

Contents

Editorial Welcome

Keith Ward

Reference measurements of elite judokas' body composition

Adam Hawkey

Measuring elite athletes' body composition: A case study evaluating analysis techniques

Adam Hawkey, Jarryd Dunn, Michelle Di Benardo, Kerry Matthews and Alan Parsons

Raising heel height alters pressure variables in experienced high-heel wearers

Adam Hawkey and Isabel Gardiner

Body position affects cycling comfort, performance, and overuse injury: A review of the relevance of discipline-specific body positions

Nicholas J. Dinsdale and Nicola J. Dinsdale

Learning and teaching strategies for Sports Therapy: Active learning (problem-based and team-based)

Mark Godwin

Editorial Welcome

Welcome to Volume 7, Issue 1 of the JST – The 2015 Spring Issue!

Keith Ward,
School of Sport and Creative Services, University College Birmingham

It has taken far too long to follow up on our last issue (Volume 6, Issue 1, 2013); for that we can only apologise and offer brief explanation. Obviously, the process of gathering, reviewing and editing articles is both time-consuming and labour-intensive – and all of that is prior to the physical task of putting the approved articles into a publishable electronic format. Furthermore, unless the publishing of a journal happens to be one of the organisation's primary priorities this rather convoluted process becomes something of a labour of love; and unfortunately only something that can be done when it can be done.

For this issue (Spring 2015) we can present five new and interesting articles. Adam Hawkey provides our Guest Editorial feature regarding the reporting of competitive judokas' body composition using Dual-Energy X-ray Absorptiometry. Adam is also the lead author on two of our other articles – one a case study comparing body composition measurement techniques in elite athletes, the other an original piece of research examining how changes in heel-height alter pressure distribution in females in a series of gait experiments. For our fourth article, father and daughter Graduate Sports Therapists Nick and Nicola Dinsdale have presented an informative article examining the effect of cycling position on the rider's comfort, performance, and potential for injury. This review particularly scrutinises the relationship between 'man/woman and machine'. Finally, Mark Godwin argues the case for more consideration of and investment into the use of problem-based and team-based learning strategies in sports therapy educational settings.

We would like to encourage readers to consider contributing to our [online Discussion Forum](#), and as always we welcome prospective contributions to future issues (i.e. original research; case studies; literature reviews; expert commentaries; book and media reviews). All in all, we hope that you find this returning issue useful and informative.

Keith Ward

Managing Editor, Journal of Sports Therapy

[\(http://jst.ucb.ac.uk/\)](http://jst.ucb.ac.uk/)

Guest Editorial

Reference measurements of elite judokas' body composition

Adam Hawkey,
Division of Sport and Exercise Sciences, Abertay University

Regulations of the International Judo Federation (IJF) and International Olympic Committee (IOC) require athletes to compete in set weight categories. As a result, judokas demonstrate relatively low levels of body fat with high strength to mass ratios (Ali et al., 2010). However, previous studies, which have reported lower levels of body fat in Olympic competitors compared to other level performers, have analysed body composition utilising methods such as skinfold thickness and bioelectrical impedance, which are less accurate than 'gold standard' analysis techniques such as dual-energy x-ray absorptiometry (DXA: Hawkey, 2012). Judokas regularly reduce weight pre-competition to obtain a competitive advantage over lighter opponents (Artioli et al., 2010). Crucially, this is often achieved using a number of aggressive nutritional strategies, which place the judoka at a high risk of injury and/or health complications, and can also limit performance. Effectively quantifying judokas' body composition, using advanced equipment with up-to-date software and reference data, is therefore fundamental to monitoring the training, health and performance of the judoka.

We* recently analysed the body composition of twelve (n=12) elite judokas (mean: age = 19 ± 1.5 yrs.; height = 1.7 ± 0.1 m; mass = 71.5 ± 16.4 kg), from the Great Britain Judo Centre of Excellence, as part of their regular health and performance monitoring. Judokas' bone mineral content (BMC), bone mineral density (BMD) and corresponding Z-Score, lean + BMC, % body fat, and visceral adipose tissue (VAT), was assessed on a Hologic Discovery W machine, using the National Health and Nutrition Examination Survey (NHANES) reference data (Table 1).

As this is the first time judokas' body composition has been reported using DXA, this data set may act as a reference point for future investigations in this population. This may assist with the identification of those suitable for 'making weight' in certain categories and for better assessment of training protocols.

References

Ali, P.N., Hanachi, P. and Nejad, N.R. (2010). The Relation of Body Fats, Anthropometric Factor and Physiological Functions of Iranian Female National Judo Team. *Modern Applied Science*. 4 (6): 25-9.

Artioli, G.G., Gualano, B., Franchini, E., Scagliusi, F.B., Takesian, M., Fuchs, M. and Lancha, A.H. Jr. (2010). Prevalence, magnitude, and methods of rapid weight loss among judo competitors. *Medicine and Science in Sport and Exercise*. 42 (3): 436-42.

Hawkey, A. (2012). Dual-energy X-ray Absorptiometry: The science behind the scan. *The Sport and Exercise Scientist*. 33: 22.

*Great Britain Judo Centre of Excellence staff, Kerry Matthews (Radiographer) and Alan Parsons (Supervising Radiographer).

Age	Sex	Mass (kg)	Height (m)	Total BMC (g)	Total BMD (g per cm ²)	Z-score	Total Lean + BMC (g)	% Fat	VAT (cm ²)
18	F	100	1.74	3473	1.449	4.3	62866	36	64.8
18	F	68	1.66	2984	1.341	3.1	52479	21.5	18.5
19	F	68	1.67	2977	1.352	3.1	53598	19.8	31.6
18	F	62	1.61	2647	1.319	2.8	47903	20.8	34.5
20	F	60	1.58	2850	1.142	2.5	46804	20.7	19.8
17	F	52	1.55	2119	1.205	1.4	38489	24	23.5
17	F	55	1.66	2596	1.22	1.6	46212	26.7	28.8
20	M	84	1.83	3469	1.354	1.6	70507	14.7	45.3
20	M	65	1.64	3103	1.442	2.4	53989	16	44.9
20	M	104	1.94	4199	1.55	2.2	84980	15	47.9
18	M	70	1.7	3119	1.417	2.3	57349	17.4	47.3
22	M	70	1.67	3170	1.425	2.2	60474	12.7	32.7

Case Study

Measuring elite athletes' body composition: A case study evaluating analysis techniques

Adam Hawkey¹ Jarryd Dunn² Michelle Di Benardo² Kerry Matthews³ and Alan Parsons⁴

¹Division of Sport and Exercise Sciences, Abertay University, UK ²Department of Sport and Physical Activity, University of Wolverhampton, UK ³HealthScan, University of Wolverhampton, UK ⁴Department of Radiography Education, University of Derby, UK

Abstract

The effective monitoring of athletes' health and performance is becoming increasingly important. One example of this is in the use of body composition measures to monitor levels of body fat, muscle mass and bone mass. These factors can all be useful when assessing training loads, rehabilitation and recovery, and the general health and wellbeing of the athlete. While the 'gold standard' of body composition measurement involves the use of dual-energy x-ray absorptiometry (DXA), other techniques such as skinfold anthropometry (SFA) and bioelectrical impedance anthropometry are widely used; due to their relative low cost and ease of operation. The purpose of the current small-scale case study was to assess the comparability of a range of techniques frequently used to assess body composition in an elite athletic population. Three elite athletes (mean age = 20 ± 3 yrs.; height = 1.79 ± 0.09 m; mass = 76 ± 15 kg) had their body composition assessed, as part of their regular monitoring, using SFA, DXA and two different BIA systems. Analysis revealed that BIA recorded very similar reading for fat mass and muscle mass to those of DXA, while SFA did not provide accurate results. If possible DXA techniques should be used to ensure accurate measurement of an athlete's body composition. However, in DXA's absence the results of this small scale case study indicate that BIA offers a useful alternative.

Key Words: DXA; DEXA; Bioelectrical impedance; Skinfold anthropometry; Callipers; athletes; body composition

An accurate assessment of body composition is necessary in order to correctly estimate an individual's risk for certain health conditions such as cardiovascular disease, hypertension, diabetes mellitus, hyperlipidemia, and certain forms of cancer (Shah and Braverman, 2012). The same measurement techniques used to monitor the relative and total amounts of body fat mass and lean body mass can also be crucial for the periodic assessment of nutritional and exercise interventions in athletic populations. There are currently a number of techniques employed to assess body composition in order to determine the amounts of fat mass, fat-free mass, and bone mass (Wagner and Heyward, 1999). Traditionally, Skinfold Anthropometry (SFA) has been the preferred method of assessing body composition in a sports population, due to it being quick and relatively inexpensive. SFA involves taking measurements (such as the lengths, circumferences and skin-

fold thickness) of the body. While SFA can be a useful tool for coaches and sports scientists to use, it uses equations dating back decades (Durnin and Womersley, 1974; Jackson et al. 1980) to estimate body fat percentage and muscle mass, which according to Guppy and Wallace (2012), requires a degree of skill from the operator that is not often demonstrated; questioning whether it is an appropriate technique to use on a sporting population. The most commonly used technique to assess body composition is Bioelectrical Impedance Analysis (BIA). BIA works by assessing the different electrical conductivity that fat and fat-free mass possess; while fat-free mass conducts a small electrical current as it has a high water content, fat mass offers much greater resistance meaning it is not such a good conductor for the electrical signal. Historically though, BIA can be quite unreliable due to it being based on a number of assumptions and greatly affected by the hydration status of the individual (Guppy and Wallace, 2012). However, recent developments regarding segmental multi-frequency BIA and the generation of normal ranges, using a relatively new seca mBCA BIA system for example, appear to have improved the validity and precision of this technique (Bosy-Westphal et al. 2013; Peine et al, 2013). DXA (or DEXA) measures the differential attenuation of two different energy level X-rays as they pass through the body. Originally designed to quantify bone health, it offers an in-depth analysis of soft tissue mass, bone mass, lean mass and fat mass (Hawkey, 2012a); with some now also being capable of distinguishing between adipose and visceral fat (Hawkey, 2012b).

Methodology

Three (n=3) elite athletes (mean age = 20 ± 3 yrs.; height = 1.79 ± 0.09 m; mass = 76 ± 15 kg), from a UK: Athletics High Performance Centre, attended for a DXA scan to assess body composition as part of their regular health and performance monitoring. All participants completed informed consent prior to involvement and their respective coaches were aware of the procedures. To minimise any fluctuations in body composition, all methods were conducted immediately after one another. BMI was calculated in accordance with World Health Organisation (WHO) guidelines (WHO, 1998). Bioelectrical impedance was measured using a BodyStat 1500 (Bodystat Ltd, Douglas, UK) and with a seca mBCA (Figure 1: seca, UK)



Figure 1. Seca mBCA in use (courtest of seca UK)

in accordance with the respective manufacturer’s guidelines. Skinfold measurement was conducted using callipers in accordance with the International Society of Anthropometry and Kinesiology’s (ISAK) 8-site protocol by an ISAK Level 1 accredited practitioner. The DXA scan was carried out on a Hologic Discovery W, running Apex 4 software, in accordance with guidelines from the manufacturer and in-line with measurements used in National Health and Nutrition Examination Survey (NHANES) study. The DXA scan was conducted by an experienced and qualified operator, validated by a registered radiographer.

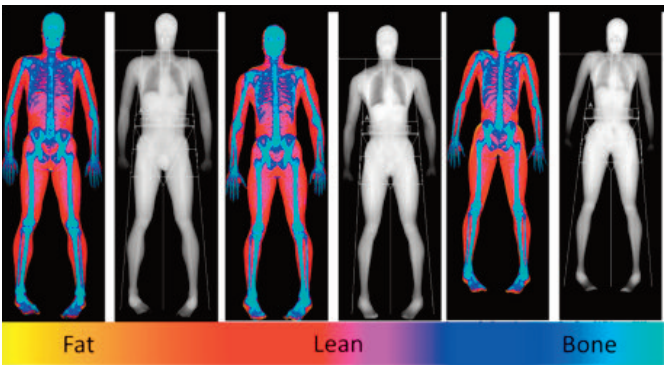
Table 1. Athletes’ body composition data from DXA, BIA & SFA

	Participant 1	Participant 2	Participant 3	Mean
Age/Sex	21 (M)	20 (M)	18 (F)	19.7/-
PB (60/100/200/400)	././21.8/46.0	./10.6/21.67/48.71	7.73/11.83/./	7/-
Mass	75.65	75.7	58.55	70.0
Height	1.82	1.78	1.65	1.8
BMI	22.8	23.9	21.5	22.7
DXA (%BF) NHANES	12.2	12.1	16.2	13.5
DXA (MM Kg)	62.16	62.48	45.74	56.8
DXA (MM %)	82.2	82.5	78.1	80.9
DXA (BMD g/cm2)	1.29	1.32	1.25	1.3
DXA (Z-score)	1	0.4	0.9	0.8
seca (%BF)	9	11	17	12.3
seca (MM Kg)	66.9	64.8	44.2	58.6
seca (MM %)	88.4	78.5	75.5	80.8
Bodystat (%BF)	7.2	11.1	19.7	12.7
Bodystat (MM Kg)	69.6	66.7	46.6	61.0
Bodystat (MM %)	92.8	88.9	80.3	87.3
SFA (%BF)	6.2	6	10.3	7.5
SFA (MM Kg)	43.6	48.8	40	44.1
SFA (MM %)	58.1	66.5	71.4	65.3

Results

Due to the small sample size of this study, no statistical analysis was performed on the data collected. Instead, evaluation of the descriptive statistics was undertaken (see Table 1). Values obtained for body fat and muscle mass using the four different systems was compared, while values of bone density (only assessed using DXA) were also obtained (Figure 2).

