Editorial Welcome

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

Keith Ward,
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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 six 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.’ Sarah Catlow and colleagues from University of St. Mark and St. John (Marjon) in Plymouth have provided a useful addition to the gathering literature surrounding kinesiology tape and its efficacy. The authors have examined the relationships existing between the tape, anatomical fascial chains and resulting flexibility. 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/)
Guest Editorial

Reference measurements of elite judokas’ body composition

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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


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

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

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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 ± 3yrs.; height = 1.79 ± 0.09m; mass = 76 ± 15kg) 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 readings 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 skinfold 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 ± 3yrs.; height = 1.79 ± 0.09m; mass = 76 ± 15kg), 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).
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

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age/sex</td>
<td>33/21.8/45.0</td>
<td>25/27.0/41.0</td>
<td>22/22.0/47.2</td>
<td>25/27/46</td>
</tr>
<tr>
<td>Mass</td>
<td>75.05</td>
<td>75.7</td>
<td>58.55</td>
<td>67.36</td>
</tr>
<tr>
<td>Height</td>
<td>1.82</td>
<td>1.78</td>
<td>1.85</td>
<td>1.80</td>
</tr>
<tr>
<td>BMI</td>
<td>22.8</td>
<td>23.9</td>
<td>21.5</td>
<td>23.12</td>
</tr>
<tr>
<td>DEXA (BMI)</td>
<td>12.2</td>
<td>12.1</td>
<td>16.2</td>
<td>13.67</td>
</tr>
<tr>
<td>DEXA (MM kg)</td>
<td>62.16</td>
<td>62.48</td>
<td>65.74</td>
<td>63.38</td>
</tr>
<tr>
<td>DEXA (MM %)</td>
<td>23.75</td>
<td>20.05</td>
<td>18.35</td>
<td>20.20</td>
</tr>
<tr>
<td>DXA (BMI) (g/cm²)</td>
<td>1.28</td>
<td>1.92</td>
<td>1.23</td>
<td>1.37</td>
</tr>
<tr>
<td>DXA (T-score)</td>
<td>2</td>
<td>0.4</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>seca (BMI)</td>
<td>9</td>
<td>11</td>
<td>17</td>
<td>11.64</td>
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<tr>
<td>seca (MM kg)</td>
<td>66.9</td>
<td>60.8</td>
<td>60.8</td>
<td>63.38</td>
</tr>
<tr>
<td>seca (MM %)</td>
<td>88.4</td>
<td>78.5</td>
<td>75.5</td>
<td>82.74</td>
</tr>
<tr>
<td>Bodyfat (BMI)</td>
<td>7.2</td>
<td>11.1</td>
<td>19.7</td>
<td>11.7</td>
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<td>Bodyfat (MM kg)</td>
<td>69.6</td>
<td>66.7</td>
<td>66.6</td>
<td>66.7</td>
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<tr>
<td>Bodyfat (MM %)</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
</tr>
<tr>
<td>SFA (BMI)</td>
<td>6.2</td>
<td>6</td>
<td>10.3</td>
<td>7.1</td>
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<td>63.6</td>
<td>48.8</td>
<td>48.8</td>
<td>48.8</td>
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<tr>
<td>SFA (MM %)</td>
<td>58.1</td>
<td>66.5</td>
<td>71.4</td>
<td>66.5</td>
</tr>
</tbody>
</table>

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

**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).

**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 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 that 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


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 ± SD: 26 ± 10yrs; Mass mean ± SD: 62.6 ± 18kg; Shoe size mean ± SD: 5.3 ± 1 UK; foot width mean ± SD: 9 ± 0.5cm; foot length mean ± SD: 25 ± 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, 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, callosities 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 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’ preferred 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).

