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Research

Effects of 4 Weeks High-Intensity Training on Running and Cycling Performance in Well-Trained Triathletes

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ABSTRACT

Introduction: The aim of this study was to investigate the effect of a 4 week high-intensity interval training (HIIT) program on running and cycling performance. HIIT is a training method which can be used to improve physical fitness in less time, and reduced training volume, than traditional endurance training. HIIT allows athletes to accumulate time at higher training intensities, which is difficult to achieve when training in a continuous method.
Methods: Twelve well-trained triathletes completed 4 traditional training weeks as a control period. They were then randomly assigned to a bike or run HIIT program completing 2 HIIT sessions each week. A 20-minute cycling time trial and maximal aerobic power test on the treadmill were measured before and after the HIIT program.
Results: Both bike and run HIIT group achieved an increase of 6.7 and 2.1% in velocity at 2 mM and a decrease of 6.4 and 8.4% in the HR variable at 2 mM, respectively. Velocity peak decreased 1.9% in the run HIIT group and 1.8% for HR at 4 mM. Velocity peak decreased ~2% in the bike group and maintained HR maximum while there was a small reduction in the run group. For cycle time trial, the bike HIIT group demonstrated a significant improvement in average velocity (8.8%), whereas, velocity was slightly lower in the run training group (-3.5%).
Conclusion: A 4-week bike HIIT program improved running performance in moderate to well-trained triathletes. However, in our study, the cycle performance was not enhanced by a 4-week HIIT running program, this may be due to the accumulated fatigue for the run group subjects.

KEYWORDS: High intensity training; Cross training; Blood lactate; Performance; Triathlon.

ABBREVIATIONS: HIIT: High-intensity interval training; AT: Anaerobic Threshold; IEC: Institutional Ethics Committee; WMA: World Medical Association; BMI: Body Mass Index; ISAK: International Society for the Advancement of Kinanthropometry; LT: Lactate Threshold; RPE: Rating of Perceived Exertion.

INTRODUCTION

The optimal training recipe for improvement in performance in each of the modes of swimming, cycling or running is one of the most important elements of competitive triathlon. Therefore the search for new training methods to achieve improved triathlon performance is of paramount significance for coaches and scientists. The running component of elite triathlon largely dictates overall race performance.[1-4] Thus, improving running performance is viewed as the most important triathlon modality to achieve a satisfactory final race outcome especially in elite

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athletes.[1] Therefore, training for many athletes should focus on optimizing running performance.

Maximal oxygen uptake (VO_{2max}) and other submaximal physiological parameters are often viewed as key performance indicators in triathletes and other endurance athletes.[5] Recently the effects of high-intensity interval training (HIIT) on VO_{2max}, anaerobic threshold (AT), running and cycling performances in endurance running and triathlon have been investigated, concluding that interval training consisting of multiple 5 min bouts at high intensity (85% of maximum heart rate (HR_{max}) was more likely to benefit 5 km running performance.[6,7] Short and long intervals at supramaximal and submaximal exercise intensities respectively, improved cycling physiology and performance.[6,7] Lindsay et al[8] concluded that, in competitive cyclists, a 4-week program of HIIT increased peak sustained power output and fatigue resistance by ~5% and significantly improved 40 km time trial performance. In contrast, Acevedo and Goldfarb found no improvement in VO_{2max} in competitive long distance runners after 8 weeks of HIIT.[9] However, 10 km race performance and time to fatigue did improve indicating that improvements in performance can be dependent of other variables in elite athletes.[9]

Some authors have defined cross-training as a) the participation in an alternative training mode exclusive to the one normally used in competition b) combining an alternative training mode with task-specific training c) cross transfer of training effects from one sport to the other one.[1,10] Several investigations have focused on cross-training transfer between swimming and running.[11-15] Millet et al[1] found that swimming training did not provide additional beneficial adaptations for the other disciplines in triathlon. They concluded that swimming training was highly specific, there were no significant relationships between training amounts in cycling or running and performance in swimming. Hence, performance improvement in swimming would be due specifically to improved swim technique and propulsive efficiency in swimming.[1] However, they were able to show that improvement in running performance may be as a result of training in cycling, which had a significant effect on running performance (τ_1=42: r=0.56: p<0.001). Additionally, performance in triathlon was related to the running training amounts (τ_1=52; fatigue function: τ_2=4: r=0.52; p<0.001).[1] Others have shown that training in cycling may help reduce over-use injuries, maintain aerobic condition and/or minimize stress during high training periods.[1,16,17] But few investigations have examined the impact of HIIT training on cycling or running performance in triathletes.[7] Similarly, there is limited evidence of the impact of HIIT in cycling and it is effects on running performance.

For these reasons, the purpose of this study was to observe the performance and physiological outcomes in incremental running and cycle time trial performance in triathletes during 4 weeks of HIIT of either cycling or running. It was hypothesized that cycling HIIT would enhance running performance in well trained triathletes.[1]

MATERIALS AND METHODS

Participants

Twelve male well-trained triathletes with a minimum of 2 years triathlon experience were invited to participate in the study. Their physical characteristics were (mean±SD); age, 34.0±5 yr; height, 178.8±3.2 cm; mass, 74.1±5.3 kg, body mass index (BMI) 23.3±1.6 kg·cm^{-2}, VO_{2max} 60.6±4.7 mL·kg^{-1}·min^{-1} (Table 1). The inclusion criteria was that they were training between 6-10 h a week to compete in a half ironman. Prior to commencement of the study the subjects completed a pre-questionnaire in order to establish background information on training patterns and medical history. The participants were divided into 2 HIIT groups: bike HIIT completed 2 sessions of HIIT cycling per week and run HIIT completed 2 sessions of HIIT running per week.

Variables	Means±SD
Age (years)	34±5
Body height (cm)	178.8±3.21
Body mass (kg)	74.1±5.3
BMI (kg·cm^{-2})	23.29±1.55
VO_{2max} (mL·kg^{-1}·min^{-1})	60.55±4.72

BMI: Body mass index; VO_{2max}: Maximum rate of oxygen consumption

Table 1: Anthropometric measures of study participants.

The Institutional Ethics Committee (IEC) *Comité De Ética en la Investigación con Seres Humanos (CEISH) de la Universidad del País Vasco (UPV/EHU)* approved on February 11th 2015, the study following the guidelines of the World Medical Association (WMA) declaration of Helsinki-Ethical principles for medical research involving human subjects. Participants were informed about the study protocols and experimental procedures, and provided written informed consent.

Testing Protocol

The participants were familiarized to the laboratory procedures before any testing. They were tested on 2 occasions (1) before the HIIT period and (2) following 4 weeks of HIIT. The subjects completed a maximal incremental treadmill test for determination of the lactate threshold, VO_{2max} and a 20 min cycle time trial at each testing period.

Anthropometric measurements were also taken including: height (cm) and body mass (kg), using International Society for the Advancement of Kinanthropometry (ISAK) criteria. After a 10 min warm-up on the treadmill (Trackmaster, USA), a maximal test was performed. This consisted of 3 min stages with 30 seconds recovery. The 1st stage started at 8 km/h and the velocity increased 2 km/h until exhaustion. The time in the stage and the speed at exhaustion was recorded. To simulate the energetic cost of outdoor running conditions, the treadmill was set at 1% gradient.[7,18]

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Heart rate (HR) was measured with a thoracic belt and wrist receiver (Polar RS400, Finland) during the test.

After each 3 min stage and during the 30 s recovery, blood Lactate concentration (BLa) was measured (Lactate Pro Analyser, Arkray, Japan). Two measures of the lactate threshold (LT) were calculated using the D-max method graph to observe the performance outcomes.[19,20] In this study, LTs were classified by 2 mM zone as lactate threshold 1 (LT_1) low intensity and >4 mM lactate threshold 2 (LT_2) as high intensity. Seiler identified the first low-intensity training zone (LITz) as a stable BLa at ~2 mM. The high-intensity training zone (HIITz) was above maximum lactate steady-state intensity, greater than or equal to 4 mM.[21] Finally, the zone between 2 and 4 mM was the threshold training (ThT). In this research, LITz was used as the training intensity area on traditional training weeks and HIITz and LITz on HIIT training weeks.

Therefore, the speed and the HR at LT_2, the velocity peak (maximum) and HR maximum achieved were observed to determine the changes on running performance.

During recovery, participants provided a value for rating of perceived exertion (RPE) using the Borg Scale 6-20.[22]

Additionally, 48 h after the VO_{2max} test the participants completed a 20 min cycling time trial (TT). Each athlete used their competition cycle mounted on a cycle roller training device (Bkool, model Bkool one; Madrid, Spain). The subject's bike was fitted with a power meter in the hub of the rear wheel (Powertap, model Powertap G3 Alloy Wheels; Madison, WI, USA) for recording average power (W). HR was recorded with a HR and power monitor (Garmin Forerunner 910XT). Average HR, velocity and cadence were measured during the TT.[23]

Training Intervention

Before the 1st laboratory test session, participants completed 4 low intensity training weeks (control) in which they trained 9 sessions per week (3 swimming, 3 cycling and 3 running). The subjects performed during 4 control weeks 26.28 km (~12 h) swimming, 19.83 h cycling and 10.42 h running. Participants exercised at less than 70% of the maximum heart rate (MHR), and trained below LT_1 (<2 mM) measured during the pre-test, accumulating 7.5 h of training per week. The 4 week control sessions were designed in order to familiarize and obtain a similar start point for all subjects before the pre-test.

After the pre-test, participants were randomly assigned into one of 2 HIIT groups. Both groups completed the same swimming sessions, however, the HIIT cycle group completed 2 HIIT cycling sessions per week and the HIIT run group performed 2 sessions of HIIT running per week. Each HIIT session was 7×5 min at 85% of MHR and HIITz (>4 mM). Running intensities were extrapolated using D-max graph and cycling intensities using 20 minutes TT test as published by Allen and Coggan.[23] All intensities were corroborated using exercise intensity categories (subjective and objective measures) Norton et al.[24] Besides the 2 HIIT sessions every week, another seven (3 swim, 1 or 2 run and 1 or 2 cycle) training sessions in each group were aerobic extensive, lower than 70% of MHR and LITz (<2 mM), identical intensity than control weeks. During HIIT training weeks, all subjects performed ~12 h swimming (25.95 km). Additionally, the bike HIIT group completed 4.2 h bike HIIT, 13.4 h cycling and 18.2 h running and the run HIIT group completed 10.8 h cycling, 4.2 h run HIIT and 6.1 h running.