Figure 2. DXA Scans of 3 athletes showing muscle, fat and bone mass



Conclusions and Recommendations

The purpose of the current small-scale case study was to assess the comparability of a range of techniques used to assess body composition in an elite athletic population. As this current study was only conducted on a very small scale, involving three athletes during routine screening, it was not designed to be an investigative research study; but one that may prove useful to the athletes and their coaches for future reference. As athletic populations often display extremes of body composition and fat mass it has been suggested that the use of BMI and skinfold, while fast and convenient, do not allow for this population’s larger muscle mass and a higher bone density; consequently affecting the validity of in these methods in this specific group (Egan et al. 2006). These deficiencies have led, where feasible, to the wide-spread use of DXA as a reference measure for analysis of body composition in competitive athletes. Guppy and Wallace (2012) state that DXA is the most appropriate method to use in an athletic population as it provides regional analysis, allowing for more specific measurements to be taken, which in turn allow for increased specificity of the measurements, greater understanding of body composition; all of these factors increase the athlete’s ability to shape their training or rehabilitation. Therefore, DXA was used as the ‘gold standard’ with which to compare the other methods against.

The main findings reported to the athletes and coaches were that both BIA methods slightly underestimated body fat levels compared to the DXA analysis (Bodystat 1500 = 12.3; seca mBCA = 12.7% respectively, compared to the 13.5% recorded using DXA). However, this was far more accurate than the SFA, which was considerably lower at 7.5% on average for the three athletes. The seca mBCA recorded almost identical results for muscle mass (%) and very similar for muscle mass (kg) compared to DXA, while the Bodystat system also performed very well. However, the SFA results were not consistent with the other measures. Previous research has stated that as DXA provides different body composition estimates than those derived from skinfold thickness measurement and BIA and therefore these methods should not be used interchangeably (De Lorenzo et al., 2000; Steiner et al., 2002). To some degree the findings of this current case study would support this notion, and where possible would recommend that DXA be used to monitor athletes' body composition as it provides highly detailed information; including the additional measure of bone mass. However, in DXA's absence the results of this small scale case study indicate that BIA offers a useful alternative when measuring athletes' body composition.

References

- Bosy-Westphal, A., Schautz, B., Later, W., Kehayias, J.J., Gallagher, D. and Müller, M.J. (2013). What makes a BIA equation unique? Validity of eight-electrode multi-frequency BIA to estimate body Composition in a healthy adult population. *European Journal of Clinical Nutrition*, 67: 14-21
- De Lorenzo, A., Bertini, I., Iacopino, L., Pagliato, E., Testolin, C. and Testolin, G. (2000). Body composition measurement in highly trained male athletes: A comparison of three methods. *The Journal of Sports Medicine and Physical Fitness*, 40(2): 178-183.
- Durnin, J. V. G. A., and Womersley, J. (1974). Body fat assessed from total body density and its estimations from skinfold thickness: measurements of 481 men and women aged from 16-72 years. *British Journal of Nutrition*, 32: 77-97
- Egan, E., Wallace, J. Reilly, T. Chantler, P. and Lawler, J. (2006). Body composition and bone mineral density changes during a premier league season as measured by dual-energy x-ray absorptiometry. *International Journal of Body Composition Research*, 4: 61-66.
- Guppy, F. and Wallace, J. (2012). The measurement of body composition in an athletic population: the importance of DXA. *Measurement and Control*, 45(6): 177-181.
- Hawkey, A. (2012a). Understanding the causes, prevention and treatment of osteoporosis (part 2): detecting and diagnosing the disease. *Journal of Sports Therapy*, 5(1): 7-14.
- Hawkey, A. (2012b). Dual-energy x-ray absorptiometry: the science behind the scan. *The Sport and Exercise Scientist*, 33: 22.
- Jackson, A. S., Pollock, M. L., and Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise*, 12: 175-182.
- Peine, S., Knabe, S., Carrero, I., Brundert, M., Wilhelm, J., Ewert, A., Denzer, U., Jensen, B. and Lilburn, P. (2013). Generation of normal ranges for measures of body composition in adults based on bioelectrical impedance analysis using the seca mBCA. *International Journal of Body Composition Research*, 11: 67-76.
- Shah, N.R. and Braverman, E.R. (2012). Measuring adiposity in patients: the utility of body mass index (BMI), percent body fat, and leptin. *PLoS ONE*, 7(4): e33308.
- Steiner, M.C. Barton, R.L. Singh, S.J., and Morgan, M.D.L. (2002). Bedside methods versus dual energy X-ray absorptiometry for body composition measurement in COPD. *European Respiratory Journal*, 19: 626-631.
- World Health Organization (1998). Obesity: preventing and managing the global epidemic. In: *Report of a World Health Organization Consultation on Obesity*. Geneva: WHO.

Original Research

Raising heel height alters pressure variables in experienced high-heel wearers

Adam Hawkey¹ and Isabel Gardiner²

¹Biomechanical Analysis and Motion-Capture Laboratory, Division of Sport and Exercise Sciences, Abertay University, UK. ²Department of Sport and Physical Activity, University of Wolverhampton, UK.

Abstract

High heels are worn by millions of women every day in both professional and social settings. Despite high heels being used prolifically, research examining the effects of different heel heights on gait patterns is limited. The current study investigated how changes in heel-height alter pressure distribution. Following institutional ethics approval, 16 high-heel wearing females (Age mean \pm SD: 26 \pm 10yrs; Mass mean \pm SD: 62.6 \pm 18kg; Shoe size mean \pm SD: 5.3 \pm 1 UK; foot width mean \pm SD: 9 \pm 0.5cm; foot length mean \pm SD: 25 \pm 1.4cm) completed three walking trials in each of four separate conditions; barefoot over a pressure plate and in three conditions wearing shoes with different heel heights (1.5cm, 5.3cm and 9cm respectively), that had a pressure-measuring insole inserted into the shoes. The anatomical points of interest for measuring pressure were the five metatarsal heads and both the lateral and medial aspects of the heel of the left foot. Repeated measures analysis of variance revealed that an increase in heel-height resulted in significant increases in pressure at the heads of metatarsal 2 ($P = 0.006$) and metatarsal 3 ($P < 0.01$) and decreases in pressure at the head of metatarsal 5 ($P = 0.002$) and the lateral heel ($P = 0.025$). The results of this study suggest that it would be advised to keep heel heights to a minimum in order to reduce any possible discomfort and mitigate the potential for other detrimental effects.

Key Words: High heels, heel height, pressure, biomechanics, metatarsals, footwear, gait.

Introduction

Throughout history shoes have been used to indicate ones position in society; the colour of a soldier's sandals was a sign of his rank in the Roman army, while in the Victorian era to have your shoes made specifically for you was a luxury of the more affluent (Yarwood, 1975; McDowell, 1994). Humans have worn shoes for thousands of years, mainly as a protective covering for the feet (Frey et al., 1993). Evidence suggests that simple sandals were prevalent throughout the Roman, Grecian and Etruscan eras, and that these designs were very similar to those worn by the ancient Egyptians and in Mediterranean cultures (Yarwood, 1975; McDowell, 1994). Yarwood (1975) states that it was during the reign of Louis XIV in France that high heels were introduced; the king was reported to have worn bright red high heeled shoes and

influenced both men and women of his court to follow suit (McDowell, 1994). In recent decades, fashion continues to be considered more important than comfort or practicality; with an increasingly greater value placed upon appearance. While the trend for men to wear high heels has all but diminished, women continue to wear high heels prolifically. According to Phillips et al. (1991) women wearing high heels can be considered more aesthetically desirable, which in turn leads to more women wearing high heels more often (Frey et al., 2003). Some studies have reported that up to 70% of women wear high-heeled shoes, in both professional and social settings, on a daily basis (Ensenyel et al., 2003). While typical shoes have an elevation of approximately 1-2cm, high-heeled shoes may have an elevation of up to, or greater than, 10cm (Stefanyshyn et al., 2000). In addition, they have a rigid heel cap that protrudes anteriorly, exhibit excessive plantar curvature and a narrowed toe-box (Stephens, 1992); the latter being particularly concerning as research has shown that the higher the heel the more the forefoot is forced down into the toe area of the shoe (Bendix et al., 1984).

Traditionally, high-heeled shoes have been blamed for a myriad of foot complaints and for the majority of foot deformities and problems that physicians encounter in women (Phillips et al., 1991; Frey et al., 1993). Merrifield (1971) has previously stated that wearing high heels causes both step length and stride length to decrease and foot forces to be concentrated more anteriorly and medially. These factors affect stability and balance, and, ultimately require the wearer to continually make adjustments to the biomechanics of their gait (Merrifield, 1971; Opila-Correia, 1990a); potentially linking common complaints of leg and back pain to the wearing of high heeled shoes. Previous research has speculated that increased pressure on certain areas of the foot have resulted in various deformities such as hallux valgus, hammertoes, callouses and metatarsalgia, and have contributed to problems with other parts of the body and with muscular fatigue (Phillips et al., 1991; Frey et al., 1993; Stefanyshyn et al., 2000). Gefen et al. (2002) states that high-heeled shoes have been shown to adversely affect gait kinematics particularly at the ankle joint, which is excessively plantar flexed, and clinical relationships have been proposed linking foot problems, or pain, to the wearing of high heels. When walking in high heeled shoes, biomechanical differences such as stride length, muscle activity, increased instability of the rear foot and plantar foot pressure have been reported (Opila-Correia, 1990a; 1990b; Phillips et al., 1991; Stefanyshyn et al., 2000).

Ebbeling et al. (1994) and Stefanyshyn et al. (2000) also reported that an increased heel height caused increases in ankle plantar flexion, knee flexion, vertical ground reaction forces and anteroposterior braking force. It has been proposed that the altered anatomical position of the foot causes functional changes that include a shift in ground reaction force toward the medial forefoot, a reduction in foot pronation during mid-stance, and an increase in the vertical ground reaction force (GRF) at heel strike (Ensenyel et al., 2003). Snow and Williams (1990) also reported that wearing high-heels significantly increased the vertical forces applied to the forefoot, due to increased plantar flexion, and a shift in the centre of mass both anteriorly and medially. These finding corresponded to those of McBride et al. (1991) who found that forces at the first metatarsophalangeal, during the toe-off phase of gait, were twice as large when wearing high heels compared to barefoot walking.

However, despite growing concerns regarding the damaging effect on gait and lower extremity function, little research has been conducted on the relationship between heel height and the consequent pressures beneath the foot; the majority of literature available on the biomechanical and metabolic responses during human locomotion has focused on athletic shoes with a minimal heel height (Ebbeling et al., 1994; Ottaviani et al., 2001; Wakeling et al., 2002). Past research that has been conducted on women wearing high heels has tended to focus on the kinematics of gait rather than the kinetics (Opila-Correia, 1990a; 1990b; Snow et al. 1992). It is only more recently, according to Speksnijder et al. (2005) that the technology, principally concerning insole pressure devices, have advanced significantly enough to allow for greater understanding of insole pressure variations. Investigating pressure measurements when women wore low heels (~2cm) and high heels (~6cm), Speksnijder et al. (2005) reported that as height increased so did the corresponding pressure on the metatarsal heads of the forefoot. Ko et al. (2009) also reported that increased heel height resulted in increasing medial forefoot loading pressure, which also resulted in stationary compressibility exhibited by the soft tissue, when the heel height was greater than 2cm; leading to a suggestion of limiting heel height to no greater than 2cm and using medial padding under the metatarsal heads to potentially reduce discomfort and injury risk. Given the large number of women who wear high-heeled shoes, examining the effects that different heel heights have on pressure variables may offer further insights into clinically preventable musculoskeletal problems.

Table 1. Participant demographics

Age (yrs.)	26 ± 10
Mass (kg)	62.6 ± 18
Height (m)	1.62 ± 0.05
Shoe Size (UK)	5.3 ± 1
Foot Width (cm)	9 ± 0.5
Foot Length (cm)	25 ± 1.4

Methods

Following institutional ethics approval, 16 experienced high-heel wearing females (Table 1) volunteered for the study. Participants were classified as experienced wearers as they wore high heels three or more times per week for approximately five hours at a time, in accordance with Snow et al. (1992) and Ebbeling et al. (1994). All participants were required to be in good health with no previous fractures or surgery of the lower limbs, pelvis, or spine and with no cardiovascular or neuromuscular disorders; identified by Opila-Correia (1990b) and Ebbeling (1994) as factors, which might affect their gait patterns. This was determined by completion of a pre-exercise questionnaire and an informed consent form. All participants were required to wear shoes of a standard size four, five or six, depending on the shoe size of the participant. All participants completed three walking trials in each of four separate conditions; barefoot over a pressure plate (RSScan International, Belgium) and in three conditions wearing shoes with different heel heights (flat heel: 1.5cm; medium heel: 5.3cm; and high heel: 9cm; Figure 1), that had a pressure-measuring insole (RSScan Instep Insole system; RSScan International, Belgium) inserted into the shoes. In order to standardise the experimental protocol, all shoes were provided by the research team and the heels of the medium and high heel were of a similar diameter. The anatomical points of interest for measuring pressure were the five metatarsal heads and both the lateral and medial aspects of the heel of the left foot.

