1-^5\). High intensity interval training (HIIT) is a specific type of vigorous intensity exercise characterised by periods of work over 85% maximum heart rate (HR\(_{\text{max}}\)) followed by periods of active recovery or rest\(^6\). One type of HIIT training, sprint interval training (SIT) is typically performed in a laboratory on a cycle ergometer with repeated low-volume Wingate tests; 10-30 seconds of maximum effort followed by rest\(^7-^9\). These protocols increased maximal oxygen consumption (VO\(_{2\text{max}}\)) by 5.5-9.3% depending on the interval to rest ratios. Additionally, Burgomaster et al.\(^10\) studied the oxidative capacity and skeletal muscle adaptations in response to low-volume repeated Wingate sprint tests and endurance training. After 6 weeks, VO\(_{2\text{max}}\) increased by 7.3% for sprint training and 9.8% for endurance training. Therefore, low-volume HIIT cycling using repeated Wingate tests has the potential to stimulate significant changes in oxidative capacity similar to those of moderate-intensity training. While these protocols are efficient for highly trained individuals, they are difficult to generalise to the rest of the population and disseminate to the community.

Physical fitness consists of cardiovascular, metabolic, and musculoskeletal fitness, as well as body composition. One of the key indicators of improvements in cardiovascular fitness is a change in VO\(_{2\text{max}}\) as previously described in laboratory SIT protocols. In untrained or moderately trained adults, Helgerud et al.\(^11\) and Nybo et al.\(^12\), reported that HIIT running at 90-95% HR\(_{\text{max}}\) increased VO\(_{2\text{max}}\) more than endurance or strength training. Gottschall et al.\(^13\) found that replacing just one 60-minute bout of moderate-intensity exercise with 2, 30-minute weight-bearing HIIT classes per week, in trained adults significantly improved cardiorespiratory, metabolic, musculoskeletal, and body composition measures more than maintaining a moderate-intensity training program.

Despite the positive findings in cardiovascular fitness, there is not yet a consensus on the effects of HIIT or SIT on other aspects of physical fitness. In general, long-term studies involving at least 6 weeks of HIIT have shown decreases in total cholesterol (TC) and low density lipoprotein (LDL-C)\(^13-^15\), while shorter term studies have shown no changes in cholesterol\(^16-^18\). Likewise, musculoskeletal fitness and body composition changes with SIT cycling are conflicting. While most studies show a decrease in body fat percentage, the magnitude of these changes range from 0.6% for protocols of at least 12 weeks to 11.2% for protocols over 15 weeks\(^19-^21\). Many studies have evaluated the effects of HIIT or SIT on anaerobic power, however few have studied leg strength, specifically isometric leg strength. In summary, the effects produced by HIIT cycling on metabolic and musculoskeletal fitness, as well as body composition, require further investigation.

A HIIT cycling program that can be implemented in the community would provide a low-impact alternative to laboratory SIT protocols and weight-bearing HIIT programs. We hypothesise that a 6-week intervention where trained individuals replace one 60-minute bout of cardiovascular training with two 30-minute bouts of HIIT cycling, will improve health and fitness more than maintaining their moderate-intensity cardiovascular exercise routine. More specifically, we expect to see an increase in peak oxygen consumption, leg strength and high density lipoprotein cholesterol (HDL-C), with accompanying decreases in blood pressure (BP), triglycerides (TRG), cholesterol (TC and LDL-C), blood glucose (GLU), and body fat percentage.

MATERIALS AND METHODS

Experimental Approach to the Problem

We measured blood pressure, peak oxygen consumption, fasting blood profile, body composition, and leg strength in two randomly designated groups of trained adults. One group was assigned to replace one of their current 60-minute cardiovascular training sessions with 2, 30-minute high intensity cycling sessions.
Participants

We recruited 36 healthy, trained adults (Table 1; 8 men, 41 ± 11 years). The participants were exceeding current physical fitness recommendations prior to the start of the study. They were involved in regular cardiovascular activity more than 3 times per week and full-body strength training 2 times per week for at least 60 minutes per bout of exercise. Furthermore, participants all had experience cycling either outdoors or on a stationary bike in the last 6 months. All of the participants gave written informed consent that followed the guidelines of The Pennsylvania State University Institutional Review Board. Individuals with cardiovascular risk factors or chronic medical conditions were not included.

Procedures

We collected data at initial (Week 0) and final (Week 6) points of the study on the same day of the week and the same time of day. The following physiological variables were measured: blood pressure, estimated maximal oxygen consumption, fasting blood profile, leg strength and body composition. We conducted a submaximal oxygen consumption cycle ergometer test using the Astrand-Rhyming protocol. The participant warmed up for 10 minutes cycling at 60 rpm until their heart rate reached 130-160 bpm. They maintained their heart rate in this range for 6 minutes pedaling at 60 rpm, adjusting the wattage accordingly as instructed by the study team. We then calculated VO$_{2peak}$ from the participants’ final work rate wattages. Additionally, following a 12-hour food, alcohol and exercise fast, the following variables were measured with a finger prick blood draw: TC, TRG, HDL-C, LDL-C, and GLU (Cholestech LDX). Previous studies have shown coefficients of variation less than 9% between and within measurement tests. We measured musculoskeletal strength through a maximal leg strength deadlift test using a dynamometer (Initial Evaluation Instruments). With maximum effort, participants pulled upward on the dynamometer with feet shoulder-width apart, knees flexed to 110 degrees, and arms fully extended. Verbal encouragement was given and participants performed three trials. The average and maximum readings were recorded. Lastly, body composition variables were also measured at initial and final: height, total mass, fat mass, and fat-free mass. We used the BodPod (COSMED), a dual chamber air displacement plethysmograph, to measure the participant’s body composition (fat and fat-free mass). The calculated coefficient of variation of the BodPod was 0.8% body fat. All the testing procedures as well as training sessions were completed at a temperature controlled group fitness studio.