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

<table>
<thead>
<tr>
<th>Anatomical Point</th>
<th>Mean Pressure (N/cm²)</th>
<th>% Change on barefoot mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st metatarsal head</td>
<td>13.88 ± 1.36</td>
<td>14.97</td>
</tr>
<tr>
<td>2nd metatarsal head</td>
<td>15.54 ± 2.89</td>
<td>50.78</td>
</tr>
<tr>
<td>3rd metatarsal head</td>
<td>16.35 ± 17.10</td>
<td>76.95</td>
</tr>
<tr>
<td>4th metatarsal head</td>
<td>11.70 ± 15.42</td>
<td>14.26</td>
</tr>
<tr>
<td>5th metatarsal head</td>
<td>11.98 ± 16.51</td>
<td>34.19</td>
</tr>
<tr>
<td>Lateral heel</td>
<td>15.95 ± 18.41</td>
<td>79.08</td>
</tr>
<tr>
<td>Medial heel</td>
<td>15.92 ± 16.08</td>
<td>10.85</td>
</tr>
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Table 3. Mean and SD values at the main anatomical points of interest in flat heel condition

<table>
<thead>
<tr>
<th>Anatomical Point</th>
<th>Mean Pressure (N/cm²)</th>
<th>% Change on barefoot mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st metatarsal head</td>
<td>20.75 ±11.72</td>
<td>71.83</td>
</tr>
<tr>
<td>2nd metatarsal head</td>
<td>16.31 ± 15.63</td>
<td>58.17</td>
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<tr>
<td>3rd metatarsal head</td>
<td>18.95 ± 7.84</td>
<td>95.30</td>
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<td>4th metatarsal head</td>
<td>11.86 ± 13.86</td>
<td>15.86</td>
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<tr>
<td>5th metatarsal head</td>
<td>7.66 ± 2.76</td>
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<tr>
<td>Lateral heel</td>
<td>21.09 ± 16.54</td>
<td>6.95</td>
</tr>
<tr>
<td>Medial heel</td>
<td>21.30 ± 14.09</td>
<td>20.12</td>
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Table 4. Mean and SD values at the main anatomical points of interest in medium heel condition

<table>
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<th>Anatomical Point</th>
<th>Mean Pressure (N/cm²)</th>
<th>% Change on barefoot mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st metatarsal head</td>
<td>22.36 ±23.52</td>
<td>85.17</td>
</tr>
<tr>
<td>2nd metatarsal head</td>
<td>19.51 ±12.47</td>
<td>89.21</td>
</tr>
<tr>
<td>3rd metatarsal head</td>
<td>18.81 ±8.81</td>
<td>103.64</td>
</tr>
<tr>
<td>4th metatarsal head</td>
<td>14.02 ±6.50</td>
<td>36.90</td>
</tr>
<tr>
<td>5th metatarsal head</td>
<td>5.46 ±2.89</td>
<td>-38.81</td>
</tr>
<tr>
<td>Lateral heel</td>
<td>16.97 ±4.02</td>
<td>-13.90</td>
</tr>
<tr>
<td>Medial heel</td>
<td>11.94 ±0.03</td>
<td>0.45</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Anatomical Point</th>
<th>Mean Pressure (N/cm²)</th>
<th>% Change on barefoot mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st metatarsal head</td>
<td>12.08 ±1.89</td>
<td>N/A</td>
</tr>
<tr>
<td>2nd metatarsal head</td>
<td>10.31 ±1.77</td>
<td>N/A</td>
</tr>
<tr>
<td>3rd metatarsal head</td>
<td>9.24 ±1.15</td>
<td>N/A</td>
</tr>
<tr>
<td>4th metatarsal head</td>
<td>10.24 ±1.02</td>
<td>N/A</td>
</tr>
<tr>
<td>5th metatarsal head</td>
<td>8.93 ±1.73</td>
<td>N/A</td>
</tr>
<tr>
<td>Lateral heel</td>
<td>19.73 ±1.56</td>
<td>N/A</td>
</tr>
<tr>
<td>Medial heel</td>
<td>17.97 ±1.56</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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


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

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Abstract

Improvements in cycling performance have focused predominately 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 (Hoevenaar 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

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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.

**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...
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 (±3°), 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 (≤10°), or prefer to use a ‘no-nose’ saddle (Dinsdale and Dinsdale, 2011). Cyclists that adopt an upright 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 ≥ 40kph, 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-
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, biomechanical 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 (Millsigle et al., 2004; Moran and McGlinn, 1995).

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.

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References


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A review of the relationship between kinesiology tape, fascial chains and flexibility.