Figure 1. Flat heel (1.5cm), medium heel (5.3cm) and high heel (9cm)



Instrumentation and Data Collection

An RSScan (RSScan International, Belgium) pressure plate was utilised during the barefoot condition; using the RSScan single step software, measuring at 500Hz. The pressure plate was positioned flush to the floor to avoid the participants stepping up onto the platform, in accordance with Challis (2001). During the three shod conditions the participants wore shoes contained the RSScan In-Step Insole system measuring at 500Hz (RSScan International, Belgium: Figure 2a-b). Each participant was required to complete three successful trials in the bare foot condition. A trial was considered to be successful when the participant made contact with centre of the pressure plate with their left foot, without hesitation or alteration of their usual movement pattern. The participants were instructed to focus upon a spot on the wall, as targeting of the plate has been reported to alter stride pattern (Challis, 2001). In each of the three shod conditions the participants were required to walk for 20m to allow the insole device to measure for a total of 8 seconds. All trials, both bare foot and shod, were conducted at the participants' pre-

Figure 2a. Frontal view of insole pressure system set-up

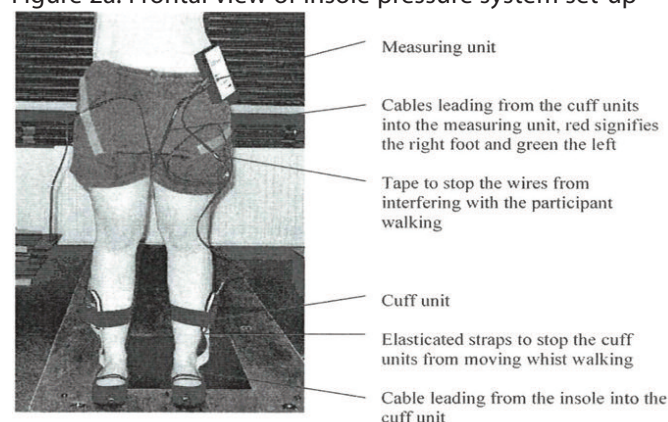
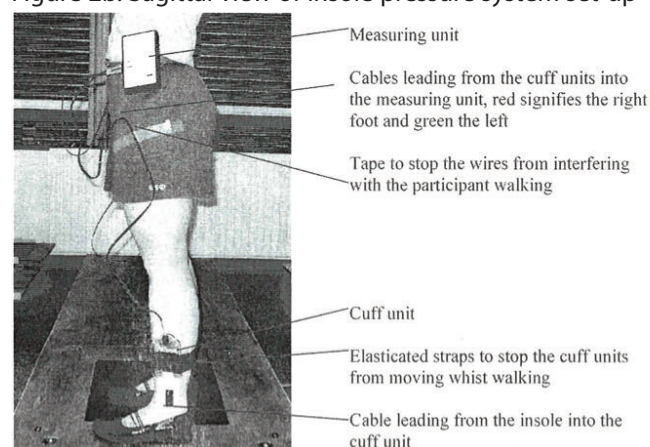
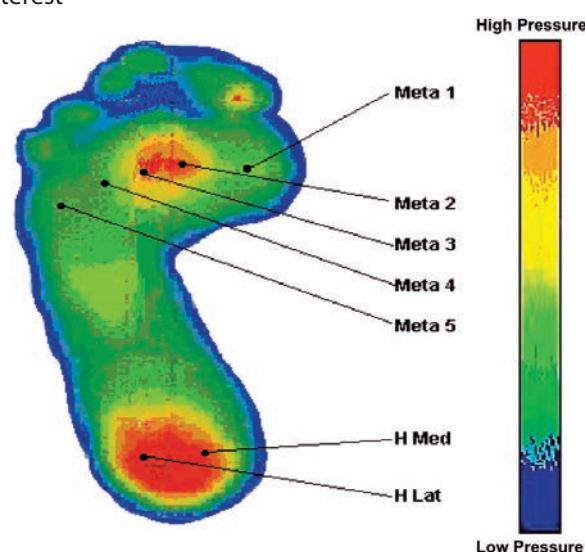


Figure 2b. Sagittal view of insole pressure system set-up



ferred walking speed to ensure ecological validity in accordance with Hayafune et al. (1999) and Cavanagh et al. (1992) who noted that requiring participants to walk at a standard prescribed speed, can disturb normal gait patterns. The results of three trials were averaged for each participant, in each condition, for analysis. Repeated measures analysis of variance (ANOVA) was performed on the maximum peak pressure on the 1st, 2nd, 3rd, 4th and 5th metatarsal heads of the left foot, and the medial and lateral aspects of the left heel (Figure 3).

Figure 3. Representation of pressure measurements at points of interest



Results

Repeated measures ANOVA reported a borderline non-significant difference ($P = 0.057$) in pressure at metatarsal 1 between the barefoot and shod conditions. There was a significant difference ($P = 0.006$) for pressure between the barefoot and shod conditions at metatarsal 2 (see Table 2 for mean pressures and % differences). A significant difference ($P = 0.006$) was found between the mean pressures recorded at metatarsal 3 for the barefoot and shod conditions (see Table 3 for mean pressures and % differences). No significant difference ($P = 0.16$) was found between the pressures at metatarsal 4 for the barefoot and three shod conditions. There was a significant difference ($P = 0.002$) in pressure at metatarsal 5 between conditions (see Table 4 for mean pressures and % differences). While there was a significant difference ($P = 0.025$) in pressure at the lateral heel between barefoot and shod conditions (see Table 5 for mean pressures and % differences), there was no significant difference ($P = 0.125$) between the pressures recorded at the medial heel between conditions.

Table 2. Mean and SD values at the main anatomical points of interest in barefoot condition

Anatomical point	Mean Pressure \pm SD (N/cm ²)	% Change on barefoot means
1st metatarsal head	13.88 \pm 8.36	14.97
2nd metatarsal head	15.54 \pm 5.89	50.78
3rd metatarsal head	16.35 \pm 7.10	76.95
4th metatarsal head	11.70 \pm 5.42	14.26
5th metatarsal head	11.98 \pm 6.51	34.19
Lateral heel	15.95 \pm 8.41	-19.08
Medial heel	19.92 \pm 6.08	10.85

Table 3. Mean and SD values at the main anatomical points of interest in flat heel condition

Anatomical point	Mean Pressure \pm SD (N/cm ²)	% Change on barefoot means
1st metatarsal head	20.75 \pm 11.72	71.83
2nd metatarsal head	16.31 \pm 5.63	58.17
3rd metatarsal head	18.05 \pm 7.78	95.30
4th metatarsal head	11.86 \pm 3.86	15.86
5th metatarsal head	7.66 \pm 2.76	-14.18
Lateral heel	21.09 \pm 6.54	6.95
Medial heel	21.70 \pm 4.99	20.74

Table 4. Mean and SD values at the main anatomical points of interest in medium heel condition

Anatomical point	Mean Pressure \pm SD (N/cm ²)	% Change on barefoot means
1st metatarsal head	22.36 \pm 23.52	85.17
2nd metatarsal head	19.51 \pm 12.47	89.21
3rd metatarsal head	18.82 \pm 5.86	103.64
4th metatarsal head	14.02 \pm 6.50	36.90
5th metatarsal head	5.46 \pm 2.89	-38.81
Lateral heel	16.97 \pm 4.02	-13.90
Medial heel	18.09 \pm 4.03	.068

Table 5. Mean and SD values at the main anatomical points of interest in high heel condition

Anatomical point	Mean Pressure \pm SD (N/cm ²)	% Change on barefoot means
1st metatarsal head	12.08 \pm 1.89	N/A
2nd metatarsal head	10.31 \pm 1.77	N/A
3rd metatarsal head	9.24 \pm 1.15	N/A
4th metatarsal head	10.24 \pm 1.02	N/A
5th metatarsal head	8.93 \pm 1.23	N/A
Lateral heel	19.72 \pm 2.96	N/A
Medial heel	17.97 \pm 2.56	N/A

Discussion

High-heeled shoes have traditionally been blamed for a myriad of foot complaints (Phillips et al., 1991; Frey et al., 1993). While previous research has speculated that increased pressure on certain areas of the foot have contributed to various deformities, and despite growing concerns regarding the damaging effect on gait and lower extremity function, there is a paucity of research investigating the relationship between heel height and consequent pressures on the foot. Ebbeling et al. (1994) and Stefanyshyn et al. (2000) reported that an increased heel height caused increases in ankle plantar flexion, knee flexion, vertical ground reaction forces and anteroposterior braking force, while Esenyel et al. (2003) found that the altered anatomical position of the foot was the main cause of functional changes including a shift in ground reaction force toward the medial forefoot, a reduction in foot

pronation during mid-stance, and an increase in the vertical ground reaction force (GRF) at heel strike. Snow and Williams (1990) also reported that wearing high-heels significantly increased the vertical forces applied to the forefoot, due to the increased plantar flexion, and a shift in the centre of mass both anteriorly and medially. The main findings of the current study were that an increase in heel height corresponded to an increase in pressure at the medial metatarsals (M2 and M3), a reduction in pressure at the outermost lateral metatarsal (M5) and an increase at the medial heel. The changes in pressure noted at the respective lateral and medial metatarsal heads indicates that as heel height increases the participants placed more pressure down the medial aspect of the foot during metatarsal loading; supporting previous studies' findings (McBride et al., 1991; Snow et al., 1992; Nyska et al., 1996; Mandato and Nester, 1999; Esenyel et al., 2003; Speksnijder et al., 2005; Ko et al., 2009). The medial aspect of the heel showed no significant difference in pressure though. This may indicate that pressure received at this site during heel strike remains relatively constant with increasing heel height. However, it has been assumed that pressure in the forefoot increases due to the presence of the heel, which forces more pressure down into the forefoot; due to the excessive plantar flexion observed when wearing high heels (Bendix et al., 1984). Other investigations have noted that wearing high heels encourages the body into falling forward and can cause the individual to shuffle, rather than pick up their feet (Adrian and Karpovich, 1966; Bendix et al., 1984). This may explain why there was little change in the pressure values noted in the medial aspect of the heel and why the pressures noted in the lateral aspect reduced as the individual may not be able to heel strike sufficiently due to the lack of leverage at the ankle.

One advantage of the current study's design was that three different heel heights were tested and reflected previous research by Stefanyshyn et al. (2000), which indicated that high heeled shoes are often up to 10cm; while Snow et al. (1992) tested three heights these only went up to a maximum of ~8cm, Speksnijder et al. (2005) tested only two heights up to a maximum of ~6cm. Other differences included the fact that participants in this current study were provided with shoes, unlike Speksnijder et al. (2005) who allowed participants to wear their own shoes. Speksnijder et al. (2005) claims this assured comfort and a more normal gait, although acknowledged that the variation in the soles, uppers and linings may influence pressure measurements; something that Hennig and Milani's (1995) and Hennig et al. (1996) findings regarding the increase in peak vertical forces with an increase in shoe hardness concur with. Despite the differences of methodologies, the findings of this current

study link well with those of previous research. The overarching message is that wearing high heels appears to shift the load from the heel region towards the central and medial forefoot; something that is accompanied by an increase in pressure at these sites. This may have implications for those vulnerable to high pressure in the forefoot, such as diabetics or those suffering from rheumatoid arthritis (Speksnijder et al. 2005). It may also affect those wearing high heels for long periods. Although no studies have assessed the effect of prolonged wearing of high heels over a number of years in terms of pressure pattern alterations, much has been written about long term changes in foot morphology thought to be caused by extended wearing of high heels (Phillips et al., 1991; Frey et al., 1993; Plank, 1995; Bryant et al., 1999; Stefanyshyn et al., 2000). Opila, (1988) notes that wearing high-heeled shoes causes statistically significant changes in the orientation of the lumbar and pelvic regions. Opila-Correia (1990b) found that those more accustomed to wearing high-heeled shoes accommodated biomechanically to walking in that type of shoe. Therefore it may be possible that certain individuals who wear high heels more often over time not only change their body position but the way in which they load the foot so as to walk 'normally' in the shoes they usually wear.

Conclusion and Recommendations

Findings of the current study support previous research and anecdotal evidence that increases in heel height cause changes in pressure distribution across the foot and have the potential to result in negative outcomes on gait patterns and health. With up to 70% of women wearing high-heeled shoes on a daily basis, in both professional and social settings, it would appear appropriate to inform women about the dangers of wearing high heels. Future research should now examine the longitudinal effects of prolonged high heel wearing, including degenerative bone and joint diseases, muscular pain and potential changes in pressure distribution patterns.