The participants were randomly assigned to one of two groups: group HIIT or group FIT. Group HIIT participants replaced a single 60-minute cardiovascular training session with 2, 30-minute high intensity LES MILLS SPRINT™ indoor cycling sessions on 2 non-consecutive days. Group FIT participants served as controls and maintained their current physical fitness routine of 3 cardiovascular sessions and 2 full-body strength training sessions. The groups were matched for age, gender, physical activity level and VO$_{2peak}$. The intensity of the HIIT sessions was 85-95% HR$_{max}$ for 20 of the 30 minutes while the intensity of the cardiovascular sessions was 70-85% HR$_{max}$ for 40 of the 60 minutes.

Each HIIT session was 30-minutes with a similar average workload to 60-minutes of cardiovascular training sessions. The HIIT sessions started with a 5-minute accelerated warm-up and continued with 3
or 4, 5-10 minute blocks for speed and power conditioning. The intervals in a block varied and consisted of work to rest ratios of 1:2, 2:1, and 3:2 with the total duration of work equal in each 30-minute session. The shortest work time period was 20 s and the longest was 120 s.

Statistical Analysis

Data were presented as mean ± standard deviation and analyzed using StatPlus Version 6 (AnalystSoft, Inc). We completed independent t-tests to evaluate differences in descriptive characteristics between the groups. Two-way analysis of variance with repeated measures was used to examine the differences in cardiovascular, metabolic, and musculoskeletal fitness as well as body composition variables, with time (initial vs final) as a within-subjects factor and group (HIIT vs FIT) as a between-subjects factor. Tukey’s post hoc test was used to detect differences between means with a resulting significant F ratio. Significance was defined at p<0.05.

RESULTS

There were no statistically significant time or group main effects. There were time x group main effects for all measured variables (p<0.05) with the six weeks of HIIT training, except HDL cholesterol. Maximal oxygen consumption and leg strength increased significantly (p<0.05) for the HIIT group, but not for the FIT group. There were significant (p<0.05) decreases in the HIIT group for blood pressure, GLU, TC, LDL, TRG, and fat mass.

Systolic blood pressure was significantly (p<0.05) higher for Group HIIT than Group FIT at initial (131 mmHg HIIT, 119 mmHg FIT). Other initial measures did not vary significantly between groups. Systolic and diastolic blood pressure were significantly (p<0.05) less after the intervention for Group HIIT. Systolic blood pressure decreased by 11 mmHg (8.4%, p<0.01) and diastolic decreased by 8 mmHg (9.9%, p<0.01). Blood pressure did not change significantly for Group FIT, nor did final values differ significantly between intervention groups.

In summary, there were multiple significant differences between initial and final cardiovascular, metabolic, and musculoskeletal fitness as well as body composition measurements in the HIIT group. First, estimated maximal oxygen consumption increased significantly (p<0.01) for the HIIT group from 41.1 ml/kg/min to 45.1 ml/kg/min (9.7%) and did not change significantly for the FIT group (Figure 1).

![Figure 1: Estimated maximal oxygen consumption for Group FIT and Group HIIT. VO2peak increased significantly (p<0.05) for Group HIIT, but not Group FIT. Similarly, there was a significant (p<0.05) difference between post-intervention VO2peak for Group HIIT and Group FIT. (* = significant difference between initial and final measurements)](image-url)
Second, for the HIIT intervention group, all of the blood cholesterol concentrations (except HDL-C) and fasting blood glucose decreased significantly (p<0.05) throughout the intervention (Figure 2); TC decreased by 11 mg/dL (6.0%), LDL-C by 7 mg/dL (7.8%), TRG by 17 mg/dL (16.3%), and glucose by 7 mg/dL (7.0%). Third, mean leg strength increased significantly (p<0.05) by 9.0 kg for the HIIT group from initial to final (11.9%). Group FIT showed no change in mean leg strength (Figure 3). Fourth, body fat percentage decreased significantly (p<0.05) by 1.1% for the HIIT group through the 6-week intervention. Group FIT body fat percentage did not change significantly from initial to final. In addition, mass decreased significantly (p<0.01) by 0.9 kg for the HIIT group (1.1%), but not for the FIT group.

Figure 2: Blood panel profile measures pre- and post intervention. Total cholesterol (TC), low density lipoprotein cholesterol (LDL-C), triglycerides (TRG), and glucose (GLU), decreased significantly (p<0.05) for Group HIIT from initial to final. High density lipoprotein cholesterol (HDL-C) is the only variable that did not change for the HIIT intervention group. (* = significant difference between initial and final measurements)

Figure 3: Changes in mean leg strength for Group HIIT and Group FIT. There were significant (p<0.05) differences between pre- and post-intervention for Group HIIT, and the final measurements for Group HIIT were significantly (p<0.05) larger than Group FIT. (* = significant difference between initial and final measurements)
DISCUSSION

Incorporating high intensity interval training cycling to the routine of active adults improved physical fitness. Our results suggest that replacing one bout of moderate intensity exercise with two 30-minute bouts of HIIT is an effective way to improve cardiovascular ($VO_{2peak}$ and blood pressure) metabolic (blood profiles) and musculoskeletal (strength) fitness as well as body composition (fat and lean mass).