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Abstract

Kinesiology Tape (K tape) is being used at the highest level of competition across a multitude of sports from cycling to football (O’Sullivan and Bird, 2011; Williams et al., 2012); this was largely the result of prominent endorsement by Olympic athletes in 2008. The link between flexibility and fascial chains has demonstrated the opportunity for K tape application techniques to be adapted to work on a global scale on the body. Research into fascial chains may have limited, or even prevented, the efficacy of K tape on flexibility during studies. This may not, however, be considered the only factor omitted from previous research that could be held responsible for the lack of definitive evidence regarding K tape and its effect on flexibility. Fundamental protocols which underpin the mechanics of flexibility have failed to be incorporated into previous study designs (Merino et al., 2010; Merino-Marban et al., 2011; Nakamura et al., 2012; Nelson, 2011; Weppeler and Magnusson, 2010). In conclusion, more research which incorporates improved standardised and validated testing methods needs to be undertaken to investigate K tape’s relationship towards both flexibility and fascial chains.

Key Words: Kinesiology tape; flexibility; fascial chains; methodological errors

Kinesiology Tape (K Tape) has gained global attention and use as an alternative sports taping method since its endorsement via the elite athletes of the 2008 Olympic games. It continues to feature as a useful product at the highest level of competition across a multitude of sports, from cycling to football (O’Sullivan and Bird, 2011; Williams et al., 2012). Unlike conventional rigid tape, which is created to act as an external ergonomic support predominantly restricting abnormal range of motion (RoM) whilst providing mechanical stability (Bot et al., 2003), K Tape is constructed to mirror the skin’s own elastic properties using thin adhesive elastic material capable of stretching between 30-40% of its resting length (Thelan et al., 2008).

This distinctive elastic feature is the driving force behind claims that K Tape can potentially increase circulation, reduce pain, enhance sensorimotor feedback, increase power output and correct mechanical dysfunction (Kase et al., 2003; Thelan et al., 2008; Wentzel et al., 2012; Wong et al., 2011; Yasukawa et al., 2006). Such effects are attributed to the elastic recoil which occurs as a result of tension within the tape. Once applied, a series of convolutions via this recoil effect lifts the skin creating a pressure difference which purportedly and subsequently frees the area allowing underlying myofascial tissue to function more effectively (Kase et al., 2003).

The concept of tape capable of mirroring the body externally to enhance function internally, is a promising notion and one which clearly invites questions towards which physiological systems qualify for enhancement by K Tape and to what extent. Athletes will aim to keep all systems within the body functioning at an optimum rate and will look to enhance all areas of their physical capabilities where possible (Soylo et al., 2011; Wentzel et al., 2012). One area which has exemplified optimal functioning is that of flexibility. Flexibility is a crucial component of performance across numerous areas including running velocity, technical execution and body positioning, movement efficiency, posture and a functionally balanced kinetic chain (Caplan et al., 2009; Cools et al., 2007; Dantas et al., 2011; Reid and McNair, 2004). Furthermore flexibility of muscle tissue provides tissue maintenance therefore lowering risk of spasms and trigger points (Celik, 2011; Fernandez De-Las-Penas, 2009; Knutson and Owens, 2003) which in this respect, suggests a relationship between flexibility and injury prevention strategies (Brooks et al., 2008; Ekstrand et al., 2009; Witvrouw et al., 2003). The quantity of published research given to this topic would suggest substantial levels of interest in terms of defining the relationship between K tape and flexibility, however to date research has failed to provide definitive evidence on this relationship (Garcia-Muro et al., 2009; Gonzalez-Iglesias et al., 2009; Merino et al., 2010; Merino-Marban et al., 2011; Nelson, 2011; Thelan et al., 2008; Yoshida and Kahanov, 2007).