Reference List

- Adrian, M. J., and Karpovich, P. V. (1966) Foot instability during walking in shoes with high heels. *The Research Quarterly*. 37: 168-175.
- Bendix, T., Sørensen, S. S., and Klausen, K. (1984). Lumbar curve, trunk muscles, and line of gravity with different heel heights. *Spine*. 9: 223-227.
- Bryant, A., Tinley, P. and Singer, K. (1999). Plantar pressure distribution in normal, hallux valgus and hallux limitus feet. *The Foot*. 9 (3): 115-119.
- Cavanagh, P. R., Hewitt, F. G., Perry, J. R., and Perry J. E. (1992). In-shoe plantar pressure measurement: A review. *The Foot*. 2 (4): 185-194.
- Challis, J. H. (2001). The variability in running gait caused by force plate targeting. *Journal of Applied Biomechanics*. 17 (1): 77-83.
- Ebbeling, C. J., Hamill, J., and Crussemeyer, J. A. (1994). Lower extremity mechanics and energy cost of walking in high-heeled shoes. *Journal of Orthopaedic and Sports Physical Therapy*. 19: 190-196.
- Esenyel, M., Walsh, K., Walden, J. G., and Gitter, A. (2003). Kinetics of high-heeled gait. *Journal of the American Podiatric Medicine Association*. 93 (1): 27-32.
- Frey, C., Thompson, F., Smith, J., Sanders, M. and Horstman, H. (1993). American orthopaedic foot and ankle society women's shoe survey. *Foot and Ankle*. 14: 78-81.
- Gefen, A., Megido, R. M., Itzchak, Y., and Arcan, M. (2002). Analysis of muscular fatigue and foot stability during high-heeled gait. *Gait Posture*. 15 (1): 56-63.
- Hayafune, N., Hayafune Y. and Jacob, H. A. C. (1999). Pressure and force distribution characteristics under the normal foot during the push-off phase in gait. *The Foot*. 9 (2): 88-92.
- Hennig, E. M. and Milani, T. L. (1995). In-shoe pressure distribution for running in various types of footwear. *Journal of Applied Biomechanics*. 11: 299-310.
- Hennig, E. M., Valiant, G. A. and Liu, Q. (1996). Biomechanical variables and the perception of cushioning for running in various types of footwear. *Journal of Applied Biomechanics*. 12:143-150.
- Hughes, J., Clark, P., Jagoe, R. R., Gerber, C. and Klenerman, L. (1991). The pattern of pressure distribution under the weight bearing forefoot. *The Foot*. 1 (3):117-124.
- Ko, P-H., Hsiao, T.Y., Kang, J-H., Wang, T-G., Shau, Y-W. and Wang, C-L. (2009). Relationship between plantar pressure and soft tissue strain under metatarsal heads with different heel heights. *Foot and Ankle International*. 30 (11): 1111-1116

- Mandato, M.G. and Nester, E. (1999). The effects of increasing heel height on forefoot pressure. *Journal of the American Podiatric Medical Association*. 89 (2): 75-80.
- McBride, I.D., Wyss, U.P., Cooke, T.D.V., Murphy, L., Phillips, J. and Olney, S.J. (1991). First metatarsophalangeal joint reaction forces during high heel gait. *Foot and Ankle International*. 11 (5): 282-288.
- McDowell, C. (1994). *Shoes: Fashion and Fantasy*. Thames and Hudson. UK
- Merrifield, H. H. (1971). Female gait patterns in shoes with different heel heights. *Ergonomics*. 14 (3): 411-417.
- Nyska, M., McCabe, C., Linge, K., and Klenerman, L. (1996). Plantar foot pressures during treadmill walking with high-heel and low-heel shoes. *Foot and Ankle International*. 17 (11): 662-6.
- Opila, K. A., Wagner, S. S., Schiowitz, S. and Chen, J. (1988). Postural alignment in barefoot and high-heeled stance. *Spine*. 13 (5): 542-7.
- Opila-Correia, K. A. (1990a). Kinematics of high-heeled gait. *Archive Physical Medicine Rehabilitation*. 71 (5): 304-9.
- Opila-Correia, K. A. (1990b). Kinematics of high-heeled gait with consideration for age and experience of wearers. *Archive Physical Medicine Rehabilitation*. 71 (11): 905-9.
- Ottaviani, R. A., Ashton- Miller, J. A. and Wojtys, E. M. (2001). Inversion and eversion strengths in the weight bearing ankle of young women: Effects of plantar flexion and basketball shoe height. *The American Orthopaedic Society for Sports Medicine*. 29 (2): 219-225.
- Phillips, R. D., Reczek, D. M., Fountain, D., Renner, J., and Park, D. B. (1991). Modification of high-heeled shoes to decrease pronation during gait. *Journal of the American Podiatric Medicine Association*. 81 (4): 215-9.
- Plank, M. J. (1995). The pattern of forefoot pressure distribution in hallux valgus. *The Foot*. 5 (1): 8-14.
- Snow, R. E. and Williams, K. R. (1990). Effects on gait, posture, and centre of mass position in women wearing high heeled shoes. *Medicine and Science in Sports and Exercise*. 22 (2): S23.
- Snow, R. E., Williams, K. R. and Holmes, G. B. (1992). The effects of wearing high-heeled shoes on pedal pressure in women. *Foot Ankle*. 13 (2): 85-92.
- Speksnijder, C.M., vd Munckhof, R. J.H., Moonen, S.A.F.C.M. and Walenkamp, G.H.I.M. (2005). The higher the heel the higher the forefoot-pressure. *The Foot*. 15: 17-21.
- Stefanyshyn, D.J., Nigg, B.M., Fisher, V., O'Flynn, B. and Liu, W. (2000). The influence of high-heeled shoes on kinematics, kinetics, and muscle EMG of normal female gait. *Journal of Applied Biomechanics*. 16 (3): 309-319.
- Stephens, M. M. (1992). Heel pain. *The Physician and Sports Medicine*. 20: 87-95.
- Wakeling, J. M., Pascual, S. A. and Nigg, B. (2002). Altering muscle activity in the lower extremities by running with different shoes. *Medicine and Science in Sports and Exercise*: 1529-1532.
- Yarwood, D. (1975). *European Costume: 4000 Years of Fashion*. B.T. Batsford. UK

Reviews and Invited Commentary

Body position affects cycling comfort, performance, and overuse injury: A review of the relevance of discipline-specific body positions

Nicholas J. Dinsdale and Nicola J. Dinsdale,
NJD Sports Injury Centre, Clitheroe, Lancashire.

Abstract

Improvements in cycling performance have focused predominantly on physiological variables and training strategies. In contrast, few studies have investigated the effects and implications of body position. Body position, especially discipline-specific, can affect comfort, performance and incidence of overuse injury – over the range of cycling disciplines. This review investigates the link between body position with respect to cycling comfort, performance, and overuse injuries. Moreover, this review scrutinises the relationship between ‘man and machine’.

Key Words: Bicycling; body position; cycle set-up; cycling injuries; cycling performance; triathlon; bike-fitting; aero-position.

Introduction

The extraordinary success of British Cycling teams has helped stimulate the rapid rise in cycling popularity, culminating with mass participation in a range of competitive cycling disciplines and to the extent where cycling has now become a fully inclusive activity throughout the UK. Cyclists of all ages, gender and ability enjoy cycling's multiple established health benefits and diverse uses. Cycling is used for commuting and recreational purposes (Peck, 2012), rehabilitation after joint replacement (Herndon et al., 2010), prevention of cardiovascular disease (Hoevenaer et al., 2011), cardiac rehabilitation (Oja et al., 2011) and to stimulate creative thinking (Colzato et al., 2013). The plethora of cycling disciplines includes mountain-biking, road cycling, road sportives, track racing, road time-trials and triathlon. Although there is disagreement within the scientific and coaching communities on cycle set-up and body position (Bini et al., 2012), this article will attempt to highlight evidence-based parameters from which meaningful guidance can be derived.

Whether cycling for recreational or competitive reasons, a proper body position (riding position) achieved through cycle set-up is imperative for comfort, performance and less injury (Burke and Pruitt, 2003). A discipline-specific body position enables the cyclist to generate power efficiently, and thereafter transfer the power to the pedal crank, with minimal wasted energy (Dinsdale, 2012a). Pruitt (2003) admirably describes cycling as “a marriage between the adaptable human body and adjustable machine”. Such a harmonious

marriage requires proper set-up parameters at the three-contact points, i.e. saddle, pedals, and handlebars (Burke and Pruitt, 2003).

Research demonstrates that body position can influence cycling comfort (Partin et al., 2012; Sommer et al., 2010), cycling performance (Bini et al., 2011; Dinsdale and Williams, 2010; Peveler and Green, 2011) and the incidence of overuse injury (Megan et al., 2003; Sabeti et al., 2010; Wanich et al., 2007). Just as modern cycles are designed discipline-specific for given demands (e.g. mountain-bike, road bike, and triathlon bike) it follows that cyclists should therefore adopt discipline-specific body positions for given cycling demands and objectives (Ashe et al., 2003; Bini et al., 2012; Heil et al., 1997).

Overuse injuries attributed to improper body position

Despite the history and popularity of cycling, the epidemiological study of overuse musculoskeletal injuries among cyclists remains lacking (Clarsen et al., 2010). This lack is probably because epidemiological studies are difficult to compare due to methodology and the diverse demographic of cyclists studied (Silberman, 2012). Nevertheless, overuse injuries have been reported amongst a wide range of cycling disciplines (e.g. mountain-bikers) (Sabeti et al., 2010), road cyclists (Callaghan, 2005) and triathletes (McHardy et al., 2006); all ages and abilities, from recreational to professional cyclists, are affected (Wanich et al., 2007). Overuse injury is caused by repetitive mechanical overload of the bone, joint and soft tissue with inadequate recovery time (Taimela et al., 1990). The aetiology of cycling-related overuse injury is often multifactorial and diverse (Asplund and St Pierre, 2004; Dinsdale and Dinsdale, 2011). An improper body position (cycle set-up) is well documented as a cause of overuse injury (Callaghan, 2005; Clarsen et al., 2010; Marsden, 2010). While not exhaustive, factors include pedal systems (Wheeler et al., 1995), issues at the shoe/pedal interface (Asplund and St Pierre, 2004; Berry et al., 2012; Dinsdale, 2012a), saddle height (Peveler and Green, 2011), saddle tilt (Sommer et al., 2010), saddle design and trunk angle (Carpes et al., 2009), handlebar position (Partin et al., 2012), and anthropometric differences (Dinsdale, 2012b). Furthermore, musculoskeletal deficits can prevent the rider from acquiring a discipline-specific body position, or compromise his ability to do so (Dinsdale and Dinsdale, 2011).

Common cycling related overuse injuries

The most commonly reported anatomical regions of overuse injuries are the knee, lower back, foot, hand, and perineum (Schwellnus and Derman, 2005). Arguably, the knee is the most common site (O'Brien, 1991; Silberman, 2012), affecting an estimated 40-60% of all regular cyclists (Wanich et al., 2007). Clarsen et al. (2010) found that symptoms of anterior knee pain were common among professional cyclists, with an annual prevalence of 36%. These findings were consistent with previous epidemiological investigations of professional cyclists (Barrios et al., 1997) and recreational cyclists (Wilber et al., 1995). More specifically, the most commonly reported knee problem is patellofemoral joint pain, often labelled 'cyclists knee' (Sanner and O'Halloran, 2000). Predisposing factors include improper saddle height i.e. too low (Bini et al., 2011; Sabeti et al., 2010), saddle position that's too far forward (Asplund and St Pierre, 2004) and issues at the shoe/pedal interface (Asplund and St Pierre, 2004; Schwellnus and Derman, 2005) which include pronation and improper foot position (Berry et al., 2012). Iliotibial Band Syndrome is arguably the second most frequently reported knee problem (Callaghan, 2005). Most commonly reported predisposing factors include improper saddle height i.e. too high (Burke and Pruitt, 2003; Farrell et al., 2003), anatomic abnormalities, excessive foot pronation and improper cleat position (Asplund and St Pierre, 2004).

Chronic lower back pain (LBP) appears to be common in cycling, yet few scientific studies exist on the epidemiology and risk factors associated with LBP in cyclists (Marsden, 2010). The prevalence of LBP in cyclists has been reported as 10-60% (Marsden, 2010), up to 50% in recreational cyclists (Schulz and Gordon, 2010) and 22% in professional cyclists (Clarsen et al., 2010). Factors for the development of LBP have been linked with increased training loads (Schulz and Gordon, 2010), improper cycle set-up i.e. low handlebars provoking increased trunk flexion (Schulz and Gordon, 2010), and improper saddle level/tilt (Bressel and Larson, 2003; Marsden, 2010).

The most commonly reported overuse hand injury is chronic ulnar nerve compression, a condition termed 'Cyclist's Palsy' (Slane et al., 2011); the median nerve is less commonly involved (Schwellnus and Derman, 2005). Ulnar and median nerve compression has been reported amongst both experienced and inexperienced cyclists (Kennedy, 2008; Slane et al., 2011), in long distance cyclists (Akuthota et al., 2005) and mountain bikers (Patterson et al., 2003; Sabeti et al., 2010). Symptoms of ulna nerve compression typically present as numbness and/or paresthesia in the fourth and fifth finger as

a result of sustained pressure on the hypothenar eminence (Kennedy, 2008). It would appear the simple solution is to reduce pressure on the hypothenar eminence. Often, this can be achieved by simple adjustments to body position, designed to unload hand pressure on the handlebars (Patterson et al., 2003; Schwellnus and Derman, 2005), or by regular changes in hand position (Slane et al., 2011), or by wearing padded gloves (Slane et al., 2011). A nose down saddle (forward tilt) tends to redistribute the body-weight, moving it forwards, as a result this can lead to increased pressure on the hands and hypothenar eminence. Likewise, hand pressures tend to increase when the handlebars are lower than the saddle (Patterson et al., 2003).

Complaints associated with increased perineum saddle pressures are common in male (Carpes et al., 2009; Sommer et al., 2010) and female cyclists (Partin et al., 2012; Sommer et al., 2010). A recent review which yielded 62 pertinent articles, reported complaints in 50-91% of cyclists (Leibovitch and Mor, 2005). The consensus of literature links the aforementioned complaints with prolonged saddle pressure (Bressel et al., 2010; Bressel and Larson, 2003; Partin et al., 2012), more specifically, excessive body weight and saddle design (Carpes et al., 2009; Schrader et al., 2008), saddle level/tilt (Bressel and Larson, 2003) and improper handlebar position (Carpes et al., 2009; Partin et al., 2012), most of which can be alleviated by proper body position facilitated by cycle set-up.

Marriage between man/woman and machine

Traditionally, cycle set-up has been performed by cycle mechanics from a mechanical perspective, often unaware of anthropometric differences, biomechanical peculiarities and/or musculoskeletal deficits prevalent in cyclists (Dinsdale and Dinsdale, 2011). Similarly, sports therapists often treat cyclists whilst unaware of cycle set-up and the relevance of body position. Common sense implies that effective management of a given problem relies on an accurate initial diagnosis. Increasingly, authors cite the growing need to consider both bicycle and cyclist as a single integrated unit (Callaghan, 2005; Sanner and O'Halloran, 2000); for example, 'a marriage between man and machine' (Pruitt, 2003). In support, Callaghan (2005) states, "to obtain a diagnosis for a cycling related problem a practitioner must evaluate faults in the bicycle as well as in the cyclist."