The substantial increase in peak oxygen consumption (9.7%) for the HIIT intervention resembled the previous $VO_{2max}$ data using repeated Wingate tests (5.5-7.3%) in both untrained and trained adults\(^8,10\). While both protocols use high intensity intervals, the Wingate tests are 10-30 seconds of maximum effort, whereas this study uses high intensity intervals up to 120 seconds. The longer intervals in the current study likely contributed to the increases in $VO_{2peak}$. As expected, past studies with inactive participants had larger improvements in oxygen consumption than seen in this study. SIT cycling increased $VO_{2max}$ by 11.1% after 2 weeks, 15.2% after 12 weeks, and 23.8% after 15 weeks in untrained adults\(^20,23-24\). Based on previous literature and the results of this study, untrained individuals may attain gains in $VO_{2max}$ without the impact involved in weight-bearing HIIT.

In comparison to weight-bearing HIIT protocols, $VO_{2peak}$ gains were similar in this intervention. Studies with similar protocols that replaced or added HIIT to previous physical activity regimens found that $VO_{2peak}$ increased by 6.4-6.9% with HIIT versus 1.8-2.7% with maintaining their previous physical activity routine\(^13,25\). In recreationally active adults, weight-bearing HIIT increases of $VO_{2peak}$ by 4.9% and 10.3%\(^6,26\). In summary, the improvements in cardiovascular fitness closely match the improvements in trained and recreationally active adults with either low-volume SIT cycling or weight-bearing HIIT protocols.

Metabolic fitness improved substantially with HIIT cycling. The decreases in total cholesterol, triglycerides, and LDL-C confirm our hypothesis and mimic the results of Ouerghi et al.\(^25\). After 12 weeks of HIIT training, TC decreased by 3 mg/dL, LDL-C by 2 mg/dL, TRG by 7 mg/dL in trained male soccer players. However, their results were not statistically significant possibly due to the small sample size (n=8 in each intervention). The decreases in triglycerides (17mg/dL) and LDL-C (7mg/dL) from the current study were similar to previous findings in 6-12 week protocols\(^13-15\). HDL-C concentrations did not change for our intervention, which match some previous findings with HIIT, both cycling and weight-bearing\(^15,27\) but not all\(^13\). It is possible that HDL-C did not change in the current study since the participants were already trained. Overall, these varying results in metabolic fitness are likely due to differences in type of HIIT (weight-bearing versus cycling) and the physical activity level of the participants. Additional studies on HIIT cycling in trained adults are necessary to corroborate an effect on metabolic fitness.

Another measure of metabolic fitness is fasting blood glucose, which decreased 7mg/dL in this intervention. This supported our hypothesis and mimics the ranges, but not the magnitude of changes reported in previous long-term studies with untrained adults. Sandvei et al.\(^14\) found that 8 weeks of HIIT decreased fasting blood glucose by 3.6 mg/dL. After 12 weeks of HIIT, Nybo et al.\(^12\) determined that HIIT decreased fasting blood glucose by 9.0 mg/dL. With trained adults, our results do not support the findings of studies over 2-3 weeks, in which HIIT did not change fasting blood glucose\(^16-18\). These results suggest that longer HIIT cycling interventions and studies with untrained individuals have greater benefits for blood glucose control. Changes in fasting blood glucose may be a response to increased adrenaline associated with HIIT, which regulates glucose metabolism, as well as changes in body composition favoring higher post-exercise metabolism\(^28-29\).

In support of our hypothesis, body composition improved significantly with HIIT. Comparatively, decreases in body fat percentage in this study were similar to results from treadmill running HIIT studies. We reported a body fat percentage decrease of 1.1% while previous studies in untrained adults...
found decreases in body fat percentage ranging from 0.6% after 12 weeks of HIIT to 11.2% after 15 weeks of HIIT 19-20,30. While the literature with untrained adults shows improvements of varying magnitude in body composition, 2-3 weeks of HIIT cycling did not elicit significant changes in body fat with trained adults 9,18. For 6 weeks of a weight-bearing HIIT intervention, however, body fat percentage decreased by 2.1% in 6 weeks in trained adults13 and by 12.4% in 6 weeks in active, younger adults26. The reduction in body fat percentage in the current study follows the general trend of HIIT in trained adults over a period of 6 weeks. The lack of change with only 2-3 weeks seems to indicate that at least 6 weeks are necessary to achieve improvements in body composition. Thus, a longer duration intervention may be more effective in eliciting these changes in trained adults.

LIMITATIONS AND FUTURE STUDIES

There were several limitations to this study. While our primary goal was to evaluate a practical alternative that can be performed by a greater segment of the population, this allows less control over environmental and lifestyle factors. For example, we asked that the participants not change their diet, however we did not strictly measure their nutritional intake over the 6 weeks. A secondary goal was to utilise methods that could be utilised in non-research settings for future comparisons. For this reason, we elected to use a heart rate based estimate of maximal oxygen consumption instead of indirect calorimetry and the portable dynamometer instead of weight machines. Obviously these procedures reduce accuracy in this single study but will hopefully encourage reports in facilities around the globe. Additionally, for the HIIT sessions, participants were asked to follow the cadence and resistance guidelines of the instructor but we did not analyse the specific wattages for each participant. Future studies could investigate heart rate data on this protocol in order to determine the high intensity to recovery time ratios that elicit the greatest improvements in physical fitness.

CONCLUSIONS AND PRACTICAL APPLICATIONS

Together, the results of this study and previous studies demonstrate the benefits of improving physical fitness (cardiovascular, metabolic, and musculoskeletal fitness, as well as body composition) with HIIT or SIT cycling. More specifically, these results suggest that replacing a bout of moderate-intensity exercise with 2-30 minute bouts of HIIT cycling bouts is an effective way to improve physical fitness. This data is beneficial to professionals including physicians, personal trainers, and exercise instructors in an effort to advise patients and clients on how to incorporate low impact, high intensity training into their current routine to maximise physical fitness.

