General Considerations for Compression Garments in Sports: Applied Pressures and Body Coverage

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Abstract Compression garments are popular among competitive and recreational athletes alike. The debate about the efficacy of compression garments in sport is similarly popular, spanning the scientific literature, public press, social media, and the sports field itself. In this chapter we aim to assist both researchers and the general reader by discussing the core elements of the compression garment story. First, we consider *compression*—the applied pressures and factors influencing those pressures. Knowing the applied pressures in vivo and characteristics of the pressures during use are important for building a clearer idea about what aspects of sports performance and recovery are affected by compression garments and why. Second, we consider *garments*—that, like other clothing, compression garments cover and interact with the body, establish a microenvironment, and influence variables such as heat and moisture exchanges. Understanding characteristics of the garments themselves can be useful for aiding interpretation of certain physiological and psychological effects, including heat balance, comfort, and wearer acceptability. We hope that the detail here helps the reader to contextualise and critically evaluate research on compression garments in sport.

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Introduction

Scope

Compression garments have been widely adopted for use in sporting contexts. The types of garments available vary and include those that cover the torso and the arms in full or part, the lower-body from the waist in full or part, and those that cover specific limb-segments only (e.g. sleeves, socks, and stockings). While the type of garments used and the time of wearing them can vary by sport, personal preference, and intended purpose, a common feature is that all compression garments apply pressure to *and* cover body surfaces. These two components—applied pressures and body coverage—are the focus of this chapter.

Applied pressures. A fundamental assumption underpinning compression garment use is that the pressures applied to the body are important in some way. During use, these pressures can be influenced by garment properties (e.g. garment dimensions, garment construction, properties of the constituent fabrics and how these change over time) and characteristics of the underlying body segment (e.g. body dimensions, tissue type, and changes related to posture and movement). Irrespective of whether specific pressures, a general range of pressures, or simply some pressure is ultimately required for a particular outcome, actually knowing what those pressures are and the characteristics during use are essential for integrating and interpreting the literature and making useful recommendations for athletes.

Body coverage. Considerations about compression garments from the perspective of a layer of clothing that covers the body are introduced. Here, we include information that attempts to bridge the sport sciences with some of the wider clothing and textile sciences.

Pressure and coverage characteristics

Since early studies in sporting contexts (e.g. Berry and McMurray 1987; Carling et al. 1995; Kraemer et al. 1996, 1998a, b), a considerable body of research has accumulated investigating various applications (during sport, during recovery) and types of compression garments (different applied pressures and body sites covered). For the purpose of gauging the status of aspects relating to pressures and body coverage in the sport sciences, we characterised the literature from a ~5-year period (2011–Jan 2016; Table 1). (Note that this search period applies only for the data presented in Table 1, not for the chapter as a whole.) Over this period, 78 % of studies investigated effects during exercise, and 29 % during recovery from exercise. Lower limb compression has been the most common with 81 % of studies including the leg (calf) and 48 % including the thigh, while comparatively few have investigated upper-body effects (<16 % for each torso, upper arm, and forearm; Table 1). While the applied pressures were often reported, these pressures were measured only in approximately one of every three studies.

Table 1 Information from located studies (n = 58, 2011–Jan 2016) in which compression garments were used during or following exercise[a]

Variable	Yes (%)	No (%)	Not clear (%)
Body sites compressed			
Torso	12	88	–
Upper arm	16	83	2
Forearm	14	83	3
Thigh	48	48	3
Leg (calf)	81	17	2
Applied pressures			
Pressures reported	74	26	–
Pressures measured in vivo by authors	34	66	–
Other garment information reported			
Placebo garment used[b]	28	72	–
>1 compression condition (including placebo)[c]	43	55	2
>1 compression condition (excluding placebo)[c]	22	76	2
No garment/normal clothing as a control	78	22	–
Comment on how participants sized	78	22	–
Fibre type reported	53	47	–
Any fabric properties reported	5	95	–

[a] A 5-year period was used because, assuming that pressure measurement is becoming more common, the inclusion of older studies may inflate the percentage not measuring the applied pressures; see "Appendix 1: Search Details for Table 1" for a details about the search

[b] As reported as being a placebo garment in the article and may have been another type of garment or the same garment in a bigger size; in some instances the placebo was the control condition and in others it was simply a different condition of compression (i.e. one with less pressure)

[c] Placebo conditions have been reported both included and excluded as a separate condition of compression because it is plausible that placebo garments are, in effect, low-level compression garments

Compression Garments and the Applied Pressures

Establishing Applied Pressures

Sporting compression garments are smaller in dimensions than the corresponding body sites to be covered. During donning and use, the garment and its constituent fabric, yarns, and fibres/filaments are subjected to mechanical forces acting over an area (stress), which cause deformation, observable as extension (strain). Thus, compression is a product of the interaction between the body (e.g. tissue and surface curvature) and the forces involved with garment strain (Troynikov et al. 2013). Some indication of how interface pressures actually influence the underlying tissue pressures can be gained from Table 2 (Murthy et al. 1994; Giele et al. 1997; Uhl et al. 2014): note that modelling indicates heterogeneous pressure distributions are likely within a limb cross-section (Dubuis et al. 2012).

Table 2 Effects of external compression on subdermal and intramuscular pressures[a]

Site	Body position	Interface pressure, mmHg	Subdermal pressure (Δ from baseline), mmHg	Intramuscular pressure (Δ from baseline), mmHg
Medial mid-calf[b]	NR	No compression	6 (0)	
		36	22 (16)	
Posterior calf[b]	NR	No compression	−3 (0)	
		66	24 (27)	
Medial lower calf[b]	NR	No compression	1 (0)	
		59	31 (30)	
Medial calf (IMP in medial gastrocnemius)[c]	Supine	No compression		11 (0)
		10		13 (2)
		20		25 (14)
		30		36 (25)
		40		43 (32)
	Standing	No compression		32 (0)
		10		41 (9)
		20		50 (18)
		30		60 (28)
		40		68 (36)
Mid-calf (IMP in soleus)[d]	Supine	No compression		8 (0)
		16 ± 1 (L1)		21 (13)
		20 ± 1 (L2)		25 (17)
	Standing	No compression		37 (0)
		19 ± 1 (L1)		56 (19)
		23 ± 1 (L2)		55 (18)
	Walking			
	Contraction	No compression		152 (0)
		23 ± 1 (L1)		162 (10)
		26 ± 1 (L2)		174 (22)
	Oscillation[e]	No compression		161 (0)
		11 ± 1 (L1)		153 (−8)
		11 ± 1 (L2)		164 (3)
	Running			
	Contraction	No compression		226 (0)
		24 ± 1 (L1)		254 (28)
		29 ± 1 (L2)		245 (19)
	Oscillation[e]	No compression		242 (0)
		13 ± 1 (L1)		263 (21)
		14 ± 1 (L2)		245 (3)

[a] Subdermal and intramuscular pressures are reported as absolute values with the change from baseline (no compression) reported in parentheses; change scores are calculated from group means. Standard deviation is presented where possible but omitted from subdermal and intramuscular pressures for clarity of presentation