Effects and implications of body positions

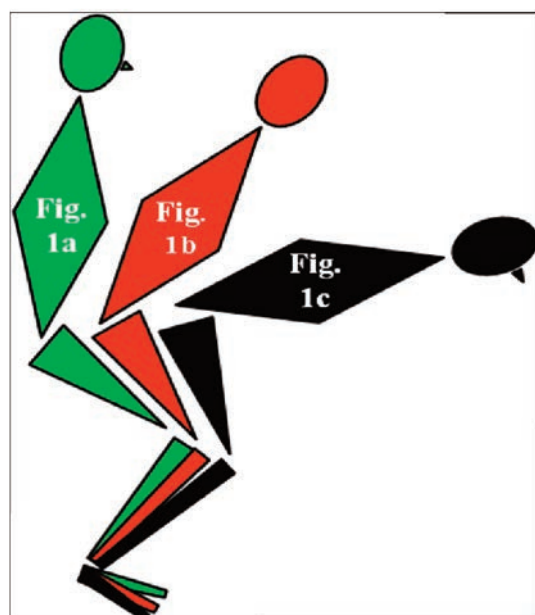
As recently stated by Bini et al. (2012), to date little attention has been given to body position on the bicycle for different cycling disciplines. The needs and objectives of recreational

and commuting cyclists are fundamentally different from those of competitive cyclists. Therefore, guidelines for cycle set-up and body position should reflect the needs and objectives for each chosen cycling discipline.

Classic body positions

Simplistically, most cycling disciplines can fit into one of three classic body positions (Pruitt, 2003) (Figure 1). Figure 1a represents the typical mountain-bike, recreational and commuting position. The rider adopts an upright trunk, almost vertical, with a slight backward saddle position. This position is not designed for aerodynamics, but for a comfortable relaxed ride to provide improved vision, stability, traction, and handling characteristics. Figure 1b is a compromise between the two extremes: it is representative of road race cyclists and sportive riders. This position provides a compromise between speed, handling and comfort. Figure 1c is the classic road time-trialist and triathlon position. This extreme aerodynamic position adopts a forward saddle position, with a highly flexed trunk, designed to minimise frontal area and aerodynamic drag – in the quest for speed.

Figure 1: The 3 classic body positions



Saddle height

The effect of saddle height on performance and injury prevention is arguably the most important and fundamental adjustment of cycle set-up and body position (Bini et al., 2011; Peveler, 2008; Peveler and Green, 2011). The reported

benefits of optimum saddle height include optimum muscle length for optimal power output (Peveler, 2008) and alleviation of compressive pressures across the patellofemoral joint (Wanich et al., 2007). For years there have been many unsubstantiated theories and multiple methods of determining optimal saddle height. Arguably, the two most common methods are Hamley and Thomas (1967) using 109% inseam leg length and Holmes et al (1994) who recommend a 25-30° knee angle flexed. Recent studies have established that saddle height based on inseam leg length is problematic as they tend to yield highly variable knee angles (Peveler et al., 2005a; Peveler et al., 2007), possibly due to anthropometric differences i.e. femur, tibia, foot differences (Bini et al., 2011), or perhaps mechanical differences i.e. variation in pedals, cleats, shoes and saddles (Dinsdale, 2012b). Consensus of recent studies universally recommends an optimum saddle height for trained and untrained cyclists of 25-35° knee angle set by goniometer, for anaerobic power output (Peveler et al., 2007; Peveler and Green, 2011), aerobic power output and cycling economy (Peveler, 2008; Peveler and Green, 2011). More specifically, Peveler (2008) and Peveler and Green (2011) found VO₂ was significantly lower at a saddle height of 25° knee angle compared with 35° knee angle. In summary, a saddle height set by goniometer (Figure 2) to a knee flexion angle 25-35° is desirable for reducing knee injuries and improving performance in trained and untrained cyclists. However, recreational cyclists, commuters, some mountain-bikers and long distance road cyclists that prefer a more relaxed and comfortable ride may opt for 30-35°. Conversely, competitive cyclists in search of optimum power output and

Figure 2: Setting saddle height



lower oxygen uptake when racing over relative short distances are more likely to opt for 25-30° (Figure 3).

Figure 3: Optimum saddle height



Saddle tilt

Generally, the conventional saddle (with nose) should be set horizontally 'level', or with a slight tilt ($\pm 3^\circ$), using a spirit level (Figure 4) (Burke and Pruitt, 2003). Women often prefer the front to be angled slightly downwards to reduce pressure on the perineal area (Partin et al., 2012) and in some cases of LBP (Bressel and Larson, 2003). Cyclists adopting the classic aero position, with a highly flexed trunk, often prefer a more drastic forward tilt ($\leq 10^\circ$), or prefer to use a 'no-nose' saddle (Dinsdale and Dinsdale, 2011). Cyclists that adopt an upright



Figure 4: Saddle tilt

trunk position, typically mountain-bike and recreational cyclists often prefer a level saddle or slightly tilted backwards (Burke and Pruitt, 2003). This position can also help alleviate pressure on the ulnar nerve by redistributing the body weight (Schwellnus and Derman, 2005).

Aero position

In cycling competitions in which drafting is not allowed (i.e. time trials and most triathlons), cyclists adopt an aero position (Figure 5) to reduce drag coefficient (Peveler et al., 2005b). Changing body position to an aero position reduces frontal projected area, and thus increases cycling speed (Bini et al., 2012). When racing at speeds of ≥ 40 kph, wind resistance (drag) accounts for 85-90% of the total energy cost (Figure 6) (Gnehm et al., 1997). The total composite of aerodynamic drag constitutes about 25-35% cycle, and about 65-75% rider (Peveler et al., 2005b). Kyle (1986) measured a 20% decrease in air drag when the sitting position was changed from upright and straight arms to hands on drops. Furthermore, Capelli et al. (1993) found another 15% decrease from hands on drops to full crouched aero-position. Therefore, crucial to performance, using the data cited above, approximately 35% reduction in drag can be expected when changing from upright into the aero-position.

However, riding in a forward aero position where the trunk is highly flexed does possess consequences (Dinsdale, 2012b). The increased lumbar flexion places increased stress on inter-

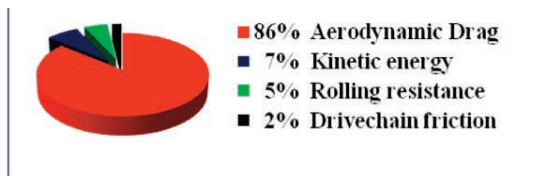
Figure 5. The ideal aero position

Extreme forward saddle position, horizontal back and highly flexed truck, designed to minimise frontal area and aero drag, thus maximising speed.

Image of Matt Bottrill multiple National TT champion.



Figure 6. Breakdown of total forces the cyclist must overcome. Aerodynamic drag represents the 'significant' component. Adapted from: (Kyle, 1986; Gnehm et al., 1997)



vertebral discs and demands high levels of spinal flexibility, combined with adequate pelvic and core stability (McHardy et al., 2006; Schulz and Gordon, 2010). Moreover, this extreme forward position can increase pressure on the anterior perineum (Carpes et al., 2009; Sommer et al., 2010). Recommendations to reduce stresses within the anterior perineum and thus improve comfort include adjusting saddle tilt downwards (i.e., nose down) (Carpes et al., 2009; Spears et al., 2003), using a saddle width sufficiently wide to support the ischial tuberosities (Sommer et al., 2010), using a 'holed' saddle for men (Bressel and Larson, 2003; Potter et al., 2008) but found none effective for women (Potter et al., 2008) or using a 'no-nose' saddle (Bressel and Larson, 2003; Schrader et al., 2008).

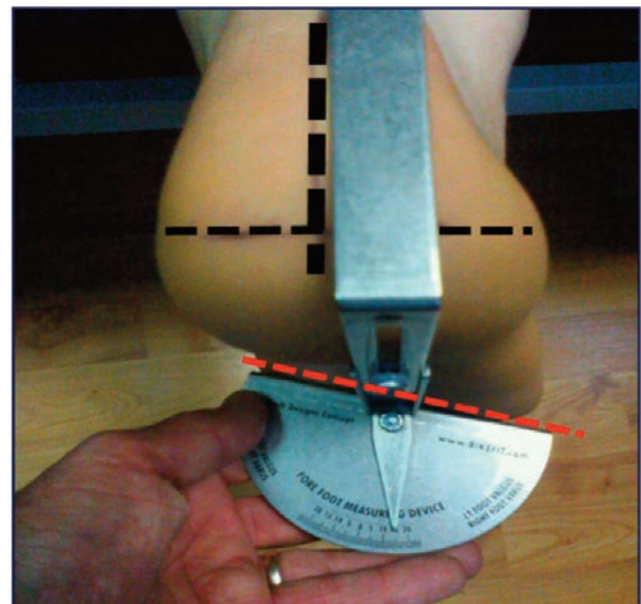
Although studies suggest riding in an aero position compared with an upright position may be associated with an increased metabolic cost (Ashe et al., 2003; Gnehm et al., 1997), it has been purported that regular training in an aero position may negate some, if not all, of the increased metabolic cost. Hence, Peveler et al. (2005b) examined the effects of training in an aero position and found that if cyclists and triathletes train in the position in which they race they could avoid potential metabolic costs. In conclusion, Peveler reported that it may be possible for time trialists and triathletes to improve their time-trial performance by training in an aero position.

Shoe/pedal interface

Although often neglected, undervalued, or misunderstood by cyclists and bikefitters alike (Dinsdale, 2012a), the shoe/pedal interface can influence power output (Dinsdale and Williams, 2010) and predispose the cyclist to overuse knee injuries (Asplund and St Pierre, 2004). The make-up and function of the shoe/pedal interface dictate how effectively pedal forces are transmitted down the cranks; and how deleterious forces may be transmitted up the kinetic chain to adversely impact on vulnerable musculoskeletal structures, principally the knee (Dinsdale, 2012b). During one hour of cycling, a cyclist can average 5,000 pedal revolutions; the smallest amount of misalignment whether anatomic, biome-

chanical or mechanically related, can lead to injury and reduced performance (Asplund and St Pierre, 2004). Using a repeated-measures design, Dinsdale and Williams (2010) examined the effect of forefoot varus wedges on cycling performance in untrained cyclists presenting with forefoot misalignment (Figure 7). Although not statistically significant $P > .05$, they found an increase of 3.8% in mean anaerobic power output in favour of using varus wedges compared to not using wedges. Moreover, a Pearson's product-moment correlation coefficient ($r = .957$, $n = 6$, $P = .003$) demonstrated that varus wedges offer greater performance benefits to riders with greater forefoot varus misalignment. Generally, these findings are consistent with those of similar investigations using conventional foot orthoses (Anderson and Sockler, 1990) and Biopedal varus adjusted foot positions (Millislagle et al., 2004; Moran and McGlinn, 1995).

Figure 7. Measuring forefoot-to-hindfoot alignment. High level of forefoot misalignment commonly found in cyclists, measured by goniometer.



It has been postulated that improper foot positioning may contribute to knee injury in cyclists. To investigate this, Berry et al. (2012) performed a study to assess the effect of changing the foot position at the shoe/pedal interface on quadriceps muscle activity, knee angle, and knee displacement in cyclists. The authors found that by altering the foot position to either 10° inversion or 10° eversion, knee angle and knee displacement can be significantly influenced. Berry et al. concluded by suggesting that clinically, subjects with a foot-type classified as pronating may benefit from some

degree of forefoot inversion wedging. The two recent studies, Dinsdale and Williams (2010) and Berry et al. (2012) highlight the potential problems, and thus the opportunities, that the shoe/pedal interface has to offer.

Summary and Conclusion

Body position unequivocally affects comfort, performance and overuse injury – over the full range of cycling disciplines and abilities. For optimum outcome, cycle set-up and subsequent body position should reflect discipline-specific objectives. Sports therapists and bike-fitters alike should approach man-and-machine as a single integrated unit. Alternatively, sports therapists and bike-fitters should consider working together as a multi-disciplinary team.

Acknowledgments

The authors would like to thank Matt Bottrill (National Champion cyclist) and Brian Hall (photographer) for their consent in supply and use of images.