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POTENTIAL CONFLICT OF INTEREST

Jinger S. Gottschall is a co-owner and founder of FITOLOGY, LLC, the studio where the participants completed the classes. Les Mills International was supportive of the present study but they did not have access to the data for analyses.

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BIOMECHANICAL ASPECTS OF AQUATIC THERAPY: A LITERATURE REVIEW ON APPLICATION AND METHODOLOGICAL CHALLENGES

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ABSTRACT

The application of aquatic therapy for health and rehabilitation purposes has been promoted for centuries. Although used predominantly in clinical settings for the treatment, rehabilitation and management of chronic conditions, the practice is also gaining popularity in athletic settings in such areas as recovery training and for the rehabilitation of acute musculoskeletal injuries.

To date, most studies on the impact of aquatic-based rehabilitation on the human body have focused on physiological aspects. There is a relative paucity of published research on the biomechanical implications associated with aquatic-based activity. The published findings have been limited to the influence of the aquatic environment on running and walking gait.

A clear challenge in this field is absence of standardised protocols for assessing the impact of aquatic therapy and its possible role in rehabilitation. For example, methodologies often differ considerably between studies, and there are no standardised reporting procedures for important variables such as water depth and temperature. The research knowledge in this area has been questioned, with current medical guidelines highlighting that high quality research into the roles of aquatic therapy in rehabilitation is warranted.

This review will summarise the current literature on water-based activity and how this can impact human movement and subsequent rehabilitation.

Keywords: water; human movement; underwater kinematics; rehabilitation; fitness; isoinertial sensors
INTRODUCTION

The health related benefits of aquatic therapy have been promoted for centuries.\(^1\) Common uses for aquatic therapy in clinical settings is managing\(^2\),\(^3\),\(^4\),\(^5\) and rehabilitating\(^6\),\(^7\),\(^8\) chronic conditions such as osteoarthritis (OA) and fibromyalgia.\(^3\),\(^9\),\(^10\) Aquatic therapy is also used for weight management, athlete rehabilitation,\(^11\),\(^12\),\(^13\),\(^14\) and recovery.\(^15\),\(^16\),\(^17\),\(^18\)

Despite decades of research examining the roles of aquatic therapy in rehabilitation, many of the results from scientific investigations are conflicting, likely due to differences in applied methodologies (Table 1). Because of the limited quality of current research, reviews published by the Cochrane Collaboration concludes that aquatic-based rehabilitation programmes are assumed equally effective to programmes performed on land, but highlights that further high-quality research is warranted.\(^2\),\(^19\),\(^20\),\(^21\),\(^22\) The lack of consensus among previous research regarding the efficacy of aquatic-based rehabilitation is resultant from several methodological challenges and a lack of consensus on the most appropriate outcome measures.

This review will briefly evaluate published literature on water-based activity; its impact on biomechanics and current role in rehabilitation protocols. Existing limitations and challenges in research methodology will also be reviewed along with gaps and limitations in the current knowledge and directions for future research will be recommended.

AQUATIC THERAPY EXPLAINED

The appeal of aquatic therapy as a tool in exercise, recovery and rehabilitation has increased over recent years.\(^23\),\(^24\),\(^25\) Previous research has identified several biomechanical and physiological effects associated with exercising in water that must be thoroughly understood by practitioners to prescribe accurate and effective programmes.\(^1\),\(^26\),\(^27\),\(^28\) These effects occur because of fundamental principles of hydrodynamics and physical properties of water, such as density, buoyancy, hydrostatic pressure, viscosity and thermodynamics.\(^1\),\(^26\),\(^29\)

THE PHYSICAL PROPERTIES OF WATER

Density

Density quantifies a substance’s mass by volume unit (Kg·m\(^{-3}\)).\(^30\) The density of 4°C freshwater is approximately 1,000 Kg·m\(^{-3}\) at sea level (999.97 Kg·m\(^{-3}\)). Although the temperature of the water affects its density, the change is considered small enough to dismiss (997.05 Kg·m\(^{-3}\) at 25°C).\(^31\) An average human body consists of approximately 60% water,\(^32\) and its density is thus slightly lower than that of water (approximately 974 Kg·m\(^{-3}\)).\(^1\) The specific density of a human body depends on body composition.\(^33\) Fat free mass, including bone, muscle, organs and connective tissue, has a density higher than water (close to 1,100 Kg·m\(^{-3}\)) whilst fat mass has a density lower than water (close to 900 Kg·m\(^{-3}\)).\(^33\) Thus, an individual with a higher percentage of fat free mass has a higher density compared to an individual with a higher fat mass percentage.

Buoyancy

A human body with a density lower than water displaces a volume of water that weighs slightly more than the body itself.\(^1\) By Archimedes principle, an upwardly directed force is exerted on the body equal to the volume of the water it displaced. This buoyant force, opposes gravity and pushes the submerged body towards the surface of the water.\(^1\),\(^34\) Accordingly, a human body with a specific gravity of 0.974 (a density of 974 Kg·m\(^{-3}\)) will achieve floating equilibrium when 97.4% of the body is submerged due to buoyancy.\(^1\) As the mass of the submerged body increases, the buoyancy force increases proportionally.\(^35\) Therefore, an individual immersed to chest level experiences a larger buoyancy force compared to someone immersed to the waist.

Hydrostatic pressure

In addition to buoyancy, the volume of water surrounding the submerged body also exerts a compressive force on the body - hydrostatic pressure.\(^36\) At sea level the pressure exerted on the
body by the air surrounding it is approximately 1013.0 Pa (7.6 mmHg), a value that is so small that it is basically imperceptible. However, the proportionally greater mass of water means that immersion in water exposes the body to considerably higher pressure, that like buoyancy, increases with the depth of immersion at a rate of approximately 981.0 Pa (73.5 mmHg) per meter. Accordingly, standing in water at neck depth will result in approximately twice the hydrostatic pressure on the calf muscles than on the chest.