Δ, change; NR, not reported; IMP, intramuscular pressure; L1, 'level 1'; L2, 'level 2'

[b] n = 1 leg, compression applied using a "pressure garment" (Giele et al. 1997)

[c] n = 10 legs from 5 participants, compression applied using a blood pressure cuff and measured at the medial calf at widest girth (Uhl et al. 2014)

[d] n = 11 legs from 11 participants, compression applied using 'level 1' and 'level 2' ankle-to-knee elastic compression garments (Murthy et al. 1994); note that the original article reports data for both elastic and inelastic compression but only data from the elastic garments are reported here

[e] Oscillation represents the difference between peak and relaxation pressures

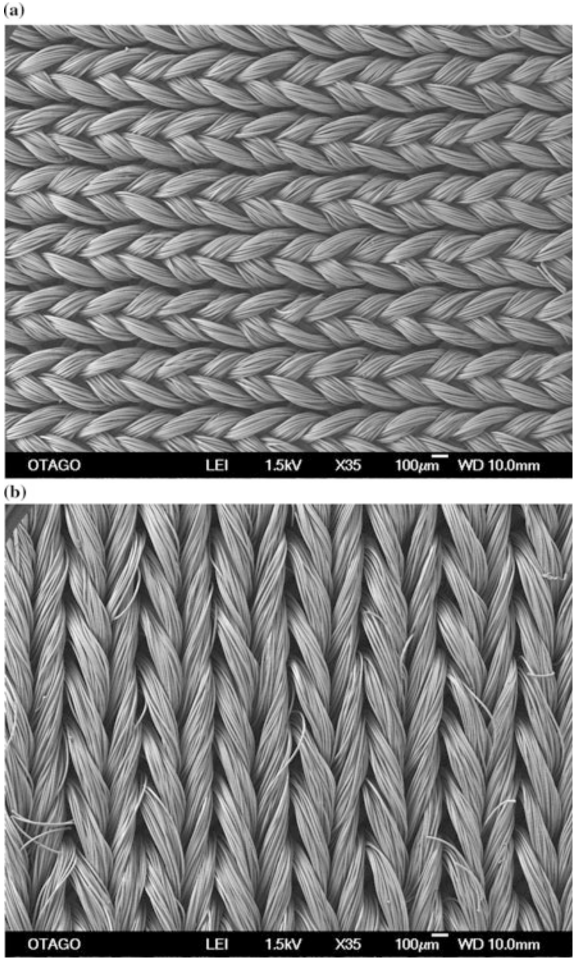

Fig. 1 Scanning electron microscope images of the fabric from a common sporting compression garment at X35 magnification; fabric outer (**a**) and inner (**b**) surfaces as used in the garment

An example of fabric from a commercially available sporting compression garment is shown in Fig. 1, imaged at 35 times magnification using a scanning electron microscope. In this case, it can be seen that filaments (fibres of indefinite length) are used to form yarns, which have then been knitted to form the fabric structure. Textile fibres are classified according to their origin and chemical composition (International Organization for Standardization 2012, 2013a). For sporting compression garments, the constituent fibres/filaments are often elastane (branded versions of this include Lycra® and spandex) and polyamide (nylon) or polyester. This particular example (Fig. 1) was reported by the manufacturer as being 76 % nylon and 24 % elastane.

A reasonable level of fabric extension and fabric elasticity (recovery following extension) will facilitate garment donning, wearer comfort, range of motion, and generic garment sizing. Extension characteristics will also influence the way the applied pressures respond when the volume or curvature of the underlying body segment changes. The related property of compression garment ‘stiffness’ is relevant here and is defined in the context of medical compression hosiery as the increase in compression pressure per 1 cm increase in leg circumference (Comité Européen de Normalisation 2001). While this definition is somewhat arbitrary and, at face value, applicable only to the lower body, understanding the relevance of garment stiffness can be of use for the sport sciences. [Note that stiffness is also used to describe fabrics in terms of resistance to bending and this is not the usage here; stiffness for compression garments or compression devices, as defined (Comité Européen de Normalisation 2001) and widely used (Partsch et al. 2006a), can be thought of as the outcome of a compression material’s resistance to extension.] As an example, stiffer garments versus those that are less stiff, exhibit greater changes in pressure following a change in position of the leg (Partsch 2005; Partsch and Mosti 2013) or arm (Hirai et al. 2010) and higher peak pressures during muscle contractions in the leg (Partsch and Mosti 2013) or arm (Hirai et al. 2010). For this reason, both the applied pressures in resting state *and* how the pressures change during use are each important to understand.

Measuring Applied Pressures

In Vitro

There are various in vitro approaches for classifying medical compression products (e.g. see Partsch et al. 2006b; Hegarty-Craver et al. 2015) and, in principle, these or similar approaches can also be used for sporting compression garments. Advantages of in vitro measurements include widespread characterisation of garments under comparable conditions (assuming the same test method is used) and the ability to systematically assess effects of fabric properties or garment characteristics (e.g. Kumar et al. 2013). These approaches help understand aspects of the applied pressures, however, the principal interest is ultimately the applied pressures when worn by people.

In Vivo

Measurement. We strongly encourage researchers to measure the applied pressures in vivo. Approximately three quarters of studies over a ~5-year period reported applied pressures but only one third reported actually measuring these (Table 1). While other characteristics are also relevant to report where possible (e.g. see Section “Some Measurable Fabric Properties and Why They Are Useful”), applied pressures should be viewed as a minimum requirement and equivalent to reporting other information such as participant height, mass, age, and trained status.

The pressures applied by compression garments are typically measured at the interface between the skin and the garment. Some pressure measuring systems have been evaluated (e.g. Flaud et al. 2010; McLaren et al. 2010; Partsch and Mosti 2010; Brophy-Williams et al. 2013). Shape, composition, and distribution of tissues comprising the underlying body segment can influence pressures measurements (Thomas 2003; Moffatt 2008; Dubuis et al. 2012), and if a sensor is placed over a bony protrusion or tendon, for example, greater localised loadings can be induced. The applied pressures have been shown to vary not only by position along a limb, but also around its circumference depending on the local curvature (Liu et al. 2005, 2007; Sperlich et al. 2013a, 2014; Miyamoto and Kawakami 2014).

Existing guides for stocking materials and the lower limb are available in the literature (Comité Européen de Normalisation 2001; Partsch et al. 2006a). Depending on garment coverage and research question, the sites of the area at which the Achilles tendon changes into the medial calf muscle (B1), the calf at its maximum girth (C), and the mid-thigh (F) seem appropriate to use as convention with sports compression as including one or a number of key sites consistent among studies ensures more direct comparisons. Other sites can be added according to research interest. Thus, specific measurement location (e.g. medial, lateral, anterior, posterior) and participant position should also be clearly described (Partsch et al. 2006a). Fewer, but still some studies in which the applied pressures of upper-body sites were measured exist (e.g. Williams and Williams 1999; Bochmann et al. 2005; Damstra and Partsch 2009; MacRae et al. 2012; Sperlich et al. 2014). The relative merit of particular sites on the upper body are less clear than that for the lower body, however, the same detail of noting location and participant position should be employed.