References

- Akuthota, V., Plastaras, C., Lindberg, K., Tobey, J., Press, J. and Garvan, C. (2005) The effect of long-distance bicycling on ulnar and median nerves: An electrophysiologic evaluation of cyclist palsy. *American Journal of Sports Medicine*. 33 (8): 1224-1230
- Anderson, J. and Sockler, J. (1990) Effects of orthoses on selected physiologic parameters in cycling. *Sports Medicine*. 80: 161-166
- Ashe, M., Scroop, G., Frisken, P., Amery, C., Wilkins, M. and Khan, K. (2003) Body position affects performance in untrained cyclists. *British Journal of Sports Medicine*. 37: 441-444
- Asplund, M.D. and St Pierre, P. (2004) Knee pain and bicycling. *The Physician and Sports Medicine*. 32: 23-30
- Barrios, C., Sala, D., Terrados, N. and Valenti, J. (1997) Traumatic and overuse injuries in elite professional cyclists. *Sports Exercise and Injury*. 3: 176-179.
- Berry, A., Phillips, N. and V. Sparkes, V. (2012) Effect of inversion and eversion of the foot at the shoe-pedal interface on quadriceps muscle activity, knee angle and knee displacement in cycling. *Journal of Bone and Joint Surgery*. British Volume 94.SUPP XXXVI: 61-61
- Bini, R., Hume, P. and Croft, J. (2011) Effects of bicycle saddle height on knee injury risk and cycling performance. *Sports Medicine*. 41 (6): 463-476
- Bini, R., Hume, P. and Croft, J. (2012) Cyclists and triathletes have different body positions on the bicycle. *European Journal of Sports Science*. DOI: 10.1080/17461391.2011.654269 [Accessed 22.11.2013]
- Bressel, E., Nash, D. and Dolny, D. (2010) Association between attributes of a cyclist and bicycle seat pressure. *Journal of Sexual Medicine*. 7: 3424-3433
- Bressel, E. and Larson, B. (2003) Bicycle seat designs and their effect on pelvic angle, trunk angle and comfort. *Journal of Medicine and Science in Sports and Medicine*. 35 (2): 327-332
- Burke, E. and Pruitt, A. (2003) Body positioning for cycling. In Burke, E. (Ed.) *High-tech Cycling*. Human Kinetics. USA
- Callaghan, M.J. (2005) Lower body problems and injury in cycling. *Journal of Bodywork and Movement Therapies*. 9: 226-236
- Capelli, G., Rosa, F., Butti, G., Ferretti, A., Veicsteinas, A. and di Prampero, P. (1993) Energy cost and efficiency of riding aerodynamic bicycles. *European Journal of Applied Physiology*. 67: 144-149
- Carpes, F., Dagnese, F., Kleinpaul, J., de Assis, M. and Bolli, M. (2009) Bicycle saddle pressure: Effects of trunk position and saddle design on healthy subjects. *Urologi Internationalis*. 82: 8-11
- Clarsen, B., Krosshaug, T. and Bahr, R. (2010) Overuse Injuries in Professional Road Cyclists. *American Journal of Sports Medicine*. 38 (12): 2494-2501
- Colzato, L., Szapora Ozturk, A., Pannekoek, J.N. and Hommel, B. (2013) The impact of physical exercise on convergent and divergent thinking. *Frontiers in Human Neuroscience*. 7:824. DOI: 10.3389/fnhum.2013.00824 [Accessed December 2013]
- Dinsdale, N.J. and Dinsdale, N.J. (Miss) (2011) The benefits of anatomical and biomechanical screening of competitive cyclists. *SportEx Dynamics*. 28: 17-20
- Dinsdale, N.J. (2012a) Musculoskeletal screening of competitive cyclists: The Association of British Cycling Coaches

Developing and Sharing Best Practice. *The Journal of Cycle Coaching*. 4: 20-21

Dinsdale, N.J. (2012b) *Musculoskeletal Screening of Competitive Cyclists prior to Cycle set-up*. Conference presentation (unpublished). 40th Annual Pedal Power Conference, Association British Cycling Coaches, Coventry, UK

Dinsdale, N.J. and Williams, A.G. (2010) Can forefoot varus wedges enhance anaerobic cycling performance in untrained males with forefoot varus? *Journal of Sport Scientific and Practical Aspects*. 7 (2): 5-10

Farrell, C., Reisinger, K. and Tillman, M. (2003) Force and repetition in cycling: Possible implications for iliotibial band friction syndrome. *The Knee*. 10: 103-109

Gnehm, P., Reichenbach, S., Altpeter, E., Widmer, H. and Hoppe, H. (1997) Influence of different racing positions on metabolic cost in elite cyclists. *Medicine and Science in Sports and Exercise*. 9 (6): 818-823

Hamley, E. and Thomas, V. (1967) Physiological and postural factors in calibration of the bicycle Ergometer. *Journal of Physiology*. 8 (2): 119-121

Heil, D., Derrick, T. and Whittlesey, S. (1997) The relationship between preferred and optimal positioning during submaximal cycle ergometry. *European Journal of Applied Physiology and Occupational Physiology*. 75 (2): 160-165

Herndon, J.H., Rorabeck, C.H., Spengler, D.M., Hanley, E.D., Weinstein, S.L., Gelberman, R.H., Stern, P.J., Primis, L. and Simon, M.A. (2010) Ergometer cycling after hip or knee replacement surgery: A randomized controlled trial. *Journal of Bone and Joint Surgery*. 92 (4): 814-822

Hoevenaer, M., Wendel-Vos, W., Spijkerman, A., Kromhout, D. and Verschuren, W. (2011) Cycling and sports, but not walking, are associated with 10-year cardiovascular disease incidence: The MORGEN Study. *European Journal of Preventive Cardiology*. 18: 41-47

Holmes, J., Pruitt, A. and Whalen, N. (1994) Lower extremity overuse in bicycling. *Clinical Sports Medicine*. 13 (1): 187-205

Kennedy, J. (2008) Neurologic injuries in cycling and bike riding. *Neurological Clinics*. 26 (1): 271-279

Kyle, C. (1986) Mechanical factors affecting the speed of a cycle. In Burke, E.R. (Ed) *Science of Cycling*. Human Kinetics. Champaign, IL, USA

Leibovitch, I. and Mor, Y. (2005) The vicious cycling: Bicycling related urogenital disorders. *European Urology*. 47 (3): 277-286

Marsden, M. (2010) Lower back pain in cyclists: A review of epidemiology, pathomechanics and risk factors: Review article. *International SportsMed Journal*. 11 (1): 216-225

McHardy, A., Pollard H. and Fernandez, M. (2006) Triathlon injuries: A review of the literature and discussion of potential injury mechanisms. *Clinical Chiropractic*. 9: 129-138

Megan, J., Patterson, M., Jaggars, M. and Boyer, M. (2003) Ulna and median nerve palsy in long-distance cyclists: A prospective study. *The American Journal of Sports Medicine*. 31 (4): 585-589

Millsagle, D., Rubbelke, S., Mullin, T., Keener, J. and Swetkovich, R. (2004) Effects of foot-pedal positions by inexperienced cyclists at the highest aerobic level. *Perceptual and Motor Skills*. 98: 1074-1080

Moran, G. and McGlinn, G. (1995) The effect of variations in the foot pedal interface on the efficiency of cycling as measured by aerobic energy cost and anaerobic power. *Biomechanics in Sport*. 12: 105-109

O'Brien, T. (1991) Lower extremity cycling biomechanics: A review and theoretical discussion. *Journal of American Podiatric Medical Association*. 81 (11): 585-592

Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B. and Kohlberger, T. (2011) Health benefits of cycling: A systematic review. *Scandinavian Journal of Medicine and Science in Sport*. 21 (4): 496-509

Partin, S., Connell, K., Schrader, S., LaCombe, J., Lowe, B., Sweeney, A., Reutman, S., Wang, A., Toennis, C., Melman, A., Mikhail, M. and Guess, M. (2012) The bar sinister: Does handlebar level damage the pelvic floor in female cyclists? *Journal of Sexual Medicine*. 9: 1367-1373

Patterson, J., Jaggars, M. and Boyer, M. (2003) Ulnar and median nerve palsy in long-distance cyclists: A prospective study. *American Journal of Sports Medicine*. 31 (4): 585-589

- Peck, C. (2012) *Surge in cycle use in 2011* [on-line] Available from; <http://www.ctc.org.uk/surge-in-cycle-use-in-2011> [Accessed November 2013]
- Peveler, W. and Green, J. (2011) Effects of saddle height on economy and anaerobic power in well trained cyclists. *Journal of Strength and Conditioning Research*. 25 (3): 629-633
- Peveler, W. (2008) Effects of saddle height on economy in cycling. *The Journal of Strength and Conditioning Research*. 22 (4): 1355-1359
- Peveler, W., Pounders, J. and Bishop, P. (2007) Effects of saddle height on anaerobic power production in cycling. *Journal of Strength and Conditioning Research*. 21 (4): 1023-1027
- Peveler, W., Bishop, P., Richardson, M. and Smith, J. (2005a) Comparing methods for setting saddle height in trained cyclist. *Journal Exercise Physiology online*. 8 (1): 51-55 [on-line] Available from <http://www.asep.org/files/PevelerSaddle.pdf> [Accessed December 2013]
- Peveler, W., Bishop, P., Smith, J. and Richardson, M. (2005b) Effects of training in an aero position on metabolic economy. *Journal Exercise Physiology online*. 8 (1): 44-50 [on-line] Available from <http://www.asep.org/files/Peveler.pdf> [Accessed December 2013]
- Potter, J., Sauer, J., Weisshaar, C., Thelen, D. and Ploeg, H. (2008) Gender differences in bicycle saddle pressure distribution during seated cycling. *Medicine and Science in Sports and Exercise*. 40 (6): 1126-1134
- Pruitt, A. (2003) Body positioning for cycling. In Burke, E. (Ed.) *High-tech cycling*. Human Kinetics. USA
- Sabeti, M., Serek, M., Geisler, M., Schmidt, M., Pachtner, T., Ochsner, A., Funovics, P. and Graf, A. (2010) Overuse Injuries Correlated to the Mountain Bike's Adjustment: A Prospective Field Study. *The Open Sports Sciences Journal*. 3: 1-6
- Sanner, W.H. and O'Halloran, W.D. (2000) The biomechanics, etiology, and treatment of cycling injuries. *Journal of the American Podiatric Medical Association*. 90 (7): 354-376
- Schrader, S., Breitenstein, M. and Lowe, B. (2008) *Cutting off the nose to save the penis*. *Journal of Sexual Medicine*. 5 (8): 1932-1940
- Schulz, S. and Gordon, S. (2010) Recreational cyclists: The relationship between low back pain and training characteristics. *International Journal of Exercise Science*. 3 (3): 79-85
- Schwellnus, M.P. and Derman, E.W. (2005) Common injuries in cycling: Prevention, diagnosis and management. *South African Family Practice*. 47 (7): 14-19
- Silberman, M.R. (2012) Bicycling injuries. *Current Sports Medicine Reports*. 12 (5): 337-345
- Slane, J., Timmerman, M., Ploeg, H. and Thelen, D. (2011) The influence of glove and hand position on pressure over the ulnar nerve during cycling. *Clinical Biomechanics*. 26 (6): 642-648
- Sommer, F., Goldstein, I. and Korda, J. (2010) Bicycle riding and erectile dysfunction: A review. *The Journal of Sexual Medicine*. 7 (7): 2346-2358
- Spears, I., Cummins, N., Brenchley, Z., Donohue, C., Turnbull, C., Burton, S. and Macho, G. (2003) The effect of saddle design on stresses in the perineum during cycling. *Medicine and Science in Sports and Exercise*. 35 (9): 1620-1625
- Taimela, S., Kujala, U.M. and Osterman, K. (1990) Intrinsic risk factors and athletic injuries. *Sports Medicine*. 9 (4): 205-215
- Wanich, T., Hodgkins, C., Columbier, J.A., Muraski, E. and Kennedy, J.G. (2007) Cycling injuries of the lower extremity. *Journal of the American Academy of Orthopaedic Surgeons*. 15: 748-756
- Wheeler, J.B., Gregor, R.J. and Broker, J.P. (1995) The effect of clipless float design on shoe-pedal interface kinetics and overuse knee injuries during cycling. *Journal of Applied Biomechanics*. 11: 119-141
- Wilber, C., Holland, G., Madison, R. and Loy, S. (1995) An epidemiological analysis of overuse injuries among recreational cyclists. *International Journal of Sports Medicine*. 16 (3): 201-206.

Reviews and Invited Commentary

Learning and Teaching Strategies for Sports Therapy: Active learning (problem-based and team-based learning)

Mark Godwin,
School of Sport and Creative Services, University College Birmingham

Sports therapy is a relatively new discipline in the field of healthcare. Within the UK, there are 30 higher educational institutes which offer both undergraduate and postgraduate courses (<http://search.ucas.com/>). Sports therapy is a branch of healthcare that utilises areas of sports medicine and sport and exercise sciences (<http://www.society-of-sports-therapists.org/whatis.htm>). Students study in both clinical and non-clinical settings covering a wide range of topics including anatomy and physiology; biomechanics; sports massage (soft tissue therapy); clinical practice; strength and conditioning; rehabilitation. Currently, there are no peer-reviewed articles which have specifically looked at learning and teaching strategies in this field. This paper explores methods of learning and teaching from disciplines of medicine, sports medicine and sports science which may be implemented into sports therapy curriculum design.

Kjellgreen et al. (2008) highlighted that the quality of students learning, development of competency and their adjustment to academia is affected by the manner at which they are introduced to their studies. Wingate (2007) described numerous factors which make adjustment to university life difficult; lack of preparation for and an understanding of the type of learning required have been demonstrated as the two most foremost factors. Furthermore Bovill et al. (2011) explained that success and progression of students is linked to their early experiences. They suggest a framework to effectively engage and empower first year students through curriculum design by deciding the curricula design process, defining programme aims and principles and defining key elements of programme content and structure. Crosling et al. (2009) discussed the growing concern for student retention and success in their studies. In addition they considered the context of widening participation for under-represented groups, increasing student diversity and educational quality assurance and accountability processes. Bovill et al. (2011) recommend that further research is required to evaluate the impact of these areas across the curriculum and to exercise contextual awareness of the country that they refer to.

Learning to learn

With a lack of understanding of the type of learning required, supporting students during the transition to higher education may be an initial strategy to facilitate a culture of learning. Learning to learn has been suggested as a method to assist students during their initial period of higher educa-

tion. However, learning to learn at university is a complex process with many universities persisting with outdated models of support which fail to recognise a fundamental change in the beliefs of students (Wingate, 2007). Cornford (2002) highlighted that society is in an information era or a knowledge society. The continuous changes in technology and the volumes of information generated make acquiring this knowledge more difficult. The ability to cope with this increased volume of information by processing information more effectively is required (Cornford, 2002). Modern day universities recruit students from diverse backgrounds and subsequently they are heterogeneous in their prior educational experiences (Kjellgren et al., 2008). Cornford (2002) showed that learning to learn skills are foundation elements and that without the establishment of such skills, learning may not occur. In addition, without these skills, more effort is required to learn and the effectiveness may be reduced unless individuals make use of the most effective learning skills (Cornford, 2002). Schutz et al. (2011) reported that in order to improve the learning experiences of students it is important to understand the relationship between learning and study strategies and academic performance. This may help to identify barriers to learning and interventions could be created to enhance the learning experiences of students (Schutz et al., 2011).