The proposed existence of fascial chains is a discovery suggesting flexibility throughout the body may not be linked to the behaviour of muscle tissue exclusively in or around specific joints as may have been previously thought and as tested in previous K tape investigations (Garcia-Muro et al., 2009; Gonzalez-Iglesias et al., 2009; Merino et al., 2010; Merino-Marban et al., 2011; Nelson, 2011; Thelan et al., 2008; Wadsworth, 2007; Yoshida and Kahanov, 2007). Instead, the apparent intricate web of connective fascial tissue presents the possibility that flexibility may ultimately result from the condition of entire links of tissue; and therefore, to potentially enhance flexibility at a joint locally, flexibility must also be enhanced throughout the body globally.
K Tape and Flexibility

At a fundamental level, flexibility is simply how much range of movement (RoM) is present at an isolated joint or multiple joints in series (Youdas et al., 2010). Extensive research exists around flexibility and its manipulation (Chalmers, 2004; Davis et al., 2005; De Weijer et al., 2003; Kubo et al., 2001; Marques et al., 2009; Nakamura et al., 2012; Reid and McNair, 2004; Spernoga et al., 2001; Youdas et al., 2010). Although this research has collected data using instruments and measurement techniques such as magnetic resonance imaging (MRI), isokinetic dynamometers, ultrasound imaging or goniometers, supported by good to excellent accounts of reliability (Drouin et al., 2004; Kolber and Hanney, 2012; Wong et al., 2011), the theories attempting to explain the adaptive mechanisms remain varied and in cases speculative (Chalmers, 2004; Davis et al., 2005; De Weijer et al., 2003; Kubo et al., 2001; Marques et al., 2009; Nakamura et al., 2012; Reid and McNair, 2004; Spernoga et al., 2001; Youdas et al., 2010). Theories of adaptation may be broadly considered as either structural or sensational (Weppler and Magnusson, 2010); and this may allow for the relationship between flexibility and K Tape to be more easily identified.

The basic premise behind this theory is that flexibility results from the physical adaptation of myofascial tissue structure allowing for associated muscle groups connected to a particular joint to achieve a longer resting length. This subsequently permits the joint to move through a greater RoM (Marques et al., 2009; Reid and McNair, 2004). The specific mechanisms which occur within the body during structural adaptation can be further separated into two possible explanations. The first and most popular explanation is that additional muscle fibres (sarcomeres) are further recruited or re-aligned in series (i.e. longitudinally) within the tissue (Kubo et al., 2001; Marques et al., 2009; Nakamura et al., 2012; Reid and McNair, 2004). In order for this to take place it is suggested that ‘myofibrillogenesis’ must occur, a process theorised to be the result of a chain reaction of molecular events sparked within the myofascial tissue (De Deyne, 2001). The molecular chain reaction is stated to be a series of ‘signal sensing’ mechanisms evolved by the human body to react to the regular external stress or forces experienced by the body on a day to day basis (De Deyne, 2001; Myhre and Pilgrim, 2011). This is reported to occur at a cellular level through neural pathways within myofascial tissue prompting gene transduction and transcription, commonly known as ‘protein synthesis’ (De Deyne, 2001; Myhre and Pilgrim, 2011). Schleip (2003) states that the nervous system should primarily be seen as a ‘liquid system’ where blood and lymph also act alongside further neural pathways to provide fluid transmission of nerve signals throughout the body, in particular to signals which prompt the process of myofibrillogenesis and protein synthesis. Muscle tension, leading to hypertonicity and potential spasms and other purported myofascial stress responses (sometimes referred to as myofascial trigger points), has been stated to have a dysfunctional and debilitating effect on neural signalling within myofascial tissue (Celik, 2011; Fernandez De-Las-Penas, 2009; Knutson and Owens, 2003).

K tape methodology proposes improved circulation and lymphatic flow whilst also potentially relaxing muscle to restore normal function (Garcia-Muro et al., 2009; Yasukawa et al., 2006). Therefore, although tape is not required in order for protein synthesis to take place, under conditions proposed by K tape, the cellular mechanisms required may happen more efficiently and effectively, translating as faster and further flexibility gains.