Reasoning. From the perspective of interpreting any outcome effects of compression in sport, understanding the applied pressures in the cohort studied is crucial. For example, if beneficial effects for a particular measure are not observed, is it because compression has no effect? Or could it be that the pressures applied by those garments were too low, or too high? Similarly, if there are discrepancies among studies investigating a certain variable, are differences in the applied pressures or areas compressed possible explanations? Irrespective of whether different levels of applied pressures are important or unimportant, knowing the pressures in the first place is a requirement to conclude either way.

The ‘intended’, in vitro, and/or manufacturer-reported pressures are, at present, insufficient for estimating the in vivo pressures for two reasons. First, they have been a mixed guide in the past for group means (e.g. Liu et al. 2005; Partsch et al. 2006b; Beliard et al. 2015), and second, there will be inherent inter-person variability with generic sizing (Hill et al. 2015). Even custom-made garments are subject to potentially relevant variation.

In a rare study from the sport sciences with both custom-made garments and investigator-measured pressures, compression shorts (covering the thigh from waist to above the knee) were made and fitted using the measured thigh girth (Sperlich et al. 2013a). Pressure at the thigh at maximum girth was aimed to be 35 mmHg. For the four measurement sites (rectus femoris, vastus lateralis, vastus medialis, biceps femoris) the group means (n = 6 participants) were 35, 36, 37, and 39 mmHg, respectively, with corresponding pressure ranges of 31–39, 33–41, 29–44, 36–42 mmHg, respectively (coefficient of variation, 5–17 %). Some variation in the applied pressures will always be expected, but the point is that an estimate, unmeasured by the authors (e.g. '20 mmHg at the calf'), while arguably better than no measurement, overlooks variation. If a range is reported (e.g. '16–22 mmHg at the calf') but not measured, the method used to attain that estimate should be reported otherwise the reader has little ability to judge the quality of that information. For example, source 'X' may have generated estimates by extensive in vivo testing using a range of athletic populations (in which case you would then also expect an indication of variation) while source 'Y' may have used rigid cylinders paired with one garment size, or worse, just guessed.

Sizing

Sizing systems can be created using a variety of methods ranging from trial and error to statistical analysis of anthropometric data (e.g. Laing et al. 1999), and are traditionally based on (or reduced to) one or a number of key dimensions (Chun-Yoon and Jasper 1993; Ashdown 1998).

As mentioned already with custom-made garments, generically sized sporting compression garments can vary appreciably in the pressures they apply, even when fitted according to the manufacturer's instructions (Hill et al. 2015). For pressures at the anterior thigh and medial calf at maximum girth, values ranged from 4 to 17 and 10 to 25 mmHg at the thigh and calf, respectively, for males (n > 26) and from 5 to 13 and 10 to 19 mmHg, respectively, for females (n = 24). This is unsurprising given that the proportional size and shape of individuals will also likely vary (Surhoff 2014). What is interesting, however, is that among a subgroup of 29 men all wearing a size medium lower-body compression garment, there were no significant correlations between anthropometric variables, including thigh and calf girths, and the measured applied pressures at the thigh and calf (Hill et al. 2015).

It may be that sizes (e.g. small, medium, large) are themselves arbitrary. Assuming it is some aspect of the applied pressures that is important for compression-related effects, the sizes are simply a vehicle to help fit an individual with particular applied pressures. Hill and colleagues (2015) demonstrated that particular 'intended' pressures, based on the work of Watanuki and Murata (1994), were often not met with correctly fitted garments. In extension of this work, it would be interesting to know whether an existing size range could be used to achieve particular pressures at particular sites by fitting garments by trial and error according to the resultant applied pressures instead (i.e. irrespective of given size). Measurement of the applied pressures would be required, which makes this more difficult outside a research setting. The other, and critical, difficulty with this approach is: what pressures are actually required for sport and in which circumstances do they apply?

What Applied Pressures?

Even with indication that compression garments can be useful in some sporting situations (Born et al. 2013; Hill et al. 2014a; Marqués-Jiménez et al. 2016), there appears to be a less cohesive story about what pressures are actually necessary (Beliard et al. 2015). There is appreciable diversity among potential compression-related effects and conditions of use (e.g. physiological or performance measures, body site, type of sport, use during sport or during recovery). It seems unlikely that one particular pressure profile will best suit all desired applications and outcomes (e.g. resting supine versus upright exercise; venous versus arterial haemodynamic effects). Thus, the influence of particular pressures across outcomes requires clarification. For these reasons, it would be surprising if manufacturers and distributors of sporting compression garments have a clear idea about what pressures are required and why.

What Pressures—An Example Using Compression Effects on Leg Haemodynamics

Sport presents a challenging set of conditions for understanding the effects of compression garments on haemodynamics. With respect to particular applied pressures, a pervasive example includes the concept of graduated compression and effects on haemodynamics. The dogma is that we need higher values distally and lower pressures proximally. Such pressure gradients are still an important quality criterion for the so-called graduated elastic compression stockings (e.g. Comité Européen de Normalisation 2001; Deutsches Institut für Gütesicherung und Kennzeichnung 2008), the basic concept being that higher pressures over the calf than over the ankle could impede rather than augment venous flow. However, while this may have some importance in the horizontal position in which compression pressure may actually lead to some venous narrowing, such effects are less likely in the upright position let alone during exercise. Indeed, compression stockings of 20–30 mmHg, for example, were found to reduce the internal diameter of posterior tibial and peroneal veins (vs. without stockings) in healthy people in a supine position, however these effects were not present when standing upright (Lord and Hamilton 2004).

Perhaps pressures remain too low to have demonstrable venous haemodynamic effects when upright (Partsch and Partsch 2005; Partsch et al. 2010) and during activity like moderate or high-intensity orthostatically stressful exercise. Central cardiovascular effects were investigated using conventional ‘elastic’ compression garments and athletic cohorts during submaximal running (Sperlich et al. 2011) and cycling (MacRae et al. 2012) and neither group found evidence for benefits from the compression garments used. Sperlich and colleagues (2011) used five separate conditions, four with knee-high socks applying different levels of compression ($\sim$14, 23, 32, and 39 mmHg at the calf at maximum girth) and one condition without compression. Cardiac output, stroke volume, and heart rate were similar during exercise irrespective of condition and may implicate the dominating influence of mechanisms like the calf muscle pump. There is some indication, however, that compression may influence cardiovascular strain during lower-intensity exercise. Lovell et al. (2011) investigated the effects of lower-body compression (waist to ankle; ~20 mmHg at the ankle and 15 mmHg at the calf) on various cardiorespiratory variables during multi-stage running at different intensities. During the two active recovery stages (6 km/h), heart rate was significantly lower by ~4–5 beats/min in the compression condition versus regular running shorts. However, no differences in heart rate were observed at the other running intensities (10 km/h and 85 % peak oxygen uptake).