Active learning

Handelsman et al. (2004) suggested that science education should be founded on scientific teaching and is approached with the same rigour as science itself. This scientific teaching should involve active learning strategies which are required to engage students in the process of science and the use of teaching methods that have been systematically tested to reach diverse students. The National Science Education Standards (USA) described active learning as "something that students do, not something that is done to them" (Anderson, 2002). Stewart et al. (2011) surveyed 2,013 individuals representing 120 colleges and schools of pharmacy recognised by the American Association of Colleges of Pharmacy for the use of active learning (Table 1). Of the 1,179 responses, 87% used active learning techniques in their classroom activities.

Ernst and Colthorpe (2007) investigated the effects of interactive lecturing during a physiology course. Interestingly, the cohorts of students came from two groups: speech pathology and occupational therapy students and physiotherapy

Table 1. Active learning strategies used in US pharmacy education (Stewart et al. , 2011).

Strategy	Brief description
Audience response system/ clickers	Use of remote control devices by students to anonymously respond to multiple-choice questions posed by the instructor; can be integrated into traditional lectures, often termed "active lecture"
Discussion-based learning, inc. deliberate discussion	Use of communication among learners (both synchronous and asynchronous) as a teaching modality; can be used with other strategies such as case studies
Interactive-spaced education	Use of repetition of content at spaced intervals combined with testing of that content; developed and used heavily within the context of medical education
Interactive learning	Use of web-based modules to deliver content and assess student understanding in an interactive format
Patient simulation	Use of human patient simulators in a laboratory environment to teach providers to respond to a variety of physiological emergencies and situations
POGIL/ discovery learning	Use of exercises specifically designed to lead teams of students through the stages of exploring data, developing concepts based on that data, and applying the concepts
PBL, inc. case based learning	Use of cases or problem sets meant to be explored in self-managed teams of students (with a facilitator); PBL sessions precede any discussion of content by instructor
Team-based learning	Use of small student groups to facilitate discussion, case study exploration, or other aspects of content; preparation required in advance and content integrated throughout the class by the facilitator (expert)
Traditional laboratory experiences	Use of traditional laboratory and benchtop experiences to provide hands-on learning experiences

POGIL - process-orientated guided inquiry learning; PBL - problem-based learning.

students. The physiotherapy subcohort was much more likely to have entered the programme with a strong science background compared to the other students. Ernst and Colthorpe (2007) reported that over a three year period, performance in summative examinations significantly increased across the respiratory physiology module for both subcohorts; whereas performance in the cardiovascular physiology module (control) did not significantly change over the three years. Furthermore, there was a greater increase for the speech pathology and occupational therapy group. Active learning maybe recommended for students from any educational background and could be particularly useful for students who enter higher education with limited science knowledge.

Problem-based and team-based learning

It has been reported that problem-based learning originated in Canada due to dissatisfaction of medical educational practices (Dochy et al., 2003). Boud and Feletti (1997) stated:

"Medical education, with its intensive pattern of basic science lectures followed by an equally exhaustive clinical teaching programme, was rapidly becoming an ineffective and inhumane way to prepare students, given the explosion in medical information and new technology and the rapidly changing demands of future practice."

At some institutions, sports therapy may be delivered in this traditional method and the effectiveness of this style of education could be questioned. The influx of a wide variety of evidence from sports medicine and sports science, new tech-

nological innovations and the changing demands of the profession make teaching of sports therapy challenging. Smith et al. (2005) described that the format of most introductory science courses at large research universities are similar; large lecture hall lectures and distinct taught laboratory sections. This traditional lecture and laboratory structure complicates changes to any programme delivery (Smith et al., 2005). It is unknown if universities who deliver sports therapy courses are using underpinning science lectures followed by exhaustive clinical teaching which may not reflect the changing demands of sports therapy practice.

Problem-based learning has been explained by numerous authors (Hmelo-Silver, 2004; Hmelo-Silver and Barrows, 2006; Kilroy, 2004; Savery, 2006). For the purpose of this article, the definition given by Hmelo-Silver (2004) will be used, that is "Problem-based learning is an instructional method in which students learn through facilitated problem solving." Savery (2006) described the characteristics of problem-based learning and reported that a viable solution to a defined problem was provided through empowering learners to conduct research, integrating theory and practice, and applying knowledge and skills. Furthermore, Savery (2006) showed that a tutor is required to guide the process and also debrief at the conclusion of the learning experience. The problem-based learning cycle begins with the tutor presenting the problem with minimal information and students asking more questions in order to obtain further information (Hmelo-Silver, 2004). Hmelo-Silver and Barrows (2006) described the role of the teacher to facilitate collaborative knowledge construction. Kilroy (2004) suggested that the facilitator does not use their knowledge to transmit facts, but to provide encouragement and guidance.

Srinivasan et al. (2007) compared problem-based learning to case-based learning and discussed advantages and disadvantages between them. The initial topic presented to students in the problem-based learning method is unknown and they would have no opportunity to conduct any preparation. However, in case-based learning the students will have the general content disclosed and will have been given the opportunity to undertake some preparation. One argument against the use of problem-based learning is that the process is time inefficient, frustrating for medical learners and may lead to erroneous conclusions (Srinivasan et al., 2007). A counter argument for this suggests that case-based learning stifles curiosity and may also encourage a faculty to lecture instead of facilitating (Srinivasan et al., 2007).

Dolmans et al. (2005) based problem-based learning on four modern insights on learning: constructive, self-directed, col-

laborative and contextual. Knowledge networks of the students are constructed or reconstructed through the emphasis that learning is an active process (Dolmans et al., 2005). Martin et al. (2008) described how the traditional learning order is reversed in problem-based learning; whereby the problem is initially presented before the dissemination of relevant theory. Embedded in problem-based learning is constructivist theory as students are required to construct their own knowledge and work in collaborative groups through integrated learning (Joham and Clarke, 2012; Martin et al., 2008). This collaborative group development within problem-based learning is shown in Table 2. Team-based learning is an active learning strategy which is led by an instructor but remains student centred and devel-

Table 2. Group development in the problem-based learning cycle (Johan and Clarke, 2012).

PBL learning cycle	Stages of group development
Problem scenario	Forming
Identify facts	
Generate hypothesis	
Identify knowledge deficiencies	Storming and norming
Apply new knowledge	
Abstraction	Performing
Evaluation	Adjourning

ops cohesive learning groups by encouraging individual preparation (Koles et al., 2010). Classical team-based learning can be described by a three phase-sequence: preparation, readiness assurance and application (Inuwa et al., 2012). Similar to problem-based learning, team-based learning conforms to the constructivist theory of learning (Khogali, 2013). During this latter type of learning, students apply previously learnt concepts to relevant course learning objectives within a large classroom setting which are relevant to their future practice (Khogali, 2013). Letassy et al. (2008) reported that delivery time can be reduced by 40% without a detrimental effect on knowledge acquisition and an increase time spent on activities. Furthermore, they describe how team-based learning requires constant student preparation and attendance with the opportunity to learn from peers and within a team (Letassy et al., 2008). Tai et al. (2008) reported that a lack of preparation hinders group cohesiveness and students must demonstrate accountability as individuals and as a group. Vasan et al. (2008) highlighted some differences between problem-based learning and team-based-learning. They stated that problem-based learning is centred on prepared case studies where students identify learning issues. During team-based learning, facilitators are used to organise learning activities which assisted students to build baseline facts in order to formulate a framework of conceptual interpretation and understanding (Vasan et al., 2007).

Tan et al. (2011) studied the effects of team-based learning for the teaching of neurology to third year medical undergraduates using a modified cross over design. The outcome measures were knowledge as the primary outcome and self-reported student engagement as the secondary outcome. The team-based learning intervention consisted of three phases (Tan et al., 2011):

1. Phase 1 – Students read preparatory material independently outside of class.
2. Phase 2 – Knowledge and concepts from phase 1 were tested using an Individual Readiness Assurance Test (IRAT). Students were placed in pre-assigned groups, between 5-7 students and the IRAT was re-administered. Students were then randomly assigned to a group and completed a Group Readiness Assurance Test once the group reached a consensus about each answer.
3. Phase 3 – Students work on clinical problems as a group using the knowledge gained in phases 1 and 2.

Three closed book tests were used to assess knowledge consisting of 40 true or false questions covering 10 clinical scenarios. The team-based learning group showed a larger increase in the primary outcome (knowledge) compared to the passive learning group. The proportion of students getting $\geq 90\%$ of the questions correct was significantly higher in the team-based learning group. Furthermore, there was a greater effect size for the weaker students for both of the post tests. In addition to the knowledge measures, 81.6% of students reported a preference to team-based learning than conventional tutorials. This preference has also been shown by Beatty et al. (2009) who used team-based learning within the workshop portion of 3 of 6 pathophysiology and therapeutics courses as part of a doctor of pharmacy curricula. Beatty et al. (2009) reported that 83% of students felt that team-based learning should continue; 75% said that it reinforced individual learning and more than 90% said that working in teams helped them gain a better understanding of course material. Tan et al. (2011) hypothesised that team-based learning encouraged self-directed learning and allowed the learners to reinforce and retain knowledge through peer discussion, self-reflection or further self-reading. In addition, the increase in performance of less academic students demonstrated that team-based learning may be used in subjects which are seen as difficult. Implementation of this type of learning may be included in group tutorials in order to foster good academic study skills. It is recommended that team-based learning should be considered for modules within sport therapy that do not achieve high grades or used for students that are less academic.

Koles et al. (2005) demonstrated that two active learning strategies in second year pathology curriculum were equally effective at the end of course examinations. Their crossover study measured the performance of 80 medical students following either a team-based learning or case-based group discussion. The results showed that there was no significant difference between the overall end of course examination results. However, it was reported that performance following team-based learning was significantly improved for students in the lowest academic quartile for 4 of the 8 modules ($P < 0.05$). These modules were immune, neoplastic, cardiovascular and parathyroid disease. Students in the highest academic quartile showed no significant difference across all eight modules. This increase in performance for students in the lowest academic quartile echoes the results shown by Tan et al. (2011). Therefore, the use of active learning strategies may be beneficial to students who are not as academically strong or those who have come from non-traditional routes to university such as mature students.

In addition to examination performance, Martin et al. (2008) showed that problem based learning strategies can also be used to increase learner autonomy. Students ($n = 25$) from a final year sports science degree programme studied a 12-week module using a problem-based approach. Measures were used to ascertain motivation, self-esteem and locus of control: the academic motivation scale (AMS-C 28; Vallerand et al., 1992); Rosenberg's self-esteem scale (Rosenberg, 1989) and the academic locus of control scale (Trice, 1985). A significant difference was shown for intrinsic motivation 'to know' subscale of the AMS-C 28. All other measures showed no significant difference although the authors did report a trend of an increase in internal motivation compared to external motivation. They suggested that the high extrinsic motivation scores may have been attributed to the timing of the study as the grades contributed to overall degree classification. Parmelee et al. (2009) analysed the changes in attitude of 180 medical students following the first and second year of medical school. Nineteen statements under the following five areas were questioned: (1) overall satisfaction with team experience; (2) team impact on quality of learning; (3) satisfaction with peer evaluation; (4) team impact on clinical reasoning ability; (5) professional development. The results showed that there were significant changes in attitudes in three of the areas (professional development, satisfaction with team experience and satisfaction with peer evaluation) and that students reported more positive attitudes during the first year (Parmelee et al., 2009). They concluded that students felt peer evaluation to be more meaningful in the first year despite reporting that students had previously struggled with it. Furthermore, Parmelee et al.

(2009) recommended that medical educators look at how to motivate students to work harder or more collaboratively in order to increase the value of peer evaluation.

Bethell and Morgan (2011) implemented problem-based learning into a module for undergraduate physical education students. Their aim was to engage students with focus groups and documented evidence as a means of analysing results. One of the areas identified as both a strength and weakness of problem-based learning was working as a group. Students reported that group work required them to develop depth in their reasoning, whilst tutors reported that dealing with conflict in a group was an emotional aspect of this type of learning (Bethell and Morgan, 2011). Demiris et al. (2010) reported that group work fostered the promotion of group work which was based upon the values of co-operative decision making and problem solving. Demiris et al. (2010) also described key elements of the group process. These included refining core elements such as the purpose and objectives of the group; the group structure and leadership, and expectations regarding the contributions of the members. Furthermore, Demiris et al. (2010) described how groups examined and monitored the process of how information would be shared through the negotiation and setting of regulations. Sports therapists have a role within a multidisciplinary team and the ability to work as a group may be seen as a desired outcome. It may therefore be recommended that problem-based learning could be used to assist in the development of team work to enhance the abilities of undergraduates and prepare them for the work place.