Viscosity

Viscosity is the magnitude of internal friction a fluid has during motion and is specific to each fluid. An immersed body moving through water, experiences resistive drag forces opposite to the direction of travel because of viscosity. The viscous resistance is directly proportional to the force exerted against the fluid. Therefore, the resistance will increase with increased velocity and surface area of the moving body. For example, a fully outstretched arm produces a greater resistance when moving through water than a hand only. As soon as movement ceases and the exerted force on the water disappears, the viscous resistance drops immediately to zero, resulting in no further resistance on the body.

Thermodynamics

Water has a superior ability to retain heat and transfer heat energy than air and has a heat capacity of approximately 1.0 J·K⁻¹ (1,000 times greater than air). Water also has a higher heat capacity compared to human body tissues (0.83 J·K⁻¹), resulting in body equilibrating faster than the surrounding water. Thus, a body immersed in water colder than core temperature will adapt to the temperature of the water and lose heat. Water warmer than core temperature therefore warms the body and raises its core temperature.

EFFECTS OF WATER-BASED EXERCISE ON THE HUMAN BODY

The physical properties of water have large biomechanical, neurological, physiological and hormonal effects on the human body. Previous research has identified many of these effects; however, to explore them individually is outside the scope of this literature review, thus only those variables implicating on human movement will be addressed. For additional insight on the effects not included here, see reviews by Becker (2009), Denning et al. (2012) and Mooventhan and Nivethitha (2014).

Biomechanical effects of immersion

Studies into biomechanical aspects forms a minority of previous research into the effects of immersion on the human body. Of these, most reported on differences in gait parameters between the water- and land-based settings, thus, insights into biomechanical implications of aquatic therapy remains unreported. The published research on water-based gait reports several significant adjustments enforced by the aquatic environment, believed to be mainly associated with buoyancy and drag forces. However, some reports on these adjustments are contradictory, most likely due to the considerable differences in utilised methodologies between studies (Table 1).