The second explanation for the theorised structural adaptation behind flexibility essentially results from myofascial tissue ‘relaxing’. Due to an altered or reduced amount of messaging from the central nervous system (CNS), this allows muscles to lengthen past their normal RoM causing ‘viscoelastic deformation’ or permanent re-shaping of muscle fibres (Spernoga et al., 2001; Youdas et al., 2010). The cause of altered or reduced CNS messaging is centred around overcoming the autonomous defence strategy known as the ‘myotatic stretch reflex’ mechanism. This mechanism suggests afferent and efferent signalling between the CNS and muscle spindles create a reflexive muscle contraction designed to protect a muscle from rupture by stretching too far too quickly (Moore, 2007; Tuabe et al., 2012). It has been proposed that an individual may bypass the stretch reflex via slow controlled static stretching or overcome it via the opposing inhibitory (preventative) effects of the golgi tendon organs, as seen in proprioceptive neuromuscular facilitation (PNF) or muscle energy techniques (MET). Antagonistic muscle contractions may also be utilised, as with reciprocal inhibition (RI) techniques. Each of these may allow the individual to achieve a new ‘end’ RoM (Davis et al., 2005; Nelson and Bandy, 2004; Spernoga et al., 2001; Youdas et al., 2010).

Another theory embraces the idea that flexibility is purely a subjective reflection based on an individual’s ‘tolerance’ of end range positions. This suggests that myofascial tissue has the potential to reach further end points but is prevented by the perceived sensation experienced by each individual preventing them from extending past that point (Ben and Harvey, 2010; Folpp et al., 2006; Weppler and Magnusson, 2010). This mechanism could, therefore eventually prompt
signals of pain or discomfort resulting from the increased tension at 'end-point' and simply reduce or stop completely any increasing flexibility. It is further suggested that routinely stretching the myofascial tissue promotes a change in the perceived sensation of discomfort or pain by the subject as the muscle reaches its stretch end-point. This routine stretching would then reduce or stop the signals of pain from the increased tension at the 'end-point' permitting further stretching and flexibility (Ben and Harvey, 2010; Follp et al., 2006; Weppler and Magnusson, 2010). Kase et al. (2003) presented a proposed pain reduction effect caused by a decreased mechanical stimulation of nociceptors. It may be logical to speculate that K tape could create more relaxed conditions with reduced afferent noxious signalling, thus the subject's 'end-point' and flexibility may be altered.

In summary, the structural theory of 'additional sarcomere' recruitment in particular, is conceptually based around 'length-tension' curve data from highly reliable isokinetic dynamometers (Aquino et al., 2007; De Deyne, 2001; Kubo et al., 2001; Marques et al., 2009; Nakamura et al., 2012; Reid and McNair, 2004; van der Ven et al., 2000). This rule states that as a muscle lengthens the corresponding 'stiffness' further increases (Reid and McNair, 2004). Findings however are interpreted via observations on animal biopsies, as cross species studies into muscle similarities are sparse (Aquino et al., 2007).

The alternative sensation theory is entirely based on conflicting data within studies using 'torque-angle' curve analysis (Ben and Harvey, 2010; Follp et al., 2006; Weppler and Magnusson, 2010). This process presents a visual graphical line representing muscle length against tensile force. If muscle structure was to change during flexibility then a new resting length should occur post tensile force visually represented by the line shifting to the right, however sensational theorists state that this evidence was not found (Aquino et al., 2007; Kilgallon et al., 2007; Weppler and Magnusson, 2010).

Both theories are therefore plausible and supported by justified arguments. However, due to methodological reliability and valid cross referencing to physical observations in animal studies, it is most probable that K tape's strongest link to flexibility is in facilitating the environment needed for protein synthesis to take place and recruit additional sarcomeres.

**Physiological properties and K tape**

The physiological properties that facilitate flexibility and which are proposed to be affected by K tape therefore create scientifically sound bases for a relationship leading to enhanced flexibility to exist. Logically, this relationship suggests that by applying K tape directly to local muscles around a joint would increase the RoM of that specific joint; however this view of flexibility may be limiting the potential of K tape application. To understand how, further attention needs to be directed back to the architecture of muscles and the specific components of myofascia.