Especially during sporting activities, rhythmic muscle contractions will lead to fluctuations in the applied pressures (see next section). The pressure amplitudes depend on the consistency of the moving tissue, on changes of the local body configuration, and on the stiffness of the compression device. Simply increasing the pressure applied by ‘elastic’ compression garments would lead to unpleasant and even painful feelings of constriction, thereby decreasing comfort and wearer acceptance (Liu et al. 2008), especially during rest. On the other hand, relatively inelastic compression which does not need to increase the resting pressure, but which is able to increase the pressure in the standing position and during walking, is an approach that has already shown promise in both patient (e.g. Mosti et al. 2008) and healthy (Partsch and Mosti 2013) cohorts (Fig. 2).

Stiff, low-yielding wraps superimposed over a sport stocking may increase the pressure peaks considerably, even without major changes in the supine resting pressures. External pressures of more than 50–60 mmHg may occur on the lower

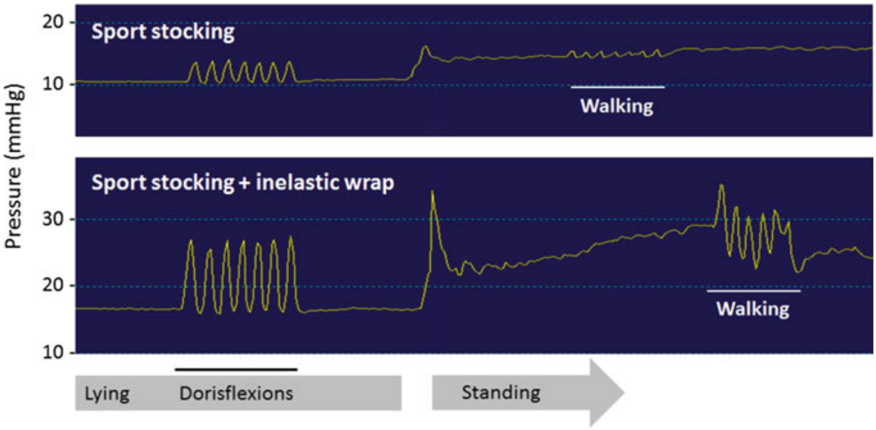

Fig. 2 Interface pressures at the medial calf at maximum girth during rest in the lying position, repeated dorsiflexion while lying, standing, and walking. Below-knee sport compression stockings (*top panel*) and compression stockings with the addition of an inelastic (i.e. ‘stiff’) strap applied lightly over the midcalf (*bottom panel*). Data are from Partsch and Mosti (2013)

leg during walking or running which are high enough to intermittently overcome the local intravenous pressure, thereby exerting hemodynamic effects. By magnetic resonance imaging (MRI) in the standing position, it could be shown that wrapping the calf with inelastic material (over a conventional sport stocking) increased the pressure to 42 mmHg which led to a narrowing of all lower leg veins, while the sport stocking alone exerting 23 mmHg had practically no influence on venous diameters (Partsch and Mosti 2013). Such venous narrowing is a prerequisite for a haemodynamic effect. By measuring the calf pump function during a standardised walking test in healthy sports people, a significant increase of the ejection fraction could be demonstrated with addition of the inelastic wrap and contrasts that of the conventional stocking alone, which did not show improvement (Partsch and Mosti 2013).

Such compression systems may capitalise on the calf region being where veins are forming a kind of dense sponge. Indeed, the idea that ‘progressive’ below-knee pressure is more effective than conventional (‘degressive’) graduated pressure was demonstrated in venous patients by showing a higher increase of ejection fraction compared to graduated pressure (Mosti and Partsch 2011). Miyamoto and Kawakami (2015) also challenged the convention of graduated compression by showing that pressure at the calf seemed to be more important (than the graduation of ankle-calf pressure) for reducing surrogates of muscle fatigue when compression garments were worn by healthy subjects during 30 min treadmill running. Unfortunately, the pressures were not measured by the authors and were instead as reported by the manufacturer.

Briefly, augmentations of arterial inflow have been demonstrated with compression of the forearm during rest and low-intensity handgrip exercise (13–23 mmHg; Bochmann et al. 2005) and leg during rest (30–40 mmHg; Mayrovitz and Larsen 1997; Mayrovitz 1998). However, reductions of blood flow in the thigh muscles have also been demonstrated with compression following high-intensity exercise ($\sim$37 mmHg; Sperlich et al. 2013a). While there is more to learn about the effects of compression on arterial haemodynamics, indications are that effective pressures are not necessarily equivalent to those that benefit venous haemodynamics when upright.

Although not exhaustive, these examples help demonstrate that the concept of broadly applicable applied pressures and pressure profiles is unlikely, particularly for encompassing all forms of sport and recovery, and that further insight may be gained by challenging the status quo.

Posture and Movement

Posture and movement influence the pressures applied as shown with compression stockings (e.g. Wildin et al. 1998; Wertheim et al. 1999; Liu et al. 2007) and sports compression garments (McLaren et al. 2010; MacRae et al. 2012; Brophy-Williams et al. 2014). An example of the real-time influence of movement can be seen in

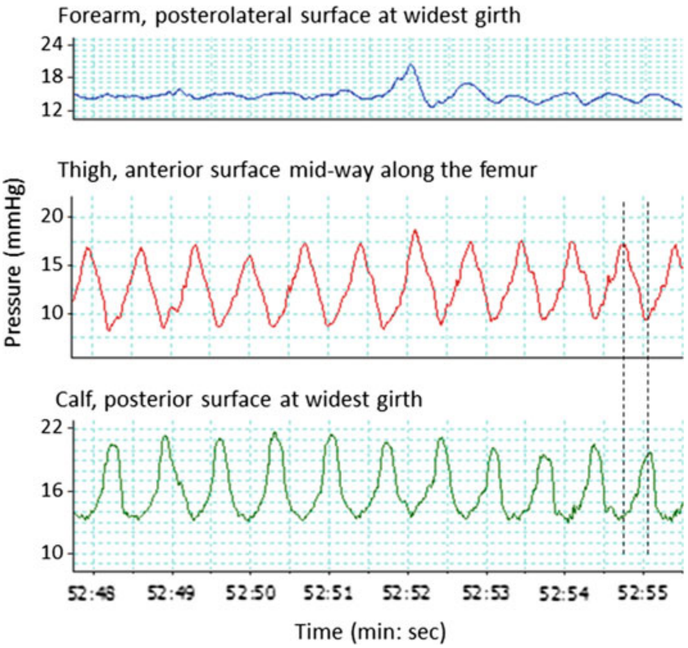

Fig. 3 Example of applied pressures in vivo during cycling exercise for sports compression garments fitted according to the manufacturer's recommendations. *Dashed vertical lines* superimposed on the thigh and calf traces are to indicate that they are out of phase. Data are from MacRae et al. (2012)

Fig. 3, showing interface pressures during cycling exercise while wearing full-body sports compression garments.