The inconsistencies in water depth and temperature alone are likely resulting in differences in reported findings as both properties are known to impact on biomechanical variables. However, as the current understanding of biomechanical adaptations to the aquatic environment is limited to these reports, their findings should still be taken into consideration. Most studies reported similar joint angles during both aquatic and land-based walking. A 2012 review on differences in gait mechanics in water and on land concluded similar joint motions at the knee and ankle during water-walking, but highlighted that the activity at the hip joint and pelvis increased. Several studies have reported on increased reliance on the hip joint
<table>
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<tr>
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<td>Barela and Duarte (2008)</td>
<td>SR</td>
<td>10 elderly adults</td>
<td>Xiphoid process</td>
<td>Not reported</td>
<td>Sagittal view video recording at 60 Hz. and force platform recording at 1000 Hz.</td>
<td>Self-selected speed on land and in water on a walkway. No significant difference in SL, but significantly lower SF in water. Slower walking speed in water. Reduced GRF, and reduced knee ROM in water.</td>
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<tr>
<td>Frangolias and Rhodes (1995)</td>
<td>DWR vs L</td>
<td>13 endurance runners</td>
<td>Neck (with buoyancy belt)</td>
<td>28 °C</td>
<td>Sagittal view video (recording rate not reported)</td>
<td>DWR had an initial water resistance of 0.5kg (female) or 0.75kg (male) with increases each minute. Significantly lower SF in water. Reliance on lower trunk musculature during DWR with no eccentric contraction.</td>
</tr>
<tr>
<td>Hall et al. (2004)</td>
<td>UT vs L</td>
<td>15 females</td>
<td>Xiphoid process</td>
<td>34.5 °C</td>
<td>Manually counting SF</td>
<td>Three bouts of five minutes at 2.5, 3.5 and 4.5 km·h⁻¹. Significantly lower SF at all speeds in water.</td>
</tr>
<tr>
<td>Hall et al. (1998)</td>
<td>UT vs L</td>
<td>8 females</td>
<td>Xiphoid process</td>
<td>28 °C and 36 °C</td>
<td>Manually counting SF</td>
<td>Three bouts of five minutes at increasing speeds (3.5, 4.5 and 5.5 km·h⁻¹). Significantly slower SF in water.</td>
</tr>
<tr>
<td>Kato et al. (2001)</td>
<td>UT vs L</td>
<td>6 males</td>
<td>Waist</td>
<td>29 °C</td>
<td>Sagittal view video recording with a shutter speed of 1/250 seconds</td>
<td>Initially 2.0 km·h⁻¹, gradually increased up to 12.0 km·h⁻¹. Lower SF for all speeds in water. Increased nonsupport phase in water. Walking to running transition occurs at lower speeds in water.</td>
</tr>
<tr>
<td>Kilgore et al. (2006)</td>
<td>DWR vs L</td>
<td>20 distance runners</td>
<td>3.96 m</td>
<td>27.2 °C</td>
<td>Sagittal view video recording at 30 frames per second</td>
<td>60% of maximal VO₂ at 0% incline for 5-6 minutes. Lower SF in water.</td>
</tr>
<tr>
<td>Masumoto et al. (2009)</td>
<td>DWR vs L</td>
<td>7 adults</td>
<td>Neck</td>
<td>28 °C</td>
<td>EMG recording at 1500 Hz. SF recording methodology not reported</td>
<td>Three exercise intensities (RPE 11, 13 and 15) per element, with 4 min per intensity and 1 min rest. Increased SF with increased RPE in water but almost 50% slower compared to land. Different muscle patterns between DWR and L.</td>
</tr>
<tr>
<td>Masumoto et al. (2008)</td>
<td>UT vs L</td>
<td>9 older females</td>
<td>Xiphoid process</td>
<td>31 °C</td>
<td>EMG recording at 1000 Hz. of thigh and shank muscles</td>
<td>Three bouts of four minutes at: UT – 1.2, 1.8 and 2.4 km·h⁻¹. L – 2.4, 3.6 and 4.8 km·h⁻¹. Greater SL at matched speeds but lower SF in water. Lower muscle activity in water.</td>
</tr>
<tr>
<td>Pohl and McNaughton (2003)</td>
<td>UT vs L</td>
<td>6 university students</td>
<td>Umbilicus, Thigh-deep (midway between ASIS and center of patella)</td>
<td>33 °C</td>
<td>SF manually counted</td>
<td>Running and walking in waist-deep and thigh-deep water and on land. Walking five minutes at 4.0 km·h⁻¹. Lower SF in water during running but lowest SF in the thigh-deep water.</td>
</tr>
<tr>
<td>Shono et al. (2001)</td>
<td>UT vs L</td>
<td>6 older females</td>
<td>Xiphoid process</td>
<td>30.7 °C</td>
<td>SF manually counted</td>
<td>Three bouts of four minutes at: UT – 1.2, 1.8 and 2.4 km·h⁻¹. L – 2.4, 3.6 and 4.8 km·h⁻¹. Lower SF in water.</td>
</tr>
<tr>
<td>Study</td>
<td>Condition</td>
<td>Participants</td>
<td>Measurement Site</td>
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<td>Shono et al. (2007)†</td>
<td>UT vs L</td>
<td>8 older females</td>
<td>Xiphoid process</td>
<td>30.7 °C</td>
<td>Sagittal view (Hz. not reported)</td>
<td>Three bouts of four minutes at: UT – 1.2, 1.8 and 2.4 km·h⁻¹, L – 2.4, 3.6 and 4.8 km·h⁻¹</td>
</tr>
<tr>
<td>Town and Bradley (1991)†</td>
<td>DWR vs SR vs L</td>
<td>9 college students</td>
<td>DWR – 2.5-4 m, SR – 1.3 m</td>
<td>Not reported</td>
<td>SF recording methodology not reported</td>
<td>DWR and SR – four minute of running, L – three minute incline increments starting at 5% incline at a predetermined running speed (males 14.48-16.90 km·h⁻¹, females 12.87-14.16 km·h⁻¹).</td>
</tr>
<tr>
<td>Orselli and Duarte (2011)†</td>
<td>WW vs L</td>
<td>10 young adults</td>
<td>Xiphoid process</td>
<td>30 °C</td>
<td>Sagittal view video at 60 Hz.</td>
<td>Walking at a self-selected speed</td>
</tr>
<tr>
<td>Miyoshi et al. (2005)†</td>
<td>WW vs L</td>
<td>16 healthy adults</td>
<td>Axillae</td>
<td>34 °C</td>
<td>2 cameras, sagittal view, recording at 30 Hz. and force platform at 1000 Hz.</td>
<td>Walking at a self-selected speed</td>
</tr>
<tr>
<td>Miyoshi et al. (2004)†</td>
<td>WW vs L</td>
<td>15 healthy adults</td>
<td>Axillae</td>
<td>34 °C</td>
<td>2 cameras. Sagittal view, recording at 30 Hz. and force platform at 1000 Hz.</td>
<td>Walking at a self-selected speed, with increases and decreases in speed</td>
</tr>
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<td>Miyoshi et al. (2003)†</td>
<td>WW vs L</td>
<td>8 healthy adults</td>
<td>Axillae</td>
<td>34 °C</td>
<td>2 cameras, sagittal view, recording at 30 Hz. and force platform at 1000 Hz.</td>
<td>Walking at a self-selected speed</td>
</tr>
<tr>
<td>Kaneda et al. (2012)†</td>
<td>WW vs L</td>
<td>6 adults</td>
<td>1.35 meters</td>
<td>27 °C</td>
<td>Sagittal video capture at 25 Hz.</td>
<td>Walking at a self-selected speed for 10 meters</td>
</tr>
<tr>
<td>Farber et al. (2008)†</td>
<td>WW vs L</td>
<td>8 young adults</td>
<td>Xiphoid process</td>
<td>30±1 °C</td>
<td>Four video cameras (placement not reported) recording at 60 Hz.</td>
<td>Forward and backwards walking at a self-selected speed for 10 meters with high and low step frequency</td>
</tr>
<tr>
<td>Barela et al. (2006)†</td>
<td>WW vs L</td>
<td>10 adults</td>
<td>Xiphoid process</td>
<td>Not reported</td>
<td>Sagittal view video recording at 60 Hz. and force platform recording at 1000 Hz.</td>
<td>Self-selected speed on land and in water on a walkway</td>
</tr>
</tbody>
</table>

during water-based walking. Kaneda et al. (2008) reported an increased hip joint range of motion (ROM) during water walking and suggested that it was a consequence of buoyancy allowing an increased hip flexion motion during swing phase. It is possible that these adaptations in hip joint kinematics may influence other movements performed in water, such as squats and lunges. Miyoshi et al. (2003) further noted a hip extension moment throughout the entire stance phase during walking in water that was not present during land-based walking. A similar study reported decreased joint torques about the knee and ankle during water-walking compared to overland, but highlighted that no decreases were noted at the hip joint. Perhaps this is because of the increased resistance supplied by the water as the hip joint attempts to translate the leg forward through the viscous fluid. These studies on gait have concluded that kinematic adaptations occur in aquatic settings, and highlights the need for future kinematic research conducted on exercises used for aquatic-based rehabilitation. One study highlighted that although drag forces of water might be advantageous for rehabilitation, they may be a contra indicator against water-based exercise if not properly understood. The added, and abnormal resistance supplied by the water element may result in compensations or prove too much for an injured tissue and should be considered when programming for rehabilitation.