The fascial network, a matrix of connective tissue running not only through muscles (myofascial) but also organs, joint capsules, bones and soft tissue (Myers, 2011a; Price, 2012; Schleip, 2003), is prompting a modern re-evaluation of the complexity and integration of the muscular system. The understanding of anatomy in terms of movement and architecture is moving away from a 'regimented' system of individual muscles, whereby each is responsible for specific movement and localised tissue condition, to a more interlinked, sophisticated system governed by fascia, which intimately runs throughout (Myers, 2011a; Myers, 2011b; Price, 2012; Schleip, 2003; Stecco et al., 2007). Fascia is intrinsically involved in both posture and movement, abundantly innervated by sensory receptors (Price, 2012; Wadsworth, 2007) and has been shown to not only exist, but to exist as a number of continuous force transmitting 'chains' throughout the body (Myers, 2011a; Myers, 2011b; Stecco et al., 2007). Stecco et al. (2007) state that the presence of referred pain, often some distance from its origin, such as that historically associated with myofascial trigger points, is evidence to support the effect of fascial chains. Wadsworth (2007) adds that even altered muscle tonus is a component capable of referring restriction distally from its proximal attachments to other distal segments of the chain. In other words, tension within one aspect of the body can create restriction elsewhere in the body – a 'tension continuity effect'. It is this suggestion – where the resultant homeostasis and relaxation within muscle tissue influenced by the properties of K tape – could produce a greater effect, and subsequent flexibility enhancement, if the tape application accommodated not just the immediate musculature surrounding a joint but the entire fascial chain of which the joint sat within.

Flexibility, therefore, is potentially not just a property defined by the behaviour of localised muscle connected to a joint but may be considered a global network defined by the fluid continuity of fascial chains which bind and support movement. The recognition of fascia's place within flexibility, combined with the enhancements stood to be gained from K tape, suggests that a tape application which embraces this global network could provide a deeper and more comprehensive approach to increasing an individual's RoM and quality of movement.
This proposal may ultimately translate as a stronger approach to an athlete’s quality of RoM and therefore links to the chain reaction of biomechanical events and flexibility. Enhancing this link may then consequently lead to enhanced movement and enhanced performance. The significance of fascial chains to K tape and flexibility is an under researched field, however if the ‘tension continuity effect’ underlying fascial chains does exist then it stands to reason that taping methods incorporating full ‘chains’ should enhance the flexibility of all joints accommodated within any particular chain.

Research in this field remains inconsistent and conflicting. Evidence ranges from an immediate RoM improvement after tape application to completely ineffective – leading to an unclear picture of K tape and flexibility. Such research falls short of accommodating crucial posterior and anterior muscle groups responsible for inhibiting movements and may therefore go some way to explaining conflicting results (García-Muro et al., 2009; Merino-Marban et al., 2011).

Research has previously utilised ‘sham’ or ‘placebo’ tapes (Merino-Marban, 2011; Thelan et al., 2008), and in some cases has reported significant improvements in both cervical and hip RoM (Gonzalez-Iglesias et al., 2009; Merino-Marban, 2011). The use of any ‘sham’ intervention is open to criticism when the associated research presumes that little or no effect will be observed due to its ‘fake’ properties. Such criticism is based on a number of principles. Skin is an integral part of the mammalian somatosensory system which communicates constantly with the brain via the peripheral nervous system. The resulting modulation of sensory inputs contributes to interpret the body’s global sensation (Delmas et al., 2011; Shao et al., 2010). Of particular relevance to the use of ‘sham’ tape are the primary mechanoreceptors situated within the skin that act as afferent sensory receptors. These include Merkel’s Discs, Meissner’s Corpuscles, Pacinian Corpuscles and Ruffini Endings and collectively these transmit electrical impulses that allow the body to detect even the slightest pressure difference (Delmas et al., 2011; Shao et al., 2009; Olausson et al., 2008). Any interface and interaction occurring via the application of ‘sham’ tape onto the skin’s surface therefore unavoidably elicits a physiological response and change within the body, which in turn means its use cannot be wholly defined as ‘ineffective’ or ‘fake’. For the results of research to be ‘externally valid’ and relative to the reader studies must use sample groups that reliably represent the general population (Fox et al., 2009). Without a sufficiently representative sample group there is limited significance to the wider context.

The use of triathletes in previous research provides a good example of a methodology design which represents a specific elite population but which is therefore of limited use to the general population, outside of highly trained individuals, where marked physiological differences would be present (Merino et al., 2010). Misrepresentation through either sample specific physiology, imbalances in gender, or research focussed on one isolated individual (García-Muro et al., 2009; Merino-Marban et al., 2011; Nelson, 2011; Thelan et al., 2008) can strongly undermine any such research which has claimed inferential results within conclusions and subsequently the findings reported.