As mentioned, the extent to which the applied pressures change with posture and movement will also be related to garment stiffness (Partsch 2005; Hirai et al. 2010; Partsch and Mosti 2013). The implications here are that the fabric/garment stiffness may be altered according to desired end-characteristics: an increase in stiffness will, for example, exhibit greater peak pressures during contraction of the underlying muscle while 'elastic' garments will show lesser changes (Fig. 2). Different body sites may have different requirements relating to pressure dynamics.

Different Applied Pressures

Blinding and placebo garments. Blinding participants is difficult with compression garment research, and this is especially so with participants who regularly use compression garments (Driller and Halson 2013a). No compression or normal garments (e.g. regular running shorts and ankle-length socks) are commonly used as a comparison condition (~78 % of studies; Table 1) with attempted placebo garments used less commonly (~28 %). Even if placebo garments are noticeably less tight, there can still be merit in controlling for body coverage.

Note that placebo garments, even 'non-compressive' tights, typically do still apply some pressure. For example, de Glanville and Hamlin (2012) reported a mid-calf pressure of 14.7 ± 2.5 mmHg with full-length lower body compression garments and 5.7 ± 0.9 mmHg at that same site with the placebo garment. These pressures, while low, could still be enough to confound a 'no compression' condition. For example, it could be shown that so-called placebo stockings were able to reduce occupational leg swelling in the evening (Partsch et al. 2004). Thus, terms like 'no compression' should be used cautiously. Approaches investigating 'different levels of compression' are also worth considering versus placebo garments per se (e.g. Ali et al. 2010; Miyamoto et al. 2011; Sperlich et al. 2013b). A view on blinding (or the lack thereof) from a practical or non-mechanistic standpoint could be that placebo effects, if found, are effects nonetheless.

Different levels of pressure. The applied pressures can vary by garment size, although the significance of this can depend on the type of garment (Brophy-Williams et al. 2014). Further, the extent to which different sizes differ in applied pressures can be of less practical significance than the difference between garment types. In a hypothetical example, for garment type 'A' there may be 5 mmHg difference between the group means of correctly sized and over-sized garments (e.g. 15 and 10 mmHg, respectively), but a difference of 15 mmHg between garment types 'A' and 'B', each correctly sized (15 and 30 mmHg, respectively). This is another reason why knowing the applied pressures is important beyond simply knowing the size itself. There are examples where changing the level of compression does have demonstrable physiological effects (e.g. Mayrovitz 1998; Bochmann et al. 2005), although such pressure-intensity effects in sport are often overshadowed by a lack of effect in the first place (e.g. Ali et al. 2010).

Changes in Pressure with Wear and Repetitive Use

Seemingly little is known about the maintenance of applied pressures in vivo with use for sport. Considerations here include issues of short-term deformation, due to mechanical forces associated with one wear period (Manshahia and Das 2014), and longer-term deformation and degradation, due to mechanical forces associated with repetitive wear and laundering and via prolonged exposure to agents such as ultraviolet light, sweat, and detergent.

Sporting compression garments are extended ('stretched') when they are worn, both during the donning process and once in place. Thus, these garments will be exposed to a combination of sustained and variable stress and strain over the duration of a period of wear. When materials such as fibres and fabrics are subjected to constant strain (i.e. when extended and held at a particular length and width, and multi-axially, as in the case of compression clothing), the stress can gradually decay with time (Morton and Hearle 2008). This phenomenon is known as stress relaxation (Walker 1993). In a variable strain environment below the breaking extension, such as cycles of extension and recovery during movement, a fibre or fabric will typically increase in length until it reaches a stable limiting value (Morton and Hearle 2008).

The observed strain in fabrics is usually comprised of a combination of elastic, viscoelastic, and permanent components of deformation (Nikolic and Mihailovic 1996). True elastic deformation is 'instantaneously' reversible when the applied force is removed, viscoelastic deformation is where the strain is time-dependent, and the permanent component is both time-dependent and irreversible (Walker 1993). The strain in compression garments associated with the stress of wear will depend on a multitude of factors, including properties and characteristics of the fibres (e.g. inter-atomic and intermolecular bonds), yarns (e.g. bending rigidity) and the fabric (e.g. stitch length and density, inter-yarn friction, and residual tensions from the knitting process) (Morton and Hearle 2008; Karimi et al. 2009).

In one study, Faulkner and colleagues (2013) reported in vivo pressures before and following a 400 m running performance test. There were two conditions for compression garments: full-length lower-body garments (hip to ankle) or a combination of compression shorts (hip to knee) with calf compression sleeves (ankle to knee). Six of the eight sites where the applied pressures were measured indicated a significant main effect of time ($P < 0.05$): for the full-length garment and the garment combination, the changes at these sites were decreases of 0.8–2.3 and 0–1.7 mmHg, respectively, from pre- to post-exercise (calculated from reported group means). A seventh site, the gluteal, showed a significant decrease with the full-length garment only (by 1.2 mmHg). In this study there were no effects of either compression condition versus regular running shorts for 400 m performance or 100 m split times, heart rate, or blood lactate profiles (Faulkner et al. 2013). Thus, the practical significance of any changes in pressure is hard to judge given the lack of pressure effect in the first place. Moreover, although statistically significant, the changes in pressures were (on average) typically small. Further investigation of changes in applied pressures with use over longer wear sessions (e.g. endurance exercise or during recovery) or with multiple wear sessions is warranted. In any such studies there is also justification for including pressure measurements at multiple time points to assess when (or if) pressures stabilise.

In previously unpublished work, fabric samples were cut from commercially available sporting compression garments in areas with no seams (see "Appendix 2: Multi-axial Extension and Recovery Testing of a Compression Garment Fabric" for more detail). In brief, fabrics were then subjected to extension and recovery cycling (repeated multi-axial 'stretching') using a laboratory tensile tester fitted with a hemispheric head and pre-loaded to 0.5 N. The number of extension and recovery cycles was chosen to approximate an exercise session of $\sim$80 min. Prior to the beginning of fabric cycling, the period of fixed strain (pre-load extension depth) resulted in stress-relaxation of the fabric: the mean minimum loads at the start of

Table 3 Multi-axial extension and recovery cycling of compression garment fabrics using a laboratory tensile tester

Cycle stage	Mean ± SD (N)
Pre-load (0.5 N)[a]	0.00
Minimum load[b]	
Start	0.25 ± 0.01
Middle	0.32 ± 0.03
End	0.35 ± 0.05
Maximum load[c]	
Start	−1.35 ± 0.05
Middle	−1.26 ± 0.06
End	−1.24 ± 0.08

SD, standard deviation

[a] Fabrics were pre-loaded with an extension that gave 0.5 N, then zeroed as the start point of extension and recovery cycling (i.e. became 0 mm and 0 N)

[b] Minimum load is the extension load at a cycle depth of 0 mm (0 N indicates complete recovery, 0.5 N indicates no recovery)

[c] Maximum load is the extension load at a cycle depth of 10 mm (negative indicates load direction)

cycling had reduced by 50 % from pre-load (Table 3). Results indicated that both the minimum and maximum loads reduced from beginning to midway through cycling (each $P \leq 0.01$), but not thereafter ($P = 0.503$ and 0.173, respectively). These results suggest that fabrics stabilise with acute use, although how this translates to pressure stabilisation is not known.