During 8 training weeks (4 control weeks and 4 HIIT weeks), each triathlete recorded their total HR data for all their training sessions (less swimming sessions), using a range of HR monitors (Polar Electro, models RCX5 and RC3, Finland and Garmin Forerunner, models 910XT and 920XT, Olathe, Kansas, USA) and the RPE for each session.

STATISTICAL ANALYSIS

The statistical analysis was performed with SPSS Statistics 20. To evaluate whether data were normally distributed the Shapiro-Wilk was used. In the case of normal distribution, for a pre- and post-test group comparison the student's *t*-test for paired samples was applied.

To determine possible interaction effects between groups a 2 factor analysis of variance (ANOVA) with repeated measures on the 2nd factor was calculated. Independent post-hoc *t*-test was applied for an inter-group comparison. The level of significance was set at $p \leq 0.05$.

RESULTS

HR and Velocity at LT_1 on a Maximal Treadmill Test

For each group, the velocity at 2 mM on the treadmill increased while HR at this point decreased in both groups, however, no significant differences were observed between pre- and post-test for these variables at 2 mM (LT_1).

Running velocity at LT_1 improved (11.9±1.7 *vs.* 12.7±1.5 km/h) in the cycle group and in the run group (11.56±1.0 *vs.* 11.8±1.5 km/h). Additionally, HR at LT_1 was reduced (157±18 *vs.* 147±11 bpm) in the cycle group and the run groups (154±9 *vs.* 141±16 bpm) (Table 2).

Velocity and HR at LT_2 on a Maximal Treadmill Test

At the post-test, velocity ($F=6.93$, $p=0.025$) and HR ($F=9.01$, $p=0.013$) at 4 mM, on treadmill showed significant differences between groups, being lower in run group than cycle group at post-test. However, no significant differences were found between tests (Figure 1, graphs B and C). Cycle group showed a greater improvement on velocity and HR at LT_2 compared with the run group which diminished both variables (Table 2) (Ve-

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	HIT BIKE			HIT RUN		
	Pre	Post	*p*-value (intra-group)	Pre	Post	*p*-value (intra-group)
V 2 mM	11.9±1.72	12.7±1.54	0.46	11.56±1.01	11.8±1.49	0.69
V 4 mM	14.85±1.48	15.62±1.01	0.28	14.4±1.47	14.13±0.94	0.50
HR 2 mM	157±18	147±11	0.77	154±9	141±16	0.66
HR 4 mM	173±13	175±5	0.77	166±10	163±8	0.29
V peak	19.00±1.09	18.67±1.03	0.36	18.00±1.26	17.33±1.03	0.36
HR peak	187±5	187±8	0.70	180±9	177±11	0.26

V: Velocity; HR: Heart rate.

Table 2: Mean±SD aerobic capacity, aerobic power and heart rate during the incremental exercise test in the Bike HIT and Run HIT groups pre- and post- the intervention program.

locity: 14.4±1.47 to 14.13±0.94; HR: 166±10 to 163±8) at this point on post-test than pre-test in run group, without significance differences.

However, no significant differences were observed between pre- and post-test for either group, in variables such as, velocity and HR at 4 mM.

Velocity and HR_{peak} (Maximal) on a Maximal Treadmill Test

Velocity peak in running tended to be lower in both groups, presenting significant differences at the post-test (F=5.0, p=0.049), from 19.0±1.1 to 18.7±1.0; 18.0±1.3 to 17.3±1.0 for bike and run group, respectively (Figure 1, graph D).

However, no significant differences were recorded for velocity or HR peak during the incremental running test between pre- and post-tests for each group (Table 2). The HR_{peak} was similar in the bike HIIT group but was slightly lower in the run group after 4 weeks of HIIT (Table 2).

HR, Velocity and Cadence Average on 20 Minutes Cycling Time Trial

The HR average during the 20 min TT cycle showed significant differences between groups at post-test (F=5.42, p=0.042). In both groups HR average decreased, but in the run group this was

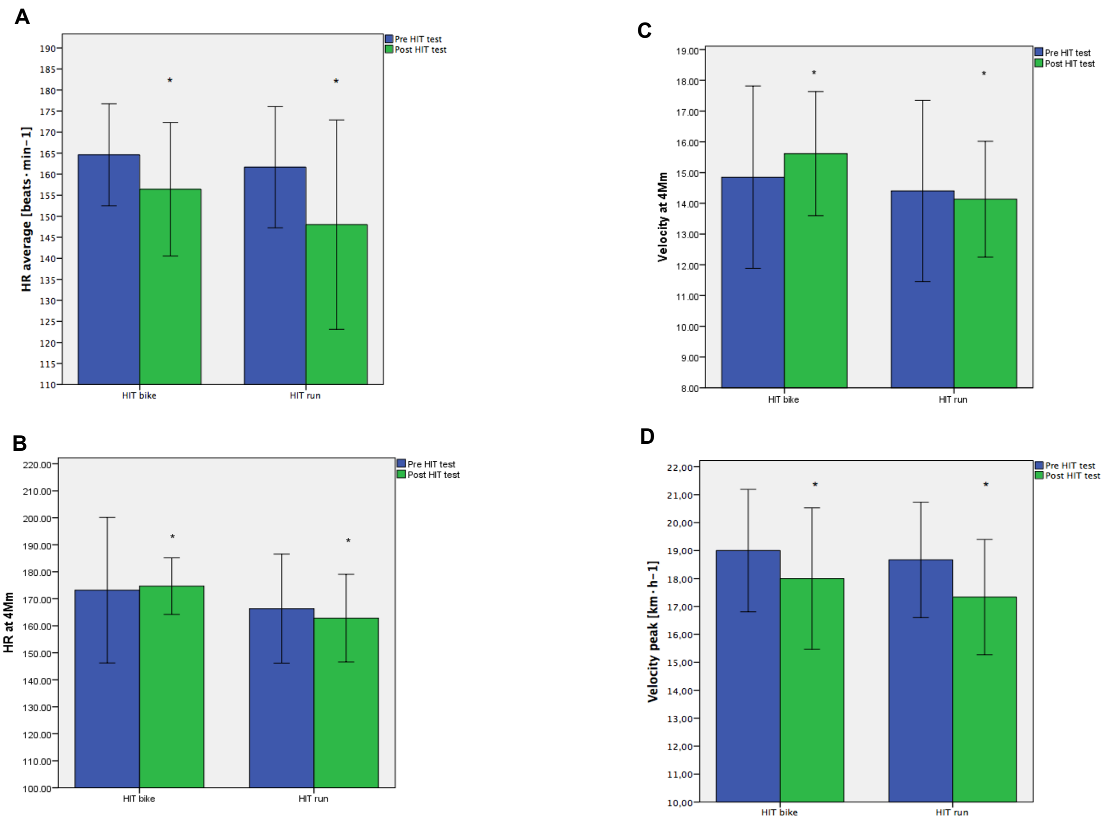

Figure 1: Mean±SD for Effects of 4 HIT weeks on HR average cycle (Panel A), HR at 4 Mmol (Panel B), Velocity at 4 Mmol (Panel C) and run velocity peak (Panel D) on treadmill running in moderate-well trained triathletes. *=p<0.05 group interaction.

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	HIT BIKE			HIT RUN		
	Pre	Post	*p*-value	Pre	Post	*p*-Value
V *av.* TT	42.0±2.14	48.97±1.62	0.72	41.80±0.94	41.05±0.94	-
HR *av.* TT	164±6	162±7	0.48	156±8	148±12	0.15
Cad *av.* TT	95.5±4.93	98.8±8.70	0.37	90.33±9.02	98.3±0.58	0.53

av.: Average; V: Velocity; HR: Heart rate; Cad: Cadence; TT: Time trial.

Table 3: Mean±SD for velocity, cadence and heart rate during the cycle time trial in the HIT Bike and Run groups pre and post the intervention program.

greater (Figure 1, graph A). No significant differences between tests were found for velocity, cadence or HR averages during the cycle TT (Table 3).

During the time trial cycle, the bike group demonstrated an improvement in average velocity, whereas, velocity was slightly lower in the run HIIT training group. The mean cadence during the cycle time trial was higher in both groups from 95.5-90.3 during bike and run pre-HIIT test to 98.8-98.3 on post-HIIT test (Table 3).

DISCUSSION

The purpose of this study was to examine the effects of a short period (4 weeks) of HIIT in either cycling or running on incremental running and cycle time trial performance in well-trained triathletes. The results of the study demonstrated that 4 weeks of HIIT cycling (7×5 min at 85% HR_{max}) induced a slight to moderate improvement in velocity and HR at 2 and 4 mM, and in HR_{peak} during an incremental treadmill test, however, these changes were not significantly different. These results are in line with previous studies, showing that cycling can result in a cross training effect on running and can be used as an alternative to increasing performance in running.[6,7,17]

Both groups enhanced velocity at the 2 mM LT or LT_1 (6.72% for bike group and 2.08% for run group) and decreased HR at LT_1 (Table 2) associated with a cardiovascular adaptation to endurance training.[25] These results were in agreement with several authors who observed that HR after endurance training was also significantly lower during submaximal exercise.[7,12,17] Therefore, it is highly likely that the use of 8×5 min at 85% HR_{max} HIIT training might improve running performance at submaximal intensities.