Biomechanical research has also been conducted into vertical ground reaction forces (GRF) during aquatic activities compared to land-based equivalents, and shown significant differences between the two environments. These differences have been attributed to the decreased loading associated with buoyancy and drag forces. Further, research comparing jumping actions in water and on land, reported increased force production, rate of force development, and power output during water based jumping actions. It was also noted the aquatic environment produced lower impact forces. These studies inferred that the aquatic environment is ideal for plyometric training as it reduces potentially harmful impact forces. Similarly, Martel et al. (2005) suggested that aquatic-based plyometric training improves land-based plyometric performance and potentially reduces muscle soreness. Although these studies were not performed in a rehabilitation context, they have provided further evidence of biomechanical implications in the aquatic environment, which should be considered in the application of aquatic therapy.

Further, authors have suggested that the aquatic environment might be beneficial for static and dynamic balance training. However, although studies have reported significant improvements in balance following aquatic-based exercise, the improvements were not significantly different from those achieved with land-based programmes. The aquatic environment is often considered a safer environment than land, as it provides increased stability and reduces the risk of injury in case of a fall. Consequently, performing some exercises in the aquatic environment offers clear advantages over the land-based equivalent for populations with a high risk of falls such as older adults and post-surgery patients.

Although previous kinematic research is limited to gait, it seems the aquatic environment has the potential to affect several parameters of human movement. Future research should include other activities common in everyday life, exercise and rehabilitation.

**AQUATIC THERAPY IN REHABILITATION OF HUMAN MOVEMENT**

Buoyancy and viscosity are the two physical properties of water believed to have considerable effect on the biomechanical aspects of rehabilitation. Buoyancy opposes gravity and thus decreases the loading on joints and muscles. Becker (2009), reported that immersion to the pubic symphysis offloads approximately 40% of the body weight, immersion to the umbilicus offloads 50%, and immersion to the xiphoid process...
offloads 60%. Reduced joint and muscle loading during immersion to these depths may allow a patient to perform exercises and activities earlier than may be possible during full gravitational loading.\(^1\) Decreased loading of joints and early rehabilitation could be beneficial across several acute and chronic injuries, and for several different populations including athletes, elderly and patients with various chronic conditions as it facilitates movement.\(^{13, 71, 72, 73, 74}\)

The viscosity of water provides resistance to movements and may therefore be helpful for building muscle strength and endurance following musculoskeletal injuries or surgery.\(^{1, 49, 51, 53, 60}\) However, research has shown the improvements in strength achieved with water-based training are significantly less than improvements achieved with similar exercises performed on land.\(^{75, 76}\) The ability of the aquatic environment to build strength with decreased joint loading constitutes the rationale for the use of aquatic therapy in improving the quality of life for an elderly or obese population, or as a part of a general weight-management programme.\(^{66, 70, 77}\)

Current rehabilitation protocols for ligamentous injuries recommend early functional treatment.\(^2\) These protocols aim to control inflammation during the acute phase and limit subsequent loading stress.\(^{13}\) The hydrostatic pressure and decreased joint loading supplied by the water caters to both these aims and constitutes the use of aquatic therapy in rehabilitation of musculoskeletal injuries.\(^{13, 78}\) Kim et al. (2010)\(^{13}\) reported that aquatic-based rehabilitation produce superior rehabilitation outcomes at two and four weeks post-injury compared to a land-based programme for ligamentous injuries in the knee. Previously, Bartels et al. (2007)\(^2\) highlighted the low quality of past studies in their meta-analysis on the use of aquatic-therapy as a rehabilitation regime for OA. It was suggested that aquatic-based rehabilitation exercise protocols offer some short-term benefits in rehabilitation of knee OA, but that further research is needed before any definitive conclusions can be drawn. Clearly, current knowledge on the roles of aquatic therapy in rehabilitation is lacking, and future research should aim to settle protocols and guidelines to ensure best outcomes.

**CURRENT METHODOLOGICAL CHALLENGES IN AQUATIC THERAPY RESEARCH**

The growing attractiveness of aquatic-based rehabilitation among medical professionals is likely based on suggestions that the aquatic environment allows for an earlier commencement of rehabilitation and reduces joint and muscle loading.\(^1, 26, 27\) However, despite being a common part of many rehabilitation programmes, there is a paucity of high-quality scientific literature on the efficacy of aquatic-based rehabilitation training regimens. The different context offered by the aquatic environment provides several challenges to researchers rending it difficult to conduct high-quality research projects.

**MOTION TRACKING IN THE AQUATIC ENVIRONMENT**

Most previous research into kinematical effects of water-based motion have relied on video analysis capturing the sagittal view only and operating at 30 or 60 Hz. (Table 1)\(^{40, 52, 53, 54, 57}\) Researchers used video cameras placed along an underwater walkway and recorded participants as they walked past.\(^{40, 51, 52, 53, 54, 57, 79}\) Caution is advised when performing kinematic analysis using video footage because of the risk of parallax error (Figure 1). Parallax error denotes a distortion of the image because of an angle of inclination between the subject and camera.\(^{80, 81}\) Further, by limiting the analysis to sagittal view due to camera positions, data on frontal and transverse plane movements are not recorded. Collecting video footage from a sagittal and frontal view allows for a more comprehensive analysis, however, the capacity of video analysis to accurately assess data on frontal and transverse plane movements have been questioned.\(^{81}\)
Further, the reliance on video analysis for kinematic parameters in gait research has been questioned as the surrounding water induces differences in basic kinematic descriptors such as stride frequency and length. The author thus recommended that electromyography (EMG) would provide valuable additional information during kinematic gait studies. A literature review on surface EMG during aquatic-based exercise concluded that muscle activity generally is lower in during activity performed in water compared to land. However, the review highlighted that the included studies were low in number and that more high-quality research is needed to fully understand the implications of this. Further, authors have reported that the use of EMG underwater requires caution as it constitutes further challenges including water interfering with the signals and safety considerations when using electrical components in water.