An example of why it may be useful to know how applied pressures change with wear comes from the work of Mayrovitz (1998), also reiterating potential arterial haemodynamic consequences of compression. With ankle-to-knee compression bandaging of ~30 mmHg, below-knee pulsatile blood flow was acutely higher by ~45 % relative to the contralateral leg (with “noncompressive” control bandaging) in resting healthy women in the supine position. Increased pulsatile blood flow (evaluated using nuclear magnetic resonance flowmetry) was attributed to an overall increase in below-knee blood flow. However, these increases were not present when re-evaluated after 7 h of normal activity. The bandage-applied pressures had reduced by ~40–50 % to 16–19 mmHg by the second measurement period, so this may represent a causal relationship between the flow and applied pressures (Mayrovitz 1998). While compression bandages are considerably different to sports compression garments (such dramatic changes in the applied pressures over this duration could only be expected using inelastic bandaging), the point remains, if a particular beneficial outcome is present, this outcome may not remain if the applied pressures change beyond certain thresholds.

Compression Garments and Body Coverage

Body Coverage

Compression garments must cover particular body sites to be able to apply compression. The result is either a higher proportion of body surface covered (the addition of coverage for sites that would otherwise be uncovered), or an additional layer of clothing (for sites already covered). Like other clothing, compression garments will influence heat and moisture exchanges between the body and its environment. The effects of coverage may be inconsequential or even useful in some situations, such as during warm up or when the ambient temperature is cool, however, in other situations this coverage must be balanced against comfort and thermoregulatory considerations. While a review of the thermophysiological effects of compression garments is beyond the scope of this chapter, here we briefly introduce some pertinent information about compression garments as a clothing layer per se.

Garment-Body Interactions

Comfort

Given the direct proximity of compression garments with the body covered, comfort is likely to influence an athlete's tolerance to wearing these garments. Conceptually, wear comfort can be considered to comprise four aspects: thermophysiological, skin sensorial, ergonomic, and psychological wear comfort (Bartels 2005; Yoo and Barker 2005). Thermophysiological wear comfort relates to the way clothing buffers, dissipates or transports metabolic or environmental heat and moisture through the clothing. Skin sensorial wear comfort embodies the mechanical sensations caused by a textile in direct contact with the skin. These sensations (and subsequent perceptions) include smoothness, softness, roughness, stiffness, and the clinging feeling of wet clothing. Ergonomic wear comfort relates to the fit of the clothing and the freedom of movement it allows, and is affected by factors such as the garment design, fabric structure, and extension properties of the materials. Psychological wear comfort is how the individual feels in that clothing, and is influenced factors such as fashion, personal preferences and ideology (Bartels 2005; Yoo and Barker 2005). In speculation, perceived advantages of wearing compression garments will contribute to psychological wear comfort, and under any given conditions, will be balanced against potential disadvantages of thermophysiological, skin sensorial, and ergonomic wear comfort, where such disadvantages exist.

Heat and Moisture

When clothing is worn it establishes a microclimate next to the body. This microclimate is comprised not only of the materials used to form the clothing (fibres, yarns and fabrics), but the air and (if present) moisture within the fabric, between clothing layers (if other layers are worn), and adhered to the surfaces as boundary layers. The exchange of heat between the body and environment occurs via conduction, convection, and radiation. Evaporation also contributes to heat exchange via mass transport (i.e. water vapour transfer). These processes of heat and mass transport depend on gradients (e.g. thermal or vapour pressure), and thus the ambient conditions are also important.

Air is a poor conductor of heat, and because fabrics act to stabilise air within its structure, fabrics are generally good insulators (Wilson et al. 2002). With body movement or ambient air movement, convection displaces warmed air within the fabric microclimate, leading to increased heat loss. Easily displaced air may be advantageous when heat loss is required and disadvantageous when insulation is required.

Sweating is crucial for heat balance during exercise. The interaction of sweat with clothing occurs in both liquid and vapour forms. Clothing typically resists the transfer of water vapour away from the body, thereby increasing the local vapour pressure and reducing the gradient for evaporation at the skin surface. Water vapour transfer, like heat transfer, is augmented by forced convection. Further, the water vapour permeability of a stretched fabric will likely be greater than that of that same fabric in a relaxed state.

Compression garments are often claimed to ‘wick’ sweat to the garment surface where it can be evaporated easily, but the role of this liquid transportation in increasing *heat loss* from the body appears to lack empirical support. Wicking, also known as capillary transport, is the spontaneous transport of a liquid driven into a porous system by capillary forces (Kissa 1996; Patnaik et al. 2006). It is plausible that capillary transport along the yarns in the spaces between fibres may act to disperse liquid moisture from a wetted area (Saricam 2015), thus contributing to speedier evaporation. Further, with higher levels of liquid, the inter-yarn capillary spaces can saturate, making transverse capillary transport possible (i.e. liquid movement from the skin surface to the outer fabric surface, perpendicular to the plane of the fabric) (Rossi et al. 2011). However, if sweat is transported from the skin surface before it evaporates, the contribution of the skin to the heat of vaporisation will decline. Indeed, the evaporation of sweat from the fabric surface of a garment is less efficient (in terms of heat loss from the body) than evaporation directly from the skin surface itself (Craig and Moffitt 1974; Nagata 1978). The site of evaporation notwithstanding, liquid sweat displaces air and increases fabric thermal conductivity (Chen et al. 2003) and so, in practice, an interaction of increases and decreases in heat and moisture transfer likely occurs with wetted fabrics.

While heat loss is typically desirable during exercise, residual sweat in the garments following exercise can lead to thermal discomfort via unwanted heat loss (‘post-exercise chill’). Garments that have a short drying time mitigate such effects (Bartels 2005).

Some Measurable Fabric Properties and Why They Are Useful

Characterising the garments. Much like characterising participants and the applied pressures is useful, so too is characterising a garment system and fabrics from which these are made. Garment properties are not static, but also respond to the conditions in which they are used: moisture from the ambient environment and from the body may be absorbed, adsorbed, or moved through a fabric by a wicking process; an extended textile may exhibit non-elastic behaviour. What properties are relevant to compression and compression products? How might products which superficially appear similar actually differ?