The cycle group participants showed a greater physiological efficiency during post-test to generate more energy, improving HR, and they were more psychologically efficient, enhancing the velocity at high intensities such as LT_2. Nevertheless, we observed that in the run HIIT group, velocity and HR at 4 mM were lower on the post-test compared with pre-test. These findings contrasted with other research results which showed an improvement for velocity at lactate threshold from 14.6±1.0 km/h on the pre-test to 15.2±0.8 km/h on the post-test after 10-weeks of high intensity-low volume training program on well-trained male middle-distance runners.[26]

In the case of the HR for the run group, the average HR during the cycle time trial was considerably lower (8.4%) potentially due to residual fatigue from the intensified training. In accordance with this suggestion we hypothesise that the HIIT approach induced significant residual and accumulated fatigue which lead to the inferior post training responses. Some authors investigated the manifestation and mechanism of fatigue and overreach after an intensified training weeks using neural, metabolic, immune function, mechanical and cognitive parameters.[27-29] Le Meur et al[27] observed a 4.4±1.1% decrease in velocity average on performance of highly trained triathletes due to overreach after an intensified training protocol. Additionally, they demonstrated a decrease in HR at submaximal and maximal intensities. In this study, the run group subjects presented a considerable HR decrease in cycle TT test. Furthermore, Hanson et al[28] reported a 5.4% decrement in overreached cyclists and Lehmann et al[29] showed an 8% decrease during an incremental exercise test in middle and long distance runners. Therefore, in some athletes, elevated training intensity in running may be counter-productive.[30] However, this requires further investigation. Also the velocity average during the cycle TT were lower (5.1%), HR_{peak}, during maximal test in the treadmill, also decreased for the run group while Bike group maintained it. Whereas, the decrease of peak running velocity during the incremental test in the running group (-1.7%) was impressive, there was a significant difference between groups in the post-test for this variable (Figure 1, graph D). It is proposed that the subjects who completed the HIIT running sustained a residual and accumulated fatigue resulting from glycogen depletion or other neurological related fatigue. Some authors explained similar occurrences (HR_{max} and performance decreases) when they investigated fatigue, overreaching and overtraining.[31,32]

The subjects who completed the HIIT cycling enhanced 16.6% for velocity, 3.5% for cadence but showed a reduction -1.2% for HR average. The change in velocity with Bike HIIT was similar to Lindsay et al[8] research that showed during a 40 km time trial the velocity average augmented 3.5% after 2 HIIT weeks. However, in the same study, absolute HR values during time trial were higher on post-HIIT test than pre-test (from 89.5±3.2% HR_{peak} on pre-test to 91.6±3.1% on post-test).[8] In our study, average HR in the Bike group showed a decrease of 6.4% at post-test. In the Lindsay et al[8] study, subjects were competitive cyclists but our study participants were triathletes with different sports backgrounds and level of performance. This may explain

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some of the conflicting adaptations. Nevertheless, our results were in agreement with several authors mentioned above, who observed that HR after running training was also significantly lower during submaximal exercise.[7,12,17] Future studies should look to examine further the relative benefits of HIIT cycle training on performance in triathletes when running training loads are manipulated.

The run HIIT group presented a decrease of 1.8% for average velocity and 5.1% for average HR. Average cadence was higher post-test (8.8%). These outcomes were dissimilar to Millet et al[1] who concluded that running was the discipline which provides the largest transfer to the other triathlon disciplines. It was highly likely that there was no transfer between running training to cycling performance due to the fatigued state and lack of experience of the run triathlete group.

CONCLUSIONS

Implementing intensified training using individual HIIT sessions in running and cycling improves running performance at low intensities in moderate to well-trained triathletes. Whereas, training using a similar HIIT training method in cycling enhances running performance at high intensities (4 mM) in moderate to well-trained triathletes. Additionally, 4 weeks of cycling HIIT training improved cycling performance, whereas, a similar period of running HIIT training did not improve cycling performance due to a possible fatigue accumulation. However, an important factor influencing adaptation to HIIT is prior aerobic conditioning and training experience of the triathletes. It is possible that using HIIT may evoke inferior performance responses due to cumulative fatigue, for this reason, it is necessary to investigate further cross training transfer using the HIIT approach in athletes of different experience and training status.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Letter to the Editor

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Looking into Central Governor Theory

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Some philosophers of science make distinction between researchers who put emphasis on experiments (empiricists) and those who try to propose theories (rationalists).[1] Even though the great majority of the scientists look for evidence to support their theories, that is impossible because of the induction logic failure.[1] This failure happens because, through this kind of logic, it is impossible to talk about absolute truth, the only thing that can be talked about is statistical probability. What the scientists should do is demonstrate theory mistakes with empirical tests. Those theories, which could be refuted through evidence, are in agreement with the demarcation criterion between science and metaphysics.[1]

The scientific knowledge evolution occurs by correcting those theoretical mistakes, or by replacing that theory for another one with more complete and/or precise predictions.[1] Sometimes several researchers cannot correct those mistakes, thus they use the relativism to explain their failure. For them, science is built with a deal among scientists to accept one theory or "paradigm". Sometimes a crisis happens, because these paradigms do not work for all scientific community. Because of such crisis, those paradigms must be changed. That is Kuhn's scientific revolution.[2] In this case, those scientists are being pessimistic with the possibility to reach the objective truth. Unhappily, that strategy is used to support the Central Governor Theory (CGT).[3]

One very important issue to help us choose the best theory is about its informative content. It is important to remember that the whole probability of one theory is equal to the product of each enunciate probability.[1] In this case, if the scientist makes good previsions with an extensive theory, that must be quite similar to the truth. This is because such theory has a very low probability to happen at random. That means, this theory must have a high truth content, low false content or both.[1]

Instead of this, Noakes[4] proposed one theory with more information, testable hypothesis and better previsions, he interpreted the literature evidence to rebuttal Hill's theory.[5,6] He based his reasoning on oxygen uptake plateau ($VO_{2plateau}$) occurrence or absence.[4,7] First, he wrote against the ergometric protocol used by Taylor et al[8] to show the $VO_{2plateau}$. For him, that treadmill protocol didn't reproduce the suitable motor recruitment that happens while running on the field.[7] But this motor recruitment didn't test directly Hill's theory.[5,6] When Noakes[4] did his literature review, he didn't choose compatible protocols with the previous theory. These protocols needed to use large muscular groups, during steady state and independent effort loads, at sea level, to show in the inhaled air what happens in muscle metabolism. The graduated continuous effort test was created to save time. On the other hand, there was no direct evidence of CGT occurring[4,7] during fatigue with or without $VO_{2plateau}$, but the fatigue always happened few moments after this last phenomenon.[8] The 2nd evidence that he used was about the opiate-inhibitor (malaxones), which increased the sense of the effort and interrupted the exercise.[7] Even though it could happen, that was a different situation and didn't refuse directly the previous theory. The 3rd evidence was about muscle partial oxygen pressure (PO_2) during maximal effort. Noakes[4] affirmed that was continuously higher than mithocondrial critical PO_2, even during the maximal effort.[7] He forgot to discuss the great variation in those data caused by the place, depth and reliability of the muscular biopsy or near infra-red spectroscopy (NIRS). The next evidence that he proposed was about the brain oxygenation measured by NIRS.[7] But that exam addressed a little and superficial area in the brain and there was difficulty to link this

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brain blood perfusion during the fatigue with and without $VO_{2plateau}$. The lactate paradox was the 5th evidence.[7] This phenomenon could not refute the previous theory because lactate production could be stimulated even by epinephrine or by isquemia. The last evidence that he proposed was about the low integrated electromyogram activity during maximal effort at high altitude.[7] That exam didn't address central nervous system (CNS) and that evidence should be interpreted like a peripheral fatigue.

In conclusion, the CGT cannot propose more previsions and/or previsions with more precision than Hill's theory. The first theory doesn't give an hypothesis directly tested. Its author does not propose one statement incompatible with CGT and creates one experiment to check if it happens. Until now, there has not been new equipment or procedure to give evidence that truly refuses previous theory and CGT can resist. Finally, there are no advantages to change from Hill's theory to Central Governor Theory, because the last one has a lot of epistemological problems and that is supported by skeptical or pessimistic views about the truth and knowledge.

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Research

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The Effects of Hyperbaric Oxygen Therapy on Reduction of Edema and Pain in Athletes With Ankle Sprain in the Acute Phase: A Pilot Study

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ABSTRACT

Background: An ankle sprain is a major soft tissue injury that can occur during sports activities; an ankle sprain in the acute phase causes localized edema that increases tissue pressure, impairs micro-circulation, and causes hypoxia in the injured tissue. Hyperbaric oxygen therapy (HBO_2 therapy) reduces tissue hypoxia and tissue edema.
Objective: The purpose of this study was to investigate the short-term effects of HBO_2 therapy on edema and pain in athletes with an ankle sprain in the acute phase.
Materials and Methods: Forty-four athletes with acute ankle sprain who underwent HBO_2 therapy within seven days after injury between the years 2007 and 2015 were included in this study. The HBO_2 therapy protocol included pressure up to 2.5 atmosphere absolute (ATA) (253.3 kPa) for 60 minutes. The foot and ankle volume was measured using a water-filled volumetric gauge and a visual analog scale (VAS).
Results: Foot and ankle volume was 1569.1±219.0 cm^3 just before HBO_2 therapy and 1557.8±218.1 cm^3 just after HBO_2 therapy ($p<0.001$).The VAS scores were 19.5±20.1 and 17.2±19.9 points for pain at rest ($p<0.05$), 41.5±27.3 and 30.9±24.4 for pain while walking ($p<0.001$), and 44.2±23.7 and 37.1±22.5 for subjective evaluation of edema ($p<0.001$) before and after an HBO_2 therapy session, respectively.
Conclusion: Our results suggested that HBO2 therapy may provide a short-term reduction of edema and pain in athletes with an ankle sprain in this pilot study.

KEYWORDS: Hyperbaric oxygen therapy; Foot and ankle volume; Visual analog scale; Edema reduction; Pain reduction.

INTRODUCTION

Injured athletes have a strong desire for rapid recovery from their injuries and therefore, multidisciplinary treatments are necessary to improve the healing process and to achieve an earlier return to training and competition. The goal is to establish safe procedures with low risk.

Soft tissue injuries in the acute phase are presented with localized edema and swelling, which is produced by plasma leakage from damaged blood vessels. Edema increases tissue pressure, decreases local perfusion, impairs micro-circulation, and causes hypoxia in the injured tissue.[1] Ankle sprains are frequent soft tissue injuries that occur during sports activities.

The effects of HBO_2 therapy on soft tissue injuries during sports activities, including sprains,[2] ligament injuries,[3-5] contusions, and muscle strains,[6-10] have been widely reported.

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HBO_2 has been reported to be an effective therapy for edema reduction, which should improve local perfusion and improving oxygenation of the injured tissues.[1,11] However, only Borromeo et al[2] have reported clinical research data providing quantitative analysis of HBO_2 therapy on ankle sprains. Their randomized control trial reported that joint function scores were more favorable in the HBO_2 group, though no significant differences were observed in ankle volume or the subjective evaluation of pain. However, detailed descriptions of the effects of HBO_2 therapy was missing, especially on the short-term effects of HBO_2 therapy in the acute phase.

The objectives of this study were to investigate the short-term effects of HBO_2 therapy on edema and to provide subjective evaluations of athletes with ankle sprains in the acute phase.