Negative aspects to group work have also been identified and consideration of these areas should be factored into curriculum design. Students mentioned the frustration of dealing with peers not turning up to meetings or undertaking research (Bethell and Morgan, 2011). These are issues that potentially face any group work and strategies to limit them should be explored before implementing problem-based learning. Gunn et al. (2012) also discovered issues involved with the use of problem-based learning for undergraduate physiotherapists. They reported variation between students with factors such as degree of maturity (50% of the learners studies were over 21 years), learning approach and motivation all contributing to engagement in this method of learning. In contrast, they found that students reported team integration and the ability to draw on the strengths of the group as a positive aspect of problem-based learning. Applin et al. (2011) compared the competencies of graduate nurses following either a problem-based learning ($n = 64$) or a non problem-based learning ($n = 57$) programme six months post graduation. The mean age was $27.36 \text{ years} \pm 7.32$ and these

were therefore considered mature students. There was no significant difference in the four outcome measures between the two groups (professionalism, knowledge, ethics and provision of service). Dissimilarly to the findings of Bethell and Morgan (2011), Applin et al. (2011) reported teamwork as one of four key areas that enabled them to meet entry to practice competencies. The nurses stated that in order to meet professional competencies, teamwork and an interdisciplinary perspective were essential. They further stated that group work enhanced communication skills, team building skills and the ability to collaborate with team members (Applin et al., 2011). Therefore, the maturity of students may have to be considered before team work can be implemented with sports therapists, but this may be difficult to measure.

Issues with problem-based and case-based learning

It is recommended that problem-based learning is used within sports therapy undergraduate programmes, but is implemented with caution. One area that may require consideration before problem-based learning is adopted is the workload involved for both students and staff. Ruiz-Gallardo et al. (2011) described student workload as one of the main elements in curriculum design and the time spent on each course and the whole undergraduate programme becomes essential in an educational context. They further recommend that the time assigned to a course may need readjusting if the efforts of students do not fit. Ross et al. (2007) highlighted issues with the implementation of problem-based learning, including: increased demands for teaching space, increase in personnel time and the lack of student recognition of the need for curricular change. Ross et al. (2007) reported that large classrooms found in academic institutions were not conducive to group discussions and that acceptable spaces had to be identified. This lack of specific space allowing for group work may present challenges when implementing both problem-based and team-based learning. It has been suggested that designing teaching cases was time consuming and may take between 20 and 80 hours to write a single case (Ross et al., 2007). This time may depend upon the complexity of the case and the expertise of the author (Ross et al., 2007). Smith et al. (2005) also reported that the incorporation of active learning was labour intensive. However, they employed a teaching team comprising of biology faculty, graduate teaching assistants, undergraduate teaching assistants, and education and information technology consultants. Kilroy (2004) highlighted advantages and disadvantages of problem-based learning within medical undergraduate programmes and these should be considered before implementation or change of curriculum (Table 3).

Table 3. Advantages and disadvantages of problem-based learning (Kilroy, 2004).

Advantages	Disadvantages
Helps develop key learning skills	Time consuming to set up at the start
Helps develop key interpersonal skills:	Time consuming to facilitate
Communication	Must be prepared to "step back" from
Prioritisation of time/resources	"traditional" teaching role
Identification of key problems	Demands easy access to internet and good quality
Team working and task sharing	medical library
Potential to increase learner confidence	Not suites to all subject areas

Demiris et al. (2010) also reported several challenges with problem-based learning. They described that students may feel challenged by the self-directed study and unsure which information is relevant and useful (Demiris et al., 2010). In addition, facilitators, flexibility in the use of technological platforms, coordination of the curriculum and faculty training are all important considerations when considering the implementation of problem-based learning (Demiris et al., 2010). Wood (2003) highlighted that problem-based learning requires tutors to acquire skills in facilitation and management of group dynamics, this also included dysfunctional groups. Wood (2003) also reported that facilitators do not have to be subject specialists as long as they are trained, know the curriculum and have adequate tutor notes. Michael (2006) described how active learning does not just happen and that helping teachers to become familiar with new approaches and helping them gain experience is a critical issue for faculty development. In addition, Michael (2006) described how it is the teachers that create the learning environment that may make active learning more likely to occur. It is recommended that institutions thinking of implementing active learning strategies do so with an emphasis upon both student and staff education.

An area identified by Koles et al. (2005) following their team-based learning intervention was that the quality of such lectures depended more heavily upon the design and content than the ability of the faculty discussion leader. In contrast, comments by students from the case-based group discussion group showed that the perceived quality of lectures were due to the skills and enthusiasm of the faculty leader (Koles et al., 2005). Eshach and Bitterman (2003) provided other disadvantages of using problem-based learning within medical schools. They reported that there may be a temptation for practitioners to use old cases; practitioners may allow cases to bias them and novice practitioners may need reminding of the most appropriate set of cases when reasoning (Eshach and Bitterman, 2003).

Conclusion

It is recommended that active learning in the form of problem-based and team-based learning should be considered for inclusion into the curriculum for sports therapy students across a variety of modules. This may positively affect the transition into higher education for a wide range of students which has been identified as an area of concern. Performance in exams, internal motivation and teamwork has been shown to increase following the implementation of problem-based and case-based learning. Team-based learning should also be considered as a method to increase self-directed learning and to encourage self-reflection; two qualities that would benefit sports therapy students and graduates. Universities should not underestimate the potential workload involved in formulating active learning strategies and the impact that an increased workload can have on new students, especially those from less academically strong backgrounds. However, there is evidence that these students may benefit from these types of active learning strategies. Universities are therefore encouraged to consider inclusion when designing the curriculum for sports therapy programmes. Future studies are required to identify the impact of numerous active learning strategies across different modules at various stages of a degree programme. The performance of students from all backgrounds should be considered in order to take into account their prior educational experiences.

References

- Anderson, R.D. (2002) Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*. 13(1): 1-12
- Applin, H., Williams, B., Day, R. and Buro, K. (2011) A comparison of competencies between problem-based learning and non-problem-based graduate nurses. *Nurse Education Today*. 31: 129-134
- Beatty, S.J., Kelley, K.A., Metzger, A.H., Bellebaum, K.L. and James, J.W. (2009) Team-based learning in therapeutics workshop sessions. *American Journal of Pharmaceutical Education*. 73(6): 1-7
- Bethall, S. and Morgan, K. (2011) Problem-based and experiential learning: Engaging students in an undergraduate physical education module. *Journal of Hospitality, Leisure, Sport and Tourism Education*. 10(1): 128-134
- Boud, D. and Feletti, G. (1997) *The challenge of problem-based learning 2nd edition*. Kogan Page. London, UK
- Bovill, C., Bulley, C.J. and Morss, K. (2011) Engaging and empowering first-year students through curriculum design: Perspectives from the literature. *Teaching in Higher Education*. 16(2): 197-209
- Cornford, I.R. (2002) Learning-to-learn strategies as a basis for effective lifelong learning. *International Journal of Lifelong Education*. 21(4): 357-368
- Crosling, G., Heagney, M. and Thomas, L. (2009) Improving student retention in higher education. *Australian Universities' Review*. 51(2): 9-18.
- Demiris, G. and Zierler, B. (2010) Integrating problem-based learning in a nursing informatics curriculum. *Nurse Education Today*. 30: 175-179.
- Dochy, F., Segers, M., Van den Bossche, P. and Gijbels, D. (2003) Effects of problem-based learning: A meta-analysis. *Learning and Instruction*. 13: 533-568
- Dolmans, D.H.J.M., De Grave, W., Wolhagen, I.H.A.P. and van der Vleuten, C.P.M. (2005) Problem-based learning: Future challenges for educational practice and research. *Medical Education*. 39: 732-741
- Ernst, H. and Colthorpe, K. (2007) The efficacy of interactive lecturing for students with diverse science backgrounds. *Advances in Physiology Education*. 31: 41-44
- Eshach, H. and Bitterman, H. (2003) From case-based reasoning to problem-based learning. *Academic Medicine*. 78(5): 491-496
- Gunn, H., Hunter, H. and Haas, B. (2012) Problem based learning in physiotherapy education: A practice perspective. *Physiotherapy*. 98: 330-335
- Handlesman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M. and Wood, W.B. (2004) Scientific teaching. *Science*. 304(5670): 521-522
- Hmelo-Silver, C.E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*. 16(3): 235-266
- Hmelo-Silver, C.E. and Barrows, H.S. (2006) Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-based Learning*. 1(1): 21-39

- Inuwa, I.M., Al-Rawahy, M., Roychoudhry, S. and Taranikanti, V. (2012) Implementing a modified team-based learning strategy in the first phase of an outcome-based curriculum: Challenges and prospects. *Medical Teacher*. 34: e492-e499
- Joham, C. and Clarke, M. (2012) Teaching critical management skills: The role of problem-based learning. *Teaching in Higher Education*. 17(1): 75-88
- Khogali, S.E. (2013) Team-based learning: A practical guide: Guide supplement 65.1 Viewpoint 1. *Medical Teacher*. 35: 163-165
- Kilroy, D.A. (2004) Problem based learning. *Emergency Medical Journal*. 21: 411-413
- Kjellgren, K.I., Hendry, G., Hultberg, J., Plos, K., Rydmark, M., Tobin, G. and Säljö, R. (2008) Learning to learn and learning to teach: Introduction to studies in higher education. *Medical Teacher*. 30: e239-e245
- Koles, P., Nelson, S., Stolfi, A., Parmalee, D. and de Stephen, D. (2005) Active learning in a year 2 pathology curriculum. *Medical Education*. 39: 1045-1055
- Koles, P.G., Stolfi, A., Borgs, N.J., Nelson, S. and Parmelee, D.X. (2010) The impact of team-based learning on medical students' academic performance. *Academic Medicine*. 85(11): 1939-1745
- Letassy, N.A., Fugate, S.E., Medina, M.S., Stroup, J.S. and Britton, M.L. (2008) Instructional design and assessment: Using team-based learning in an endocrine module taught across two campuses. *American Journal of Pharmaceutical Education*. 72(5): 1-6
- Martin, L., West, J. and Bill, K. (2008) Incorporating problem-based learning strategies to develop learner autonomy and employability skills in sports science undergraduates. *Journal of Hospitality, Leisure, Sport and Tourism Education*. 7(1): 18-30
- Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiological Education*. 30: 159-167
- Parmelee, D.X., DeStephen, D. and Borges, N.J. (2009). Medical students' attitudes about team-based learning in a pre-clinical curriculum. *Medical Education Online*. 14(1): 1-7
- Rosenberg, M. (1989). *Society and the adolescent self image*. (Revised edition). Wesleyan University Press. USA
- Ross, L.A., Crabtree, B.L, Theilman, G.D., Ross, B.S., Cleary, J.D. and Byrd, H.J. (2007) Implementation and refinement of a problem-based learning model: A ten-year experience. *American Journal of Pharmaceutical Education*. 71(1): Article 17
- Ruiz-Gallardo, J., Castaño, S., Gómez-Alday, J.J. and Valdes, A. (2011) Assessing student workload in problem based learning: Relationships among teaching method, student workload and achievement. A case study in natural sciences. *Teaching and Teacher Education*. 27: 619-627
- Savery, J.R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*. 1(1): 9-20
- Schutz, C.M., Gallagher, M.L. and Tepe, R.E. (2011). Differences in learning and study strategies inventory scores between chiropractic students with lower and higher grade point averages. *Journal of Chiropractic Education*. 25(1): 5-10
- Smith, A.C., Stewart, R., Shields, P., Hayes-Klosteridis, J., Robinson, P. and Yuan, R. (2005) Introductory biology courses: A framework to support active learning in large enrolment introductory science courses. *Cell Biology Education*. 4: 143-156
- Srinivasan, M., Wilkes, M., Stevenson, F., Nguyen, T. and Slavin, S. (2007). Comparing problem-based learning with case-based learning: Effects of a major curricular shift at two institutions. *Academic Medicine*. 82(1): 74-82
- Stewart, M., Lido, C., Morgan, J., Solomon, L. and May, S. (2011) The impact of engagement with extracurricular activities on the student experience and graduate outcomes for widening participation populations. *Active Learning in Higher Education*. 12(3): 203-215
- Tai, B.C. and Koh, W.P. (2008) Does team learning motivate students' engagement in an evidence-based medicine course? *Annals Academy of Medicine*. 37(12): 1019-1023
- Tan, N.C.K., Kandiah, N., Chan, Y.H., Umapathi, T., Lee, S.H. and Tan, K. (2011) A controlled study of team-based learning for undergraduate clinical neurology education. *BMC Medical Education*. 11(91): 1-8
- Trice, A.D. (1985) An academic locus of control scale for college students. *Perceptual and Motor Skills*. 61(3): 1043-1046

Vallerand, R.J., Pelletier, L.G, Blais, M.R., Briere, N.M. and Senecal, C. (1992) The academic motivation scale: A measure of intrinsic, extrinsic, and amotivation in education. *Educational and Psychological Measurement*. 52: 1002-1017

Vasan, N.S., DeFouw, D.O. and Holland, B.K. (2008) Modified use of team-based learning for effective delivery of medical gross anatomy and embryology. *Anatomical Sciences Education*. 1: 3-9

Wingate, U. (2007) A framework for transition: Supporting 'Learning to Learn in Higher Education.' *Higher Education Quarterly*. 61(3): 391-405

Wood, D.F. (2003) ABC of learning and teaching in medicine: Problem based learning. *British Medical Journal*. 326: 328-330

JST Editorial Board 2015

Managing Editor

Mr Keith Ward BSc (Hons) MSST F HEA University College Birmingham

Editorial Board

Mr Aaron Caseley B.Ost MSc BOsC Leeds Metropolitan University

Mr Mark Godwin BSc MSc University College Birmingham

Mr Adam Hawkey BSc MSc FBIS Abertay University

Mr David Jenkins MSc

Mrs Jeannette Lewis BSc MSST University College Birmingham

Mr Paul Robertson BSc MSc BASES UKSCA University College Birmingham

Editorial Associates

Mr Rob Di Leva MSc

Mr Ian Lahart MSc University of Wolverhampton

Mr Greg Littler BSc MSc MCSP MSST University of Central Lancashire

Mr Richard Morgan Coventry University

Dr Andy Roberts PhD University College Birmingham

Publishing Designer

Ms Kirendeeep Jagdev BSc PG Dip ODE University College Birmingham