Table 4 lists two groups of fabric properties: those related to structure of the fabric and those related to performance, and for each a list of test methods relevant to compression garments. Note that international test methods dominate, as compliance with these is more likely to yield agreement among interested parties. Note

Table 4 Selected fabric test methods relevant to compression clothing

Property	Test method	Test determines	Title (reference)
Structure			
Thickness	ISO 5084: 1996 (reviewed 2013)	Thickness of textiles and textile products under specified pressure	Textiles—Determination of thickness of textiles and textile products (International Organization for Standardization 1996)
Mass	ISO 3801: 1977 (reviewed 2011)	Mass per unit length and mass per unit area of piece or sample length of fabric and mass per area of small samples	Textiles—Woven fabrics—Determination of mass per unit length and mass per unit area (International Organization for Standardization 1977)
Mass	BS EN 12127: 1998 (current)	Mass per unit area based on measurement of small samples of fabrics	Determination of mass per unit area using small samples (British Standards Institution 1998)
Mass	ASTM D3776 M—09a (reapproved 2013)	Mass per unit area of full piece, bolt, cut, full width specimens, small swatch and narrow fabrics	Standard test methods for mass per unit area (weight) of fabric (ASTM International 2013)

(continued)

Table 4 (continued)

Property	Test method	Test determines	Title (reference)
Elongation with force	ISO 13934-1: 2013	Maximum force, force of rupture, elongation at maximum force and at rupture	Textiles—Tensile properties of fabrics—Part 1: Determination of maximum force and elongation at maximum force using the strip method (International Organization for Standardization 2013b)
Elongation with force	ISO 13934-2: 2014	Maximum force, force of rupture, elongation at maximum force and at rupture of fabrics containing elastomeric fibre	Textiles—Tensile properties of fabrics—Part 2: Determination of maximum force using the grab method (International Organization for Standardization 2014a)
Elasticity	BS EN 14704-1: 2005 (current)	Recovery from extension of fabrics	Determination of the elasticity of fabrics. Strip tests (British Standards Institution 2005)
Performance			
Absorption	ISO 18696: 2006 (reviewed 2015)	Resistance of fabrics to wetting (the absorption of water into, but not through, the fabric). Suitable for measuring the water-repellent efficacy of applied finishes	Textiles—Determination of resistance to water absorption—Tumble-jar absorption test (International Organization for Standardization 2006)
Water penetration (rain resistance)	ISO 18695: 2007 (reviewed 2011)	Resistance of fabrics to the penetration of water by low impact—can predict the probable rain penetration resistance	Textiles—Determination of resistance to water penetration—Impact penetration test (International Organization for Standardization 2007)
Water penetration (water under pressure)	ISO 811: 1981 (revision in progress as ISO/WD811)	Resistance to the passage of water through the fabric	Textiles—Determination of resistance to water penetration—Hydrostatic pressure test (International Organization for Standardization 1981)
Air permeability	ISO 9237: 1995 (reviewed 2011)	Permeability of fabrics to air	Textiles—Determination of the permeability of fabrics to air (International Organization for Standardization 1995)
Thermal resistance	ISO 5085-1: 1989 (reviewed 2015)	Thermal insulation provided by textiles/transmission of heat through a textile	Textiles—Determination of thermal resistance—Part 1: Low thermal resistance (International Organization for Standardization 1989)

(continued)

Table 4 (continued)

Property	Test method	Test determines	Title (reference)
Thermal and water-vapour resistance	ISO 11092: 2014	Thermal and water-vapour resistance using a variety of environmental conditions, involving combinations of temperature, relative humidity, air speed, and in the liquid or gaseous phase, to simulate different wear and environmental situations	Textiles—Physiological effects—Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test) (International Organization for Standardization 2014b)
Exothermic and endothermic properties	ISO 16533: 2014	Exothermic and endothermic properties by moisture absorption and desorption	Textiles—Measurement of exothermic and endothermic properties of textiles under humidity change (International Organization for Standardization 2014c)
Force of seam rupture	ISO 13935-1: 2014	Maximum force of sewn seams when the force is applied perpendicular to the seam	Textiles—Seam tensile properties of fabrics and made-up textile articles—Part 1: Determination of maximum force to seam rupture using the strip method (International Organization for Standardization 2014d)
Force of seam rupture	ISO 13935-2: 2014	Maximum force of sewn seams when the force is applied perpendicular to the seam for fabrics containing elastomeric fibre	Textiles—Seam tensile properties of fabrics and made-up textile articles—Part 2: Determination of maximum force to seam rupture using the grab method (International Organization for Standardization 2014e)
UV	AATCC TM183-2014	Ultraviolet radiation blocked or transmitted by textile fabrics	Transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics (American Association of Textile Chemists and Colorists 2014)
UV	AS/NZS 4399: 1996 (current)	Requirements for determining the rated UV protection factor of sun protective textiles	Sun Protective Clothing—Evaluation and Classification (Standards Australia and Standards New Zealand 1996)

too, that because many properties of textiles differ with ambient conditions, the testing of fibres, yarns, fabrics, and garments is conducted under standard environmental conditions following a period of conditioning in that same environment [typically 24 h at 20 ± 2 °C, 65 ± 4 % relative humidity according to ISO 139 (International Organization for Standardization 2005) or 21 ± 2 °C, 65 ± 5 % relative humidity according to ASTM D1776 (ASTM International 2016)]. However, there may be good reason to test under different conditions, perhaps simulating conditions of use.

Structural properties. Most fabrics are constructed of fibre and in compression products these are typically synthetic fibres (e.g. polyester, polyamide) which may be blended (e.g. with some form of elastane). Most are continuous filaments with various cross-sectional structures, typically with a smooth surface, and may be single or plied. These yarns then are knitted either using weft or warp technologies, yielding different fabric properties, particularly elasticity. Warp knits are typically more resistance to extension than weft knits.

Consider the structural properties listed in Table 4 (and take the following remarks as 'if all other factors are equal'). Thickness of a fabric has a major effect on thermal resistance: the thicker the fabric, the more thermally resistant. Because most fabrics are themselves compressible, the test method for fabric thickness specifies the pressure under which the thickness is measured. Mass of fabrics is expressed in grams per square metre (g/m^2). The relevance here to compression garments is the effect that fabric mass per unit area has on mass of the total garment. The trend in garments generally is for apparel fabrics to be manufactured so the end products are lighter. Elongation is one of several tensile-related properties. Note that while the test requires the strip of fabric to be extended to rupture, investigators are often more interested in extending a fabric/garment an estimated percentage and typically allowing recovery, and repeated extension/recovery cycles (elasticity). Changes evident with this type of test (decay) are a better reflection of a compression garment or bandage, yet, surprisingly few examples of fabric cycling experiments exist (see Section "Changes in Pressure with Wear and Repetitive Use" and "Appendix 2: Multi-axial Extension and Recovery Testing of a Compression Garment Fabric"). Elastic recovery is more likely when the fabric contains an elastane filament (e.g. Lycra® or spandex, or a non-branded elastane). So from the perspective of an end-user interested in compression, knowing that the elasticity changes over time is highly relevant.