Current practice considers motion capture technologies the gold standard for analysing human movement. Motion capture using infrared cameras to track reflective markers on participants are capable of capturing at frequencies of up to 50 KHz. However, motion capture systems are expensive, complicated, and limited to laboratory settings. Therefore, their availability and application in clinical and practical settings are restricted. In addition, as the refractory index differs between air and water, light travels differently in the two mediums. Thus using systems relying on infrared cameras in water remains challenging.

The use of isoinertial sensors, such as accelerometers and gyroscopes, is gaining popularity amongst researchers in attempts to track human motion in non-laboratory settings. These sensors are small, inexpensive and portable, thus allowing for testing in various settings. Studies have confirmed the accuracy of these sensors during walking, the timed-up-and-go test, and the sit-to-stand test. However, only sagittal plane data, peak velocities and power were reported. Thus, future research should aim to examine the use of isoinertial sensors in non-sagittal plane human motion, as this could further establish their role in biomechanical research. In addition, isoinertial sensors rely on measurements from within the sensor itself and so can therefore be used to track human movement in water. Research into the effectiveness of isoinertial sensors for tracking human movement in aquatic environments would provide valuable and exciting additions to current knowledge and research methodologies.

**LACKING PROTOCOLS**

To date, the consensus on the biomechanical and physiological effects of aquatic based activity are lacking. A likely reason for reported contradictions is differences in methodological protocols, including differences in water depth, temperature, activity and intensity (Table 1). These factors are all known to impact biomechanical and physiological responses to exercise. Caution is therefore warranted when comparing studies reporting on effects of aquatic-based exercise, and target population and exercise specifications should be considered. Establishment of guidelines for water temperature and depth would also be beneficial for aquatic-based exercise and research.
COMPARATIVE STUDIES – LAND VERSUS WATER

There are numerous systematic reviews and meta-analyses published assessing the differences in water- and land-based rehabilitation for patients with lower limb OA, fibromyalgia, chronic obstructive pulmonary disorder, asthma and stroke. However, these reviews agree that previous research is of poor quality and fails to show significantly different outcomes between the two environments. These reviews highlight the need for high quality comparative studies in this domain.

Much of the research in this domain relies on outcome measures, typically including subjective pain scales, functional tests with hand-held stopwatches, isolated muscle strength testing using non-specific hand-held dynamometers and isolated ROM tests. Although scientifically validated in clinical settings, research has questioned the application of these measurements in comparative research. Hatfield et al. (2011) highlighted that subjective reports are insensitive and likely produce skewed results. Further research has reported that pain is not necessarily reflective of functional outcomes and so the use of pain scales as an assessment tool may not be a valid measure of performance. The reliability of ROM tests have also been questioned following total knee replacement (TKR) surgeries, as ROM may be affected by several factors including the prosthetic design, preoperative motion and surgical technique.

An objective alternative to the outcome measures in question is the use of motion capture systems to determine pre- and post-intervention changes in kinematics. Although motion capture testing comprises several known limitations, it provides objective information on human movement that subjective data cannot provide. A recent literature review by Komnik et al. (2015) showed that motion capture is a common method to identify differences in kinematics following TKR. The review highlighted several lingering alterations in kinematics following surgery, including asymmetries between the limbs, and have provided useful information on the use of rehabilitation programmes following TKR surgery. However, this review was limited to include studies assessing kinematics following only land-based rehabilitation protocols.

Surprisingly, despite providing no empirical evidence to support these claims, highly regarded medical research foundations such as the Cochrane Collaboration and BioMed Central have indicated that aquatic-based rehabilitation is comparable to conventional land-based protocols. However, at the time of this review no published studies have investigated biomechanical differences between the two media using empirical methods such as motion capture. Research comparing pre- and post-rehabilitation kinematics of individuals following land- or water-based rehabilitation programmes would provide new information on the roles of aquatic therapy in rehabilitation and its effect on human movements.

SUMMARY

Aquatic therapy can aid in the rehabilitation of musculoskeletal, cardiovascular and neurological conditions as it offers a safe and social alternative to common land-based protocols. The physical properties of the water including buoyancy, viscosity and hydrostatic pressure has beneficial effects on joint loading, pain perception and blood flow. Studies have assessed the effectiveness of water based rehabilitation programmes for management of various medical conditions. However, these studies relied on subjective or clinical outcome measures. Although the subjective experience is an important aspect of rehabilitation, its scientific validity has been questioned.

Further, previous research into the biomechanical and physiological effects of water-based rehabilitation present contradicting results and a consent on practices such as water depth and temperature have not been established. Additionally, the current limitations in motion tracking methodologies adds further complexities to this research area, as it is possible that exercises...
performed in the aquatic environment has biomechanical implications that remain unknown.

This literature review identifies several gaps in the current knowledge and highlights possible pathways for future research. By bridging the gaps and gaining new knowledge in the roles of aquatic therapy in rehabilitation, we can establish protocols and procedures to ensure optimal recovery for individuals with injuries and pathologies.

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