MATERIALS AND METHODS

Subjects

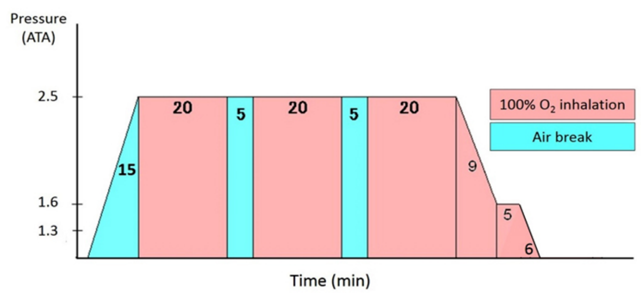
We performed a before-after analysis of patients who visited our clinic between the years of 2007 to 2015 with an acute ankle sprain sustained during sports activities within 7 days after the injury. The protocol for this study was approved by the Institutional Review Board of Tokyo Medical and Dental University, and informed consent was obtained from all subjects prior to participation. Forty-four patients (39 male, 5 female) were included in this study. Five of the subjects had a history of ankle sprain on the same side. The mean age of the patients was 23.2±3.8 years (range; 13-36 years).

The types of sports activities at the time of injury were as follows: Rugby (n=23), soccer (n=6), American football (n=4), baseball (n=3), and others (n=8). A diagnosis was made by the history of ankle sprains in sports activities and an assessment performed by a trained examiner (KY). The type of injury was classified as an inward twist (n=37), an outward twist (n=3), plantar flexion stress (n=3), or dorsal flexion stress (n=1) and by whether it affected the right (n=23) or left ankle (n=21). The severity of injury was classified into one of three grades; I: Stretched ligaments (not torn), with a stable joint and a negative anterior drawer test, II: A partially torn ligament with a lax joint and a partially positive anterior drawer test, III: Complete ligament rupture with an unstable joint and a positive anterior drawer test.[13] In this study, the distribution of the severity of the injury was as follows: Grade 1 (n=6), grade 2 (n=35), and grade 3 (n=3). The mean number of days from injury to the first admission of HBO_2 treatment was 2.1±1.2 days (0-5 days).

HBO_2 Therapy Protocol and Treatment

The HBO_2 chamber in our university hospital was used; the maximum capacity of our multi-place HBO_2 chamber is 16 persons (NHC-412-A, Nakamura Tekko-Sho Corp., Tokyo, Japan). The HBO_2 therapy protocol included pressure up to 2.5 ATA (253.3 kPa) with treatment time of 60 minutes for inhalation of pure oxygen according to the HBO_2 therapy protocol for compartment syndrome (Figure 1).[14] The HBO_2 therapy was performed within 7 days after injury, for a maximum of 5 times within a 7-day period in all cases. In total, 110 sessions of HBO_2 therapy were performed in the 44 patients (1 session (n=12), 2 sessions (n=11), 3 sessions (n=10), 4 sessions (n=9), and 5 sessions (n=2)). Other conventional treatments such as RICE (rest, ice, compression, and elevation) in the acute phase were performed concomitantly during HBO_2 therapy. RICE procedures were performed during the first week of the acute phase, range of motion exercises were applied beginning one week after injury, strength and flexibility rehabilitation was applied beginning one or two weeks after injury depending on pain and edema. The patients gradually returned to activities without any recurrence of injury.

Figure 1: HBO_2 Treatment Table.



Evaluation Procedures

Foot and ankle volume measurements were used to quantitatively evaluate ankle swelling; subjective evaluations using a VAS were also performed. In order to evaluate the short-term effects of HBO_2 therapy, all evaluations were performed immediately before and after the 105-minute HBO_2 therapy session.

To measure foot and ankle volume, the overflow water volume was measured using a water-filled volumetric edema gauge of our own making (Figure 2). This device measured 7.5 cm wide×12.5 cm long×33 cm high, and the bottom of the outflow cylinder was placed at the height of 16.5 cm from the floor so that foot and ankle volume up to 16.5 cm from the plantar face was measured. This device improves measurement accuracy compared to existing devices by reducing the water surface area. The patients were instructed to stand-bearing the same weight on both legs. The weight of the overflow water was measured and converted to volume as 1 g/cm^3 specific gravity.

To evaluate the repeatability of the foot and ankle volume measurement, 5 volunteers (4 males, 1 female, mean age of 36.0±7.6 years; range 29-48 years old) were used. The volume measurements of the bilateral feet and ankles, a total of 10 feet and ankles, were performed 5 times each, and the Intraclass Correlation Coefficients ($ICC_{1,5}$) was evaluated. The $ICC_{1,5}$ was 0.997 (95% CI, 0.993-0.999).

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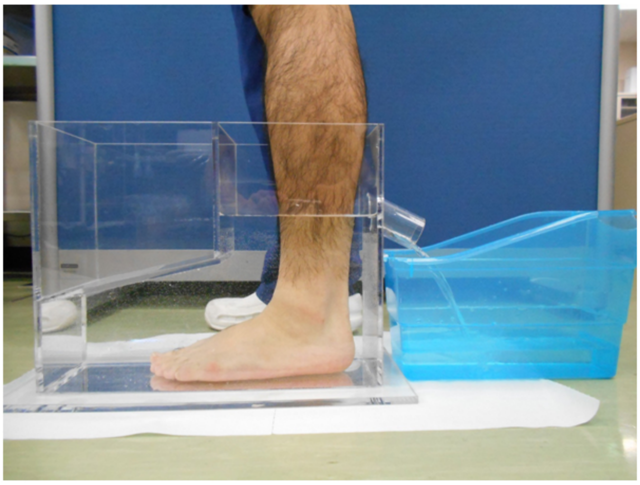
Figure 2: Measurement of Foot and Ankle. Measurement of Foot and Ankle by Water-Filled Volumetric Edema Gauge.



Eighty-five measurements of the VAS out of 110 sessions of HBO_2 therapy were fully recorded and were used for analysis in this study. The VAS evaluation included questions about pain at rest, pain while walking and a subjective evaluation of edema. The VAS consisted of a maximum of 100 points at full mark, where 100 points indicates the worst condition and 0 points indicates no complaint.

To assess the HBO_2 therapy efficacy in detail, the foot and ankle volume and VAS measurements were evaluated taking into consideration the number of HBO_2 therapy sessions and the amount of time between from the time of injury to when therapy was started.

Statistical Analysis

The data are presented as the mean±standard error of the mean (SEM). Differences were analyzed using the Paired *t*-test, and significance was accepted if the *p*-value was less than 0.05. Kruskal-Wallis one-way analysis of variance (ANOVA) tests were utilized to detect differences of foot and ankle volume in the grade of injury, the number of HBO_2 sessions and duration from injury, and differences of the VAS score in the number of HBO_2 sessions and duration from injury. Where appropriate, post hoc Bonferroni multiple comparison procedures were used. All data were analyzed using SPSS version 19.0 (SPSS Inc., 233 Wacker Dr, 11th Fl, Chicago, IL 60606, USA).

RESULTS

Foot and Ankle Volume

The foot and ankle volume in all sessions (n=110) were 1569.1±219.0 cm^3 just before and 1557.8±218.1 cm^3 just after HBO_2 therapy, with a reduction of 11.3±20.8 cm^3 ($p<0.001$) during the 105-minute HBO_2 therapy. The foot and ankle volumes before the first session of HBO_2 therapy and after the final session of HBO_2 therapy (n=44) were 1598.1±216.8 cm^3 and 1566.4±217.0 cm^3, respectively, with a reduction of 31.7 cm^3 ($p<0.05$). The foot and ankle volume before and after a HBO_2 therapy session depending on the severity of the injury are presented in Table 1, and there were no statistically significant differences of reduction of the foot and ankle volume in the severity of the injury.

The foot and ankle volume and reduction of volume before and after a HBO_2 therapy session depending on the number of HBO_2 therapy sessions are presented in Table 2. The foot and ankle volume and reduction of volume before and after a HBO_2 therapy session depending on the day after injury arepresented in Table 3.

Table 1: Foot and Ankle Volume Depending on Severity of the Injury.

The grade of injury (n)	The number of HBO_2 sessions	Pre-HBO_2	Post-HBO_2 (cm^3)	reduction (cm^3) §
Grade 1 (9)	1.5±0.8	1554.9±142.3	1552.2±137.9	2.6±13.3
Grade 2 (91)	2.6±1.2	1564.2±224.9	1552.6±223.5*	11.5±21.7
Grade 3 (10)	3.3±1.2	1626.3±230.2	1609.8±236.9*	16.5±16.7

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with Paired *t*-test ($p<0.05$).
§: No statistically significant differences in the severity of injury performed with Kruskal-Wallis one-way ANOVA.

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Table 2: Foot and Ankle Volume Depending on HBO_2 Therapy Sessions.

The number of HBO_2 sessions (n)	Pre-HBO_2	Post-HBO_2 (cm³)	Reduction (cm³) §
1 (44)	1598.1±216.8	1584.0±214.8*	14.1±23.1
2 (32)	1572.3±216.0	1562.6±214.4*	9.8±19.5
3 (21)	1553.1±196.4	1542.3±202.8*	10.8±22.3
4 (11)	1516.0 ±248.9	1510.3±249.3*	5.7±9.6

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test (p<0.05).
§: No statistically significant differences in the number of HBO_2 sessions performed with Kruskal-Wallis one-way ANOVA.

Table 3: Foot and Ankle Volume Depending on Duration from Injury.

Duration from injury day (n)	Pre-HBO_2	Post-HBO_2 (cm³)	Reduction (cm³) §
1 (11)	1541.5±205.0	1521.6±206.1*	19.9±30.2
2 (23)	1638.5±213.5	1628.4±214.9*	10.2±22.1
3 (23)	1598.6±219.2	1591.2±213.7*	7.4±16.1
4 (20)	1508.2±230.2	1494.8±227.9*	13.4±21.9
5 (16)	1524.7±221.6	1518.1±225.3	6.6±15.8
6 (11)	1552.3±235.4	1540.7±229.0	11.6±24.9

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test (p<0.05).
§: No statistically significant differences in the duration from injury performed with Kruskal-Wallis one-way ANOVA.

Visual Analog Scale (VAS)

VAS scores were 19.5±20.1 points and 17.2±19.9 for pain at rest (p<0.05), 41.5±27.3 and 30.9±24.4 for pain while walking (p<0.05), and 44.2±23.7 and 37.1±22.5 for subjective evaluation of edema (p<0.05) before and after HBO_2 therapy (Table 4).

When considering the severity of the injury, there were no statistically significant differences of improvement between groups (Table 5). When considering the number of therapy sessions, the VAS scores for pain while walking were 60.6±25.3 points and 43.2±24.6 (p<0.05) for the first HBO_2 therapy session (n=26) and 33.4±25.4 points and 25.8±24.6 (p<0.05) for the third HBO_2 therapy session (n=22) before and after an HBO_2 therapy session, respectively (Table 6). There were statistically significant differences of 1 against 2, 3 and 4 of the number of HBO_2 sessions regarding to the VAS scores for pain while walking (p<0.05).