Performance properties. The second part of the table focuses on some examples of performance properties. Together these deal with water, air, thermal, and UV properties. In relation to water, interest may be in the extent to which the fabric absorbs moisture (from sweat or from an external source). If a fabric absorbs and holds moisture, either in the fibre itself or in the fabric, this may have a measureable effect on thermal resistance and on perceptions of discomfort of the wearer. Air permeability is self-explanatory: to what extent does air pass through the fabric? The instrument settings for this test depend on the fabric structure, so comparison of test results obtained on different fabrics where the settings have differed is not appropriate. Thermal resistance too, is self-explanatory: to what extent does a fabric resist transmission of heat? The physical set-up for the test attempts to simulate the skin-fabric interface. Fabrics differ in thickness and mass, as noted in the preceding section, and both of these properties affect thermal transmission: a thicker fabric will typically exhibit greater resistance. So for comparisons among fabrics, derived values can also be used (e.g. warmth: weight, warmth: thickness). Resistance to water vapour transmission is measured using a similar set-up, with a thin layer of water on the plate, and ratios are also derived for appropriate comparisons among fabrics. Compression garments are often worn outdoors, and in Australasia, protection against UV penetration is a health-related consideration. Fabrics will be extended during wear so testing when extended will provide a more useful indicator of fabric performance in this regard.

To summarise, fabrics for compression items, while appearing similar, will differ in properties when new and when worn. They are not static, but change during use, absorbing moisture (or not), changing in thickness when extended, which in turn reduces thermal resistance. Thus, simply reporting fibre content and perhaps country of origin (manufacture) on a label or promotional information for a compression item is unlikely to provide sufficient information for use in scientific investigations of effects of compression garments, or indeed, for the consumer's personal information. Further, while test results on some fabrics may be provided by manufacturers/suppliers, these need to be scrutinised to ensure an appropriate method has been used. Reporting fabric and garment properties also helps identification of/changes in manufacturing trends over time and, in particular, assists in establishing whether comparability of findings from different studies are warranted. For example, the compression shorts used in one highly cited study were 4.76 mm thick and made from 75 % closed-cell neoprene and 25 % butyl rubber (Doan et al. 2003); conventional sporting compression garment fabrics have been reported as less than 0.7 mm thick (MacRae et al. 2012; Del Coso et al. 2014).

Comments and Conclusions

Compression garments apply pressure to *and* cover body surfaces. In this chapter we have deliberately highlighted aspects of pressure and coverage that can be of importance yet often have been overlooked. In particular, we argue that measuring, reporting, and understanding characteristics of the applied pressures in vivo are essential for integrating the literature irrespective of whether or not compression influences a particular outcome. That is, to support or rule out the influence of compression, the compression itself must be known. Further, it is not yet clear what applied pressures are required, particularly across different outcomes. We have also introduced aspects relevant for compression garments from the perspective of a layer of clothing that covers the body. Body coverage can have consequences for heat and moisture interactions with the environment, and for wearer comfort. We hope that the detail here helps the reader to contextualise and critically evaluate research on compression garments in sport.

For further detail specifically about the physiological or performance effects of compression garments in sport we refer the reader to the other chapters in this book and previously published reviews or commentaries (e.g. Kraemer et al. 2004; Perrey 2008; MacRae et al. 2011; Born et al. 2013; Hill et al. 2014a; Surhoff 2014; Beliard et al. 2015; Marqués-Jiménez et al. 2016).

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Appendix 1: Search Details for Table 1

For the purpose of summarising key characteristics (Table 1), a systematic search was performed to identify relevant journal articles published over a ~5-year period (2011 to 15 Jan 2016). Inclusion criteria were: (1) original research studies involving human participants and published in English, (2) studies in which compression garments were worn for sport and exercise or recovery from sport and exercise, and (3) that compression garments were worn for a period or periods during and/or after sport and exercise. There was no restriction on type of compression garment in terms of body area covered, although the garment was to be similar to commercially available sporting garments (e.g. bandaging was excluded). Exclusion criteria were: (1) studies in which compression garments were used for recovery from injury, (2) use for disease prophylaxis, even if in association with exercise (e.g. exercise in patients with lymphedema), and (3) abstracts and unpublished studies. The search was performed in Ovid® MEDLINE using the search strategy (Table 5), identifying 166 articles. One author (BM) screened the results first by title and abstract (101 excluded: 9 reviews or commentaries, 1 repetition, 91 topic medical, not compression garments, and/or not sport) then by full text (12 excluded: 3 injury related, 5 not sport or exercise, 4 due to garment); 5 further articles were located from reference lists giving a total of 58 included (Ali et al. 2011; Dascombe et al. 2011a; Goh et al. 2011; Lovell et al. 2011; Ménétrier et al. 2011; Miyamoto et al. 2011; Sperlich et al. 2011; Varela-Sanz et al. 2011; Dascombe et al. 2011b; Burden and Glaister 2012; Coza et al. 2012; de Glanville and Hamlin 2012; Hamlin et al. 2012; MacRae et al. 2012; Rimaud et al. 2012; Wahl et al. 2012; Argus et al. 2013; Bahnert et al. 2013; Barwood et al. 2013; Bovenschen et al. 2013; Driller and Halson 2013a; Faulkner et al. 2013; Pruscino et al. 2013; Rugg and Sternlicht 2013; Sperlich et al. 2013a; Tsuruike and Ellenbecker 2013; Valle et al. 2013; Driller and Halson 2013b; Bieuzen et al. 2014; Born et al. 2014a; Del Coso et al. 2014; Duffield et al. 2014; Ferguson et al. 2014; Goto and Morishima 2014; Lien et al. 2014; Michael et al. 2014; Miyamoto and Kawakami 2014; Pereira et al. 2014a; Rider et al. 2014; Sperlich et al. 2014; Venckunas et al. 2014; Vercruyssen et al. 2014; Born et al. 2014b; Hill et al. 2014b;

Table 5 Search terms

Item #	Search term/search restriction	Number of results
1	compression.ti,ab.	82,145
2	compressive.ti,ab.	15,945
3	1 or 2	94,566
4	clothing.mp.	16,689
5	(garment or garments).mp.	1929
6	(stocking or stockings).mp.	4479
7	(sock or socks).mp.	811
8	(sleeve or sleeves).mp.	6599
9	tights.mp.	48
10	leggings.mp.	23
11	shorts.mp.	277
12	top.mp.	67,366
13	upper-body.mp.	3442
14	lower-body.mp.	9254
15	4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14	108,307
16	3 and 15	2951
17	exercise*.mp.	278,507
18	sport*.mp.	71,794
19	physical activity.mp.	66,804
20	(run or running or ran).mp.	118,260
21	(cycle or cycling or cycled).mp.	432,976
22	endurance.mp.	28,954
23	sprint*.mp.	4923
24	resistance.mp.	654,350
25	17 or 18 or 19 or 20 or 21 or 22 or 23 or 24	1,500,610
26	16 and 25	429
27	limit 26 to yr = “2011—Current”	175
28	limit 27 to english language	166

Pereira et al. 2014b; Areces et al. 2015; Armstrong et al. 2015; Gupta et al. 2015; Hooper et al. 2015; Lucas-Cuevas et al. 2015; Martorelli et