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Another methodological void, which significantly lowers the reliability of all previous research reviewed is the complete lack of any protocols which ensure a measured amount of tension is running throughout the tape upon application (García-Muro et al., 2009; Gonzalez-Iglesias et al., 2009; Merino-Marban et al., 2011; Nelson, 2011; Merino et al., 2010; Thelan et al., 2008; Yoshida and Kahanov, 2007). Kase et al. (2003) outlined tape tension as one of the most critical factors towards gaining successful effects from its use. Tension in previous research is both conflicting and unclear. Certain research has used the ‘paper off’ method which relies on the stretch placed and held within the tape whilst on the backing paper. Percentages ‘reliably’ within the tapes confusingly appear as anything from 10% to 15% to 25% (Gonzalez-Iglesias et al., 2009; Merino-Marban et al., 2011; Thelan et al., 2008). Further to this, some research proceeded to investigate the effects of K tape onto RoM whilst declaring no known or intended degree of tension during research at all, leading to a high degree of irrelevance within their results (García-Muro et al., 2009; Nelson, 2011; Merino et al., 2010; Yoshida and Kahanov, 2007).

Perhaps the most alarming and questionable aspect from previous research is the seemingly overly simplistic concept they all have of the factors actually facilitating flexibility (Gar-
cia-Muro et al., 2009; Gonzalez-Iglesias et al., 2009; Merino et al., 2010; Merino-Marban et al., 2011; Nelson, 2011; Thelan et al., 2008; Yoshida and Kahanov, 2007). Experimental designs have, in all circumstances, simply applied K tape to subjects in a bid to then measure a potential increase in RoM. However, as highlighted earlier, flexibility is ultimately a product of some form of regular, applied force (such as stretching) which stimulates the muscle to adapt either its length or neural and cellular functioning (Davis et al., 2004; Kubo et al., 2001; Marques et al., 2009; Nakamura et al., 2012; Nelson and Bandy, 2004; Reid and McNair, 2004; Spernoga et al., 2001; Weppler and Magnusson, 2010; Youdas et al., 2010). K tape cannot be viewed separately from these factors within studies that research its effects onto RoM, as in so doing would be to omit the crucial stimulants that are fundamentally needed for increasing RoM. Furthermore, despite the supported existence of fascial chains and the role they may well have in creating global flexibility, none of the research reviewed incorporate a taping method which reflects or acknowledges this issue (Myers, 2011a; Myers, 2011b; Price, 2012; Schleip, 2003; Stecco et al., 2007; Wadsworth, 2007).

Summary

In conclusion, existing studies are fraught with undermining features leading to an inability to conduct a reliable, valid or ‘true’ assessment of K tape. The inferential power of research is often highly questionable and many of the questions surrounding K tape remain largely unanswered. K tape in many investigations has been tested under conditions where it was under-appreciated and misplaced. Mechanisms of flexibility appear to operate under the architecture of fascia, yet these issues are not overtly reflected in the research in relation to any form of stretch routine or taping method. It would therefore appear appropriate to conduct further research which incorporates improved standardised valid and reliable testing methods to investigate K tape’s relationship towards both flexibility and fascial chains.

References


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.

Kjellgren 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 education. However, learning to learn at university is a complex process with many universities persisting with outdated models of support which fail to recognize 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
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 technological 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 stifies 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-
Table 2. Group development in the problem-based learning cycle (Johan and Clarke, 2012).

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<tr>
<th>PBL learning cycle</th>
<th>Stages of group development</th>
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<td>Problem scenario</td>
<td>Forming</td>
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<td>Identify facts</td>
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<tr>
<td>Generate hypothesis</td>
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<td>Identify knowledge deficiencies</td>
<td>Storming and norming</td>
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<tr>
<td>Apply new knowledge</td>
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<td>Abstraction</td>
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<td>Evaluation</td>
<td>Adjourning</td>
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tives 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 ≥ 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 medial 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 years ± 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).

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).

| 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: Communication | Time consuming to facilitate |
| Prioritisation of time/resources | Must be prepared to “step back” from “traditional” teaching role |
| Identification of key problems | Demands easy access to internet and good quality medical library |
| Team working and task sharing | Not suits to all subject areas |
| Potential to increase learner confidence | |

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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.

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