With respect to the time after injury when treatment began, the VAS scores for pain while walking were 55.5±27.5 points and 36.6±23.5 (n=17) when started 2 days post injury

Table 4: VAS Scores.
(Point)

Pain at rest		Pain while walking		Subjective evaluation of edema	
Pre-HBO_2	Post-HBO_2 (cm³)	Pre-HBO_2	Post-HBO_2 (cm³)	Pre-HBO_2	Post-HBO_2 (cm³)
19.3±20.1	17.2±19.9*	41.5±27.3	30.9±24.4*	44.2±23.7	37.1±22.5*

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test (p<0.05).

Table 5: VAS Scores Depending on the Severity of the Injury.
(Point)

The grade of injury	Pain at rest			Pain while walking			Subjective evaluation of edema		
(n)	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §
Grade 1 (5)	23.2±25.1	18.8±22.1*	4.4±6.4	45.6±28.4	29.4±25.3*	16.2±12.2	36.2±27.6	26.6±23.6	9.6±12.9
Grade 2 (74)	19.6±19.9	17.4±20.3*	2.2±10.1	41.2±27.4	31.9±25.4*	9.4±10.1	44.3±22.9	38.1±22.7*	6.1±15.0
Grade 3 (8)	16.0±17.4	14.5±13.2	1.5±11.8	45.8±26.7	26.4±10.9*	19.4±24.1	53.4±28.2	35.6±17.0*	17.8±12.3

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test (p<0.05).
§: No statistically significant differences in the severity of the injury performed with Kruskal-Wallis one-way ANOVA

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Table 6: VAS Scores Depending on HBO_2 Therapy Sessions.

(Point)

The number of HBO_2 sessions	Pain at rest			Pain while walking			Subjective evaluation of edema		
(n)	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §
1 (26)	28.1±25.1	24.2±21.7*	3.9±8.0	60.6±25.3	43.2±24.6*	17.5±12.5‡	59.8±25.4	52.3±23.3	7.5±20.6
2 (24)	19.7±18.5	13.5±16.8*	6.2±7.1†	34.5±22.2	26.9±20.9*	7.6±12.2	44.1±20.3	34.6±19.7*	9.5±13.6
3 (22)	15.7±16.8	18.4±23.3	-2.7±13.6†	33.4±25.4	25.8±24.6*	7.6±10.4	36.0±20.5	30.2±20.8*	5.8±12.3
4 (11)	8.9±7.2	8.3±8.7	0.6±9.1	24.4±21.2	19.8±22.4	4.6±9.6	27.2±11.3	22.0±10.1*	5.2±7.0

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test ($p<0.05$).
†: Statistical differences between 2 and 3 of the number of HBO_2 sessions performed with post hoc Bonferroni multiple comparison procedure ($p<0.05$).
‡: Statistical differences of 1 against 2, 3 and 4 of the number of HBO_2 sessions performed with post hoc Bonferroni multiple comparison procedure ($p<0.05$).
§: No statistically significant differences in the number of HBO_2 sessions performed with Kruskal-Wallis one-way ANOVA.

Table 7: VAS Scores Depending on Duration from Injury.

(Point)

Duration from injury	Pain at rest			Pain while walking			Subjective evaluation of edema		
Day (n)	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §	Pre-HBO_2	Post-HBO_2	Improvement §
1 (5)	21.0±18.7	16.0±14.6	5.0±7.9	59.0±23.2	48.0±19.5*	11.0±6.5	56.0±12.6	47.6±15.1	8.4±13.2
2 (17)	25.1±20.8	21.0±17.6*	4.1±7.2	55.5±27.5	36.6±23.5*	18.9±15.9†	59.5±22.2	45.9±20.9*	13.5±16.5
3 (21)	20.6±19.6	15.2±17.7*	5.3±7.9	43.6±24.1	33.5±23.4*	10.1±10.8	48.6±25.4	41.8±24.9*	6.8±8.6
4 (17)	15.5±17.1	14.0±17.2	1.5±7.6	30.1±20.7	20.9±19.1*	9.2±12.8	40.4±20.1	31.2±20.1	9.1±18.1
5 (16)	11.8±14.1	14.6±19.0	-2.8±15.3	28.8±24.9	24.0±23.4*	4.8±8.7†	27.8±17.7	24.9±19.0	2.9±8.5
6 (5)	28.8±30.1	30.8±40.0	-2.0±14.6	40.2±35.2	36.6±39.9	3.6±7.4	44.0±27.4	39.4±24.0	4.6±7.2

*: Statistical differences between pre-HBO_2 and post-HBO_2 performed with paired *t*-test ($p<0.05$).
†: Statistical difference between 2 days and 5 days of the duration from injury performed with post hoc Bonferroni multiple comparison procedure ($p<0.05$).
§: No statistically significant differences in the number of HBO_2 sessions performed with Kruskal-Wallis one-way ANOVA.

($p<0.05$) and 28.8±24.9 points and 24.0±23.4 (n=16) 5 days post injury ($p<0.05$) just before and after HBO_2 therapy, respectively (Table 7). There was a statistically significant difference between 2 days and 5 days of the duration from injury regarding to the VAS scores for pain while walking ($p<0.05$).

DISCUSSION

In the present study, we administrated HBO_2 therapy to athletes with acute ankle sprains and quantitatively evaluated the short-term effects of HBO_2 therapy in the acute phase, though the RICE treatment is also effective in the acute phase, and HBO_2 therapy and the RICE treatment are confounding factors correlating to the outcomes.

The results of this pilot study revealed significant edema reduction of 11.3 cm^3 and significant improvement in the VAS scores for pain at rest, pain while walking and subjective evaluation of edema after HBO_2 therapy.

We also evaluated the effectiveness of HBO_2 therapy as it relates to the severity of the injury, the number of HBO_2 therapy sessions and the duration of time from injury to the start of treatment. HBO_2 therapy was most effective at the first application with an average reduction of 14 cm^3 in foot and ankle volume, and with an improvement of 17.5±12.5 points in the VAS scores for pain while walking, which was statistically significant differences against the second, third and fourth application. Edema reduction of more than 10 cm^3 was observed within 3 sessions, and the significant reductions in the VAS scores were observed within 4 sessions. Edema reduction of more than 10 cm^3 was observed within 4 days from injury and significant reductions in the VAS scores were observed when treatment started within 5 days from injury. Too long HBO_2 therapy per session should be avoided due to the possibility of the manifestation of oxygen toxicity, even though the possibility is very low.[15]

Basic and clinical studies of HBO_2 therapy for soft tissue injuries, mainly for sprains,[2] ligament injuries[3-5] and muscle injuries[6-10] that occurred during sports activities, have been reported. Regarding to the effects of HBO_2 therapy on edema in the acute phase, Skyhar et al[1] examined the effects of HBO_2 therapy using a dog hemorrhagic model for acute compartment syndrome and reported that it significantly reduced edema and occurrence of muscle necrotic tissue. They speculated that those findings might be the result of hyper-oxygenation and vasoconstriction. Hyper-oxygenation increases the amount of oxygen in the peripheral tissue without hemoglobin involvement, and vasoconstriction reduces blood flow by 20 % while outflow is maintained.[12] This resulted in an increase of resorption of the extra-vascular solution, and the net effect was edema reduction. Strauss et al[11] induced compartment syndrome in the hind limbs of 12 dogs and revealed a reduction of muscle necrosis and edema in the experimental compartment. According to these

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past reports, it is expected that HBO_2 therapy will accelerate the reduction of edema by oxygenation of the localized hypoxic environment and that HBO_2 therapy can result in an earlier withdrawal from the vicious circle of localized hypoxia and edema in the acute phase.

In patients with ankle sprains, ankle edema increases the sensation of pain and restricts the ankle range of motion leading to delayed rehabilitation.[16] Multidisciplinary treatments including RICE are required for rapid reduction of ankle edema, especially for high-performance athletes who need accelerated healing in order to return to competition as soon as possible.

In a previous clinical study of HBO_2 therapy for acute ankle sprains, Borromeo et al[2] reported a randomized control trial for patients with acute ankle sprain, and HBO_2 treated group receiving oxygen at 2.0 ATA (202.7 kPa) compared to a control group who received air at 1.1 ATA (111.5 kPa). They reported that joint function scores were more favorable in the HBO_2 group, although no significant differences were observed for ankle volume, subjective evaluation of pain, or range of ankle movement. As we applied an HBO_2 therapy protocol of 2.5 ATA (253.3 kPa), a slightly higher pressure than that used by Borromeo[2] we expected to see significant effects of HBO_2 therapy.

We recognize that a fundamental limitation of this study is the lack of a control group and therefore we could not definitively conclude the superiority of HBO_2 treatment over the conventional treatment including RICE therapy without HBO_2. Thus, we reported this study as a pilot study. The second limitation of this study was the absence of evaluation of the long-term effects of HBO_2 therapy on ankle sprains. Time to return to competition was not measured and was not compared to a control group or past reports. Additionally, the VAS evaluation is highly subjective and the placebo effects cannot be discounted; this limitation is also related to the lack of a control group. Lastly, a potential limitation of this study is an incomplete collection of VAS measurements from all subjects.

Future studies should determine whether HBO_2 therapy can accelerate healing processes and reduce the period for return to competition.

CONCLUSION

This pilot and observational study in athletes with ankle sprains in the acute phase found that a reduction of foot and ankle volume was measured with 11.3±20.8 cm^3 during the 105-minute HBO_2 therapy, and the VAS sores were measured with 19.5±20.1 points and 17.2±19.9 for pain at rest ($p<0.05$), 41.5±27.3 and 30.9±24.4 for pain while walking ($p<0.05$), and 44.2± 23.7 and 37.1±22.5 for subjective evaluation of edema ($p<0.05$) before and after HBO_2 therapy.

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CONFLICTS OF INTEREST

The authors have declared that no conflict of interest exists with this submission.

ETHICAL CONSIDERATIONS

This study was approved by the Institutional Review Board of Tokyo Medical and Dental University in 2005, and all patients signed an informed consent form before participation. This study was undertaken in full accordance with the ethical standards in the Helsinki Declaration.

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SPORTS AND EXERCISE MEDICINE

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Short Communication

Exercise as Medicine: Possible Applications for Improving Home Based Programs

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Epidemiological, clinical and laboratory studies have provided a large body of evidence on the benefit of physical exercise in reducing the morbidity and mortality of chronic diseases such as cardiovascular, type 2 diabetes (T2D), hypertension, cancer, obesity, depression, solid organ transplantation and others. There are guidelines available regarding the type, frequency, duration and intensity of the exercise to alleviate the related underlying disease. Therefore physical exercises is an important cost effective tool for primary and secondary prevention measures.[1]

Despite these facts, people do not engage in regular physical activities. In United States, only 1 in 5 adult American (21%) meet the 2008 Physical Activity Guidelines and less than 3 in 10 high school students get at least 60 minutes of moderate to high intensity physical activity every day.[2] Supervised exercise performance has shown remarkable effectiveness, but is associated with poor compliance the long-term,[3] therefore it becomes necessary to include physical activity as an integral part of everyday lifestyle. To change the routine of the life in terms of implementing the physical activity, it is necessary to create a model that allows long-term therapeutic efficacy. The subject must be made aware of the program goal and in addition must test the individual skills to perform the self-monitored physical exercises.[4]

The common difficulties that people encounter when undertaking physical exercises programmes are include[5]: lack of time and architectural barriers in the cities. Since daily tasks are time consuming and many people are unable to utilize health clubs or similar venues for various reasons.

It becomes necessary to find an action plan that places physical activity within a routine of daily life, modulating the personal lifestyle of the people living in the cities.

Issues that need to be addressed to promote physical activity on a large scale are:

1. Technology: in particular, the recent development of fitness apps, can be used in order to have a remote management of activity participation and volume with regards to energy expenditure.[6]
2. Make a scientific snapshot of the current and the future state of the health and fitness possibilities at the urban level for all the cities.[7]

Internet is an important tool with an easy accessibility and the app stores are huge, especially for those who are involved in the physical activity and want to track their progress. Recently, smart, wearable, mobile and portable technologies have enabled the usage of the large number of health applications on the go. It has been noticed that web-based apps help to improve and self-monitor one's physical activity as long as the information was delivered quickly and it was user friendly.[8] The use of Smartphones gives such an opportunity of real-time feedback on user's progress.[9] While active engagement in self-monitoring and self-regulation

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are essential for the maintenance of health-related behavior in an autonomous environment, it is also imperative to provide individuals with personalized feedback on their progress.[10] Personalized interventions have been demonstrated to be more effective than non-personalized interventions for changing health behavior.[11] Generally people receive a personalized physical exercise program to start as not-supervised, following critical issues may arise that could endanger the continuation of the program but do not require specialist visits, in this context through mobile health apps is possible to give a personalized intervention would allow a health professional to provide tailored feedback to an individual user in a time-efficient manner.[11]

There are many mobile apps that operate without user interface and users cannot receive personalized information on their activities and about the status of its program. In addition, these apps do not provide any information about the other facilities where people can engage in the regular exercise routine.

Other apps are more advanced but have not been designed for fitness specific purposes. However, it is possible that there is already a pre-disposition for a possible remote assistance in future.

In 2008, the American College of Sports Medicine launched the American Fitness Index® program.[12] The American Fitness Index® program revolves around an annual data report that measures the 50 most populous metropolitan areas in the United States and provides a score and ranking reflecting a composite of preventive health behaviors, levels of chronic disease conditions, health care access and community resources and policies that support physical activity. Included in the report are benchmarks for each data indicator to highlight areas that need improvement. With the help of this report, municipalities, community groups, health organizations and individual citizens can assess factors contributing to their metro area's level of fitness, health and quality of life.[7] The report is also an evaluation tool for measuring progress at the community level. As a program, American Fitness Index® also provides resources to help communities focus their efforts and in assisting the communities in connecting with health promoting partners.[12]

Therefore, checking benchmarks to highlight areas that needs improvement is an important tool in order to promote physical activity of citizens and tourists of the cities.

There are applications available which guide throughout and includes the list of routes that are walkable paths with the description of historical and architecture information of the landscape.

These initiatives may encourage the onset of physical activity, but having the option of a remote professional assistance appears to be a good strategy to ensure a proper compliance to a long-term active lifestyle.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Brief Research

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Agreement Between Methods to Determine Procedure for Maximal Exhalation During Hydrostatic Weighing: A Methodological Investigation

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ABSTRACT

Introduction: Current evidence suggests that there are many contentious issues that can significantly impact upon hydrostatic weighing assessments, for instance, obtaining reliable and precise data values within the testing environment. Whilst some researchers have addressed some of these issues, but there is still much uncertainty and significant challenges in terms of the procedure for maximal exhalation during hydrostatic weighing. Therefore, due to some of these challenges, it was necessary to conduct a methodological investigation to reduce measurement error.
Methods: Twenty-two students (n=22) were recruited from the University of Gloucestershire (BSc Hons) undergraduate programmes. All participants were over 18 years of age and all were free from disease, illness or injury ($\bar{x}\pm s$; age=20.5±1.7 years, body mass=68.7±1.5 kg and stretched stature=172.0±8.3 cm).
Results: When comparing body mass in water values between the two exhalation techniques, (pre-submersion and post-submersion exhalation) results indicated systematic bias (lower value for post-submersion technique). There was a significant difference in body mass values between pre-submersion technique (Mean±SD=2.6±1.2 kg) and post-submersion technique (2.2±1.1 kg), $t_{21}=4.19$, $p<0.01$.
Conclusion: When using hydrostatic weighing, the post-submersion exhalation technique was associated with greater measurement benefits thus resulting in a more reliable method.

KEY WORDS: Hydrostatic weighing; Maximal exhalation technique; Methods; Measurement error.

INTRODUCTION

Hydrostatic weighing can be demanding on the participant even after an initial period of familiarisation.[1-3] For instance, the weighing procedure requires the participant's cooperation whilst totally submerged in water.[4] Being submerged can be a daunting experience for participants, particularly as they are required to exhale maximally whilst keeping as still as possible in a crouched seated position.[4,5] These procedural difficulties were reported by Jüurimäe et al[4] Demura et al[2] and Slater et al[3] who suggested that some participants were unable to maximally exhale due to uncertainty, and in some cases apprehension, induced by the required technique. In other words, this apprehension can result in the deliberate retention of surplus air in the lungs, thereby influencing measurement results, making collected data unreliable.[6-8]

The ability of the primary investigator to achieve complete compliance should improve the criterion validity of the hydrostatic weighing procedure.[3,4] Hence, the requirement for complete compliance has resulted in researchers using various body positions and breathing

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manoeuvres that improve comfort and reduce apprehension for participants. Therefore, the aim of this methodological investigation was to determine the agreement between two commonly used maximal exhalation techniques for the hydrostatic weighing procedure.

METHODS

Twenty-two volunteers (n=10 male and n=12 female) were recruited from the University of Gloucestershire, School of Sports and Exercise, (BSc Hons) undergraduate programmes. All participants were over 18 years of age and all were free from disease, illness or injury ($\bar{x}\pm s$; age=20.5±1.7 years, body mass=68.7±1.5 kg and stretched stature=172.0±8.3 cm) (see Table 1). Ethical approval for the methodological procedures was granted from the University of Gloucestershire's Research Ethics Committee. All participants were given an informed consent form and understood their involvement and their right to withdraw. Consent was secured with a participant signature.

Participants undertook two separate underwater weighing technique trials in a cross-over order with 5 minutes break between each trial. One trial involved a '*pre-submersion exhalation*' technique and the other trial involved a '*post-submersion exhalation*' technique. Each trial comprised of ten attempts at the technique as illustrated in Figure 1.

For both trials participants sat in an upright position, applied a nose clip and held the ropes of the underwater tank seating system having weights. They were submerged to chin level *via* a hydraulic hoist that was operated by the primary investigator. Rest intervals between each measurement attempt were given at the discretion of the primary investigator and were dependent on whether the participant felt able to repeat the measurement attempt.

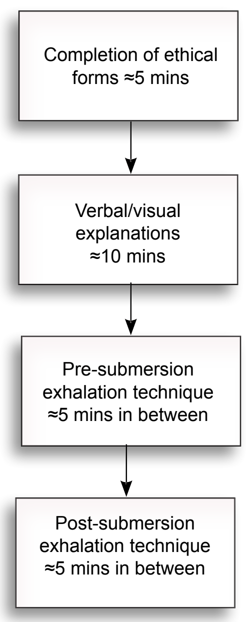
Pre-Submersion Exhalation Technique

The rate of breathing for each participant was called by the primary investigator and comprised of three cycles of normal inhalation and exhalation. On the third cycle the primary investigator asked the participant to take a maximal inhalation

Table 1: General Summary ($\bar{x}$±s) Characteristics for (n=22) Participants.

Variables	$\bar{x}$±s	Range
Age (yr)	20.5±1.7	18.0-25.0
Body mass (kg)	68.7±1.5	53.8-116.6
Stretched stature (cm)	172.0±8.3	156.8-188.4
Vital Capacity (mean) (l)	4.33±1.1	2.48-7.38
Exhalation Techniques		
Pre-submersion (mean) (kg)	0.95±1.4	0.75-5.33
Post-submersion (mean) (kg)	1.40±1.3	0.65-5.03

Figure 1: Standardised Testing Schedule.



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immediately followed by a maximal exhalation. The participant was then instructed to blow out maximally just below the surface of the water to avoid temptation of inhalation prior to submerging the head. When the participant felt that they could no longer force any more air out of their lungs, they were instructed to submerge their head fully and keep as still as possible underneath the water. Once submerged, the primary investigator took the measurement of the participant's body mass in water (kg) from the wall mounted digital weighing scale adjacent to the hydrostatic weighing tank. Following the measurement reading, the primary investigator rapped loudly on the side of the tank thereby instructing the participant to return to the surface.

Post-Submersion Exhalation Technique

Participants were asked to initiate their own breathing rate and when ready, take a small inhalation, lean forwards and submerge themselves fully. Once underwater and keeping as still as possible the participant exhaled maximally. The primary investigator watched for the ending of exhalation bubbles and took the measurement of the participant's body mass in water (kg) from the wall mounted digital weighing scale adjacent to the hydrostatic weighing tank. Following the measurement, the primary investigator rapped loudly on the side of the tank instructing the participants to return to the surface. The agreement between the average underwater weights (from ten attempts) for each participant across both measurement techniques was illustrated in the form of a scatter plot (Figure 2). The bias, residual error and heteroscedasticity between the two techniques are illustrated (Figure 3) to determine whether significant differences (under-reporting) were evident between the exhalation techniques.

RESULTS

Results from the pre-submersion exhalation technique revealed that four participants were unable to successfully carry out a single attempt and the remaining participants were only able to complete a mean average of four underwater weighing attempts. Participant's claimed that this technique was uncomfortable and stressful, thereby questioning the usefulness of this measurement. Conversely, the primary investigator found that all participants using the post-submersion exhalation technique were able to perform a mean average of nine underwater weighing attempts. All participants albeit subjectively, claimed that this measurement was far more comfortable. When comparing body mass in water values between the two exhalation techniques, results indicated systematic bias (lower value for post-submersion technique). There was a significant difference in body mass values between pre-submersion technique (Mean±SD=2.6±1.2 kg) and post-submersion technique (2.2-1.1 kg), t_{21}=4.19, p<0.01 (Figures 2 and 3).

Figure 2: Comparison of Pre-Submersion and Post-Submersion Exhalation Techniques for Underwater Weighing.

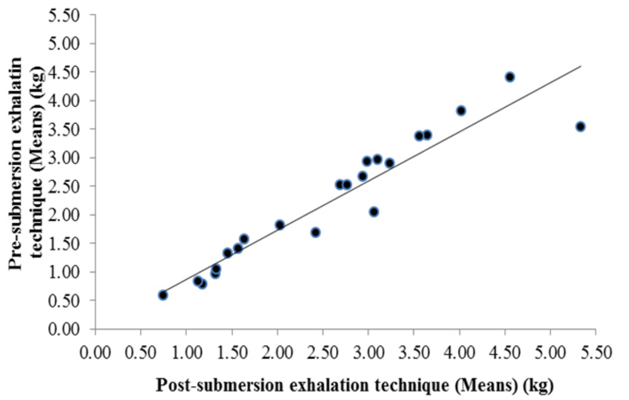
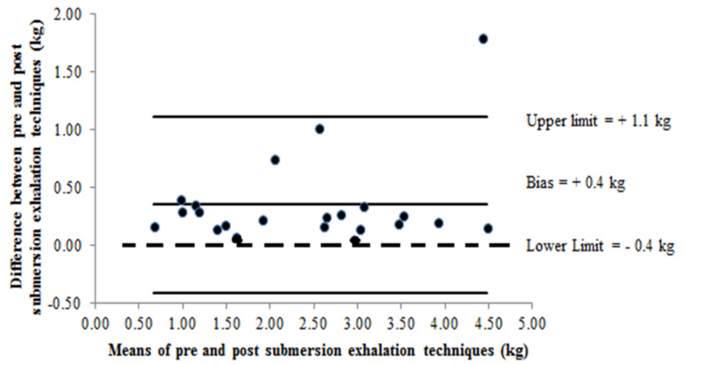


Figure 3: Bland and Altman Plot Showing Bias and 95% Limits of Agreement for the Pre-Submersion and Post-Submersion Exhalation Techniques for Underwater Weighing.



Note: positive bias indicates lower values for post-submersion technique

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CONCLUSION

Whilst the process of obtaining underwater weight *via* hydrostatic weighting can vary according to laboratory and researchers, it is crucial to reduce measurement error with the measurement technique.[7-9] Results from this methodological investigation suggest that the post-submersion exhalation technique was associated with less apprehension, greater comfort and reduced water disturbance than the pre-submersion method, thus resulting in more reliable values for underwater weight. Since higher values for underwater weight are a reflection of more a complete exhalation cycle, it can be concluded that the post-submersion exhalation technique was the preferred technique for all future hydrostatic weighing testing in the future.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Commentary

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The Importance of Measuring Body Composition in Professional Football Players: A Commentary

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ABSTRACT

Professional football players are not considered to be excessively fat, but there is continuous pressure made by managers, coaches and physiotherapists to monitor player's body composition to help reach optimal performance potential. Consequently, it is not uncommon for sport scientists to assume responsibility for monitoring and managing their players' body composition over the playing season. As body fat is one of the main factors affecting body composition, the knowledge and understanding of whole body density and how it influences the body could be useful to quantify the effectiveness of a prescribed training programme and/or optimal performance potential.

KEY WORDS: Body composition; Body fat; Football; Whole body density; Anthropometry; Optimal performance.

INTRODUCTION

Given the seasonal nature of football, it might be expected that players have to perform consistently at a high level up to 50 matches per season, thereby generating a demand to maintain levels of conditioning to sustain levels of performances. It seems reasonable then to assume that these varying playing roles impose specific physiological demands on a player.[1] These demands will be different dependent upon playing position, but a player will need to be at an optimum status in several aspects of fitness including energy from the aerobic system and the anaerobic system, muscular strength, flexibility and agility.[2]

In a game so variable in its physiological demands, football players must consequently attain a high level of conditioning to cope in the modern game which is played at an even faster pace and intensity than in previous decades. In order to achieve this higher level, Gil et al[3] claim that the relationship between the physiological demands of football and the composition of the player's body is of considerable importance. Although all too often, the judgement concerning optimal playing body fat is made on a trial and error basis with reference to body mass alone, disregarding the players overall body composition characteristics. There is evidence to suggest that optimal body mass could influence the ratio of power to body mass when moved against gravity, hence a low level of body fat is desirable for competitive success in football.[3] Vestberg et al[4] suggest that it is important to recognise that it is possible to lose fat but increase body mass due to increased muscle mass, especially in the pre-season period. A point already substantiated by Egan et al[5] and Wallace[6] where findings suggest that football players accumulated body fat in the off-season, and then reduced fat mass during pre-season. Possible reasons why these fluctuations occur can be a result of injury, habitual activity of players, energy stores, nutritional status and what stage of the competitive season the body composition assessments were executed.[4] Therefore, football players must strive to achieve an optimum sport performance potential with optimal levels of body fat taking into account their

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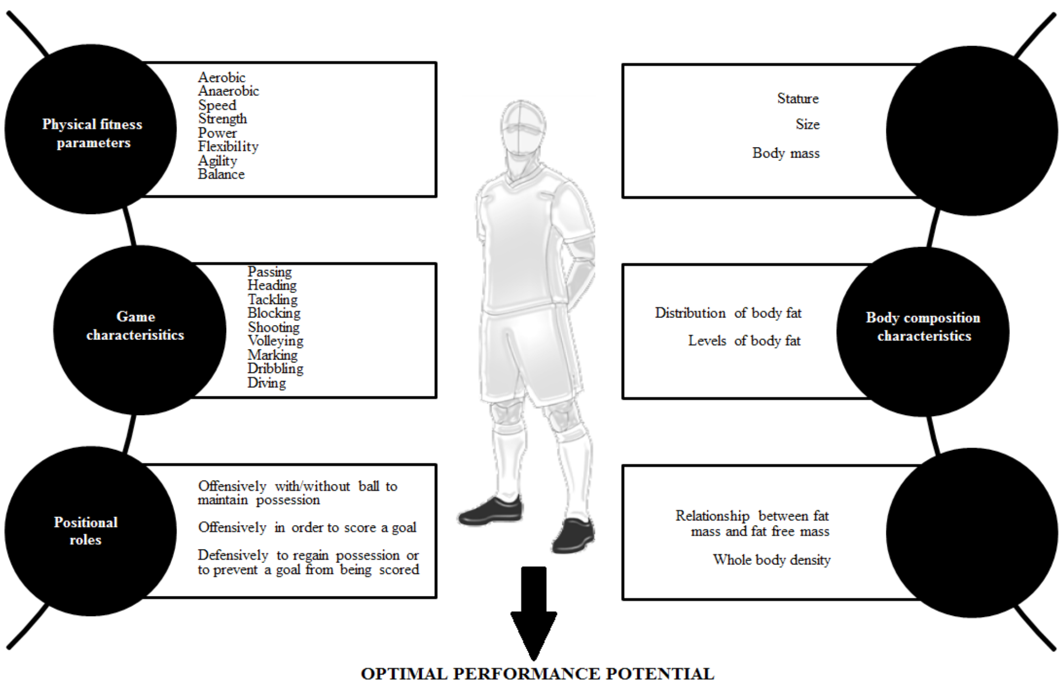
playing position.[1] By achieving optimal body fat the football player can minimise the negative effects of excess body fat on activity without sacrificing power, assuming of course, that the desired amount and intensity of training is executed.

Body Composition and Football Players

Fortunately, body composition analysis is becoming increasingly widespread in professional football as it helps to further understand the relationships between changes in body fat over time with different fitness parameters. Although not every body composition characteristic is expected to play a role in optimal performance in professional football, it has been recognised by researchers such as Rienzi et al[7] and Gil et al[3] that lower levels of body fat (that is specific to each individual player) is desirable for optimal performance as body mass must be moved against gravity. However, if there are higher levels of body fat (typically found in the visceral area around the waist) then additional metabolic energy is required to displace the excess.[6,7] In other words, body fat does not contribute to force production, so by achieving optimal levels of body fat and fat-free mass, the player can minimise the negative effects of excess body fat without sacrificing skill (Figure 1).

In recent years, sport scientists have made considerable progress in identifying footballers optimum anthropometric characteristics required to cope with football at the highest level.[8] A number of authorities such as Pyke,[9] Hencken and White,[10] Gil et al[11] and Santos et al[12] recommend establishing relationships between anthropometry and aspects of performance to assist management, coaches, national governing bodies, sports science teams and players to reach their full potential. However, it has been considered by Norton and Olds,[8] Reilly et al[13] and Hencken and White[10] that there are many anthropometric pre-dispositions for certain positional roles within football. Not every body composition characteristic is expected to play a role in successful performance, but notably stature and body mass have been considered the most important anthropometric pre-dispositions irrespective of playing position.[8] It is important to recognise that considerable individual differences in low and high levels of body fat occur between players and this might play a bigger role in optimal performance potential than generalisations about body fat itself. Although, today's professional football players are not considered excessively fat, there is continuous pressure by coaches, physiotherapists, managers and sport scientists to reduce players (ranging from professional to academy) body fat to minimum levels in the knowledge that low levels of body fat can enable them to perform more effectively.[14] However, up to a certain point, low levels of body fat are beneficial to performance, as the energy cost of physical activity will be lower and the ability to maintain core temperature during prolonged exercise will be enhanced. Consequently, those responsible for these players who view fat as detrimental to performance might not always recognise its importance for health.[14] When body fat is reduced to dangerously low-levels, there is a risk of encroachment into essential fat reserves that can cause metabolic dysfunction and at worst affect the health status of the football player.[14] Furthermore, it might offset performance benefits of

Figure 1: Relationships between Body Composition and Optimal Performance Potential in Professional Football Players.[1,7]



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training and compromise fat-free mass and energy.[15] As a result, players, coaches and sport scientists need to acknowledge that optimal performance levels may be adversely affected by excessively low levels of body fat, therefore, it is not necessary or desirable that they achieve the lowest levels.[15]

In contrast, high levels of body fat (that is specific to each individual player) have been reported many times by Reilly,[13,16-18] suggesting that high metabolic loading imposed by match play and training is not optimal for performance. Indeed the greater levels of body fat, the greater the detriment to performance, as the fat cells are not contributing toward energy production and the energy costs needed to move the fat is high.[1] A notion supported by Rienzi et al[19] who postulate that excess body fat can lead to an earlier onset of fatigue which not only adversely affects the ability to work, but is also associated with deterioration on skill, increased injury risk and a decreased adherence to training requirements and adaptations. Nevertheless, players cannot afford to reduce their muscle mass, as the power component might be compromised. Football players should therefore concentrate on reducing the quantity of body fat, but within safe limits.[19] As these factors are strongly influenced by age, sex, genetics and training, an argument has been made that football players levels of body fat should be determined when they are healthy and performing at their best. Overall, it is wiser to set individual goals than to expect all players to achieve the same level of body fatness, which illustrates the significance of treating each player as an individual, and not as a member of a team. However, this view challenges Wilmore's[20] theory, whereby all players are actively encouraged to achieve similar levels of body fat. Arguably, football players (with too much body fat) could feel pressured to engage in unsafe fat loss practices such as prolonged physical exercise, semi-starvation, malnutrition and disordered eating behaviours in an attempt to meet unrealistic fat loss.[21]

Reasons for Measuring Body Composition

Sport coaches and sport scientists recognise that the most efficacious way of preparing players for competition is based upon a complex and challenging blend of many component factors necessary for successful sport performance.[22] This places significant professional and academic challenges on the sport scientist. For instance, how the body is categorised its individual compositional characteristics has a profound influence on our health and capacity for exercise.[23] The assessment of body composition is often used as a tool for gauging these various morphological components, therefore this application provides a unique link between the different realms of health and sports performance. The measurement of whole body density is one such method.

Whole body density is the ratio of body mass to volume and can be used to help estimate the proportion of body fat present. The density of the whole body is however dependent upon the relative size of the components of both fat mass and fat-free mass components. Behnke et al[24] quantified both the fat mass and fat-free components to have densities of 1.100 $g.ml^{-1}$ and 0.900 $g.ml^{-1}$ respectively. However, the assumptions that this delimitation is based upon, have been questioned.[23] For instance, the density of fat remains constant over time for individuals, however, this literature suggests that densities vary dependent upon age, sex, ethnicity and levels of physical activity.[23] This has led to the conclusion that fat mass has a lower density than fat-free mass, therefore, an estimate of proportion of fat mass to fat free mass can be established. Direct measures of whole body density can only be made through cadaver analysis which is limited by practical, ethical and legal considerations. Yet such methods are essential for the validation and comparison of indirect methods of estimation for whole body density. However, due to these practical, ethical and legal concerns, it is not surprising that the development of indirect measures of estimating whole body density have increased over the years.

Table 1 summarises a range of available laboratory techniques and their relative accuracy with strengths and limitations. Not all the measures illustrated in Table 1 measure whole body density indirectly. Although it is important to acknowledge that some of these measures such as air displacement plethysmography (BodPod) and dual energy X-ray absorptiometry (DEXA) offer an attractive methodological alternative to hydrostatic weighting due to being faster, and requiring minimal participant cooperation. Despite these alternatives, hydrostatic weighing is still considered by many researchers to be the criterion method against which all other indirect methods should be validated; this is mainly attributable to its reliability.[25]

Some of the measures illustrated in Table 1 have served to promote a renewed interest in the sports science field due to its ability to subdivide the body, however, these methods are not generally accessible for football clubs and sport scientists attached to them due to their clinical application time commitments of participants and testers and expense.[15] Whilst there may be exceptions, such as access to university laboratories, sport scientists require a more accessible and convenient method for obtaining data on players body composition. This accessibility relates to the ease with which the various body sites required for measurement can be located, the time taken to carry out the measurements, minimal financial outlay and the relatively low technical expertise required. The most commonly used method employed by sports scientists *via* anthropometry, with measures consisting of skinfold thickness, girths, breadths, widths and depths.[4,5]

In turn, these measures can often be transferred to calibration models to estimate whole body density.[22] The calibration models are normally subdivided into regression equations generally developed on anthropometric-based formulae that predict the dependent variable (usually whole body density) from a series of independent variables such as body mass, stretched stature, skinfolds, girths, breadths, depths

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Table 1: Summary of Some Laboratory Techniques Available for the Estimation of Total Body Composition Characteristics of the General Population.

Method	Measurement	Precision error	Percentage Accuracy	Strengths	Limitations
HW	Density	±2%	96-98%	Criterion method applicable for large participants	Water immersion requires lung volume impractical
BodPod	Density	±4.5%	>95%	Quick, non-invasive immediate results applicable for various populations	Claustrophobia requires lung volume stature and mass restrictions
DEXA	FM/FFM	±1%	97-99%	Quick, non-invasive immediate results applicable for various populations	Radiation loses accuracy with increased fat mass affected by hydration status
MRI	Areas/volumes	<2%	96-98%	Generates accurate total and regional body volumes and dimensions	High levels of training required very expensive
CT	Areas/volumes	<1%	96-98%	Generates accurate total and regional body volumes and dimensions	Radiation high levels of training required very expensive
A	Density	±2.5%	>95%	Portable inexpensive large database	Invasive affected by dehydration and skin thickness technician error
BIA	Total body water [converted to FFM]	±4.5%	<80%	Portable fast non-invasive	Affected by hydration and tmperature status accuracy and precision concerns not recommended for obese/athletic populations

KEY: HW: Hydrostatic Weighing; Bod Pod: Air Displacement Plethysmography; DEXA: Dual Energy X-ray Absorptiometry; MRI: Magnetic Resonance Imaging; CT: Computed Tomography; A: Anthropometry (skinfolds, girths, breadths, widths); BIA: Bioelectrical Impedance Analysis. Percentage accuracy is determined as (100 - % error), where the error is the percentage difference from the true value.[23]

and widths.[22] As there are many anthropometric pre-dispositions within football, a number of authors have recommended establishing statistical relationships between body composition, health and aspects of sport performance to benefit management, coaches, national governing bodies, sports science team and players to reach their full potential.[25] This might be achieved in the following ways:

Help to determine important characteristics of body composition: This is often the major fundamental reason for testing a player's body composition. In order to achieve this, the sport scientist would have to be able to identify the major components of physical fitness required for successful football performance, although, it might be difficult to isolate each of the requisite components for evaluation in a field-testing setting, due to the complexities of each measurement. In a laboratory environment however, sport scientists are often able to isolate components of physical fitness and assess objectively the players performance on that particular variable. Ultimately they should be able to identify which players, playing in a particular playing position might have a functional advantage. For instance, findings from the soccer of kinanthropometry international project (SOKIP)[26] revealed that goalkeepers and defenders were the tallest and heaviest players compared to the midfield and strikers. Furthermore, goalkeepers showed systematically higher proportional girths and skinfolds than other players. These findings might help to quantify the important characteristics required for key positional roles, where body composition, rather than playing skills, provides an advantage to assist with optimisation in football. Although it is important to note that stature is not in itself a bar to success in football, it might be a functional advantage and may be exploited for tactical purposes, and therefore could determine the choice of playing position and success in performance.[5]

Help to customise training for specific positions and roles within the team: To provide baseline data for the development of a players individual training programme, measurement results, objectively gathered and analysed, can form the basis for training pre-scriptions that are specific to a particular player's position and then can be aimed at optimising that player's performance within the team.[8]

Help to track changes in a player's body composition: If the sport scientist repeats body composition measurements at regular intervals, comparisons of a player's results can help assess the effectiveness of their pre-scribed training programme or dietary regimen.[6] This however, is based on the assumption that individuals will respond comparably to similar training programmes. Indeed the sport scientist might well find that training prescribed to one player proves to be effective, but when prescribed to another may be less effective or not effective at all.[27] Additionally, evidence of the Hawthorne effect has been suggested by Falk and Heckman[28] where players are somewhat liable to modify their performance if they know that a test variable will be repeated at a later date.

Help to provide information about the health and wellbeing of players: Training for high level competition is a demanding and stressful process that can, in certain players, induce a negative

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health status. Certain tests can be adapted to screen and monitor players to help detect disease and disorders associated with excessively low levels of body fat that might not otherwise be identified by a standard medical examination.[6] The measurement of body composition is frequently used as a tool for monitoring and gauging levels of body fat and could prove useful if players engage in unsafe fat loss practices. Indeed, there is an ethical expectation that the sport scientist should be aware of the consequences of low levels of body fat which might influence the morbidity of a player. In other words, how the health of the player could impede their ability to perform at an optimal level.[29]

Help to educate players in the area of optimising their body composition: Sport scientists have an opportunity to provide an educational process where players learn to better understand their own body composition attributes and those required for success in football. This requires systematic planning of a player's development programmes, where sport scientists interpret test results directly to the player. In turn, this helps the player increase their appreciation of the components of football as well as an awareness of their own strengths and limitations.

Help in the development of a whole body density calibration model: The generation of different body composition variables among elite football players might help to provide valuable data in the future development of calibration models aimed at estimating whole body density in this sport.[23]

CONCLUSION

Our quest for knowledge and understanding regarding body composition and how it can affect performance potential has indeed intensified in recent years. This quest has been driven in part by the desire to gain an advantage within the sports science arena. Yet for the non-expert, such as the football coach, understanding why body composition measures are important and useful can often be confusing. With the primary goal of assessing whole body density to help determine the proportion of fat mass relative to fat-free mass, understanding these proportions can influence the effectiveness of a prescribed training programme and/or athletic performance potential.

Irrespective of the number of body composition parameters that are available, body composition assessment should be conducted on a regular basis to establish relationships between body composition, health and aspects of football performance. Recommendations should therefore ensure that a football player firstly maintains overall health by reducing the quantity of body fat, but within safe limits and secondly reaches optimal physical requirements needed for football performance in their specific playing position.[4,27] The recognition of treating each player as an individual and not as a team is equally important, especially with the setting of body composition goals. These recommendations could benefit management, coaches, national governing bodies and the sports science team to enable players to reach their full potential.[19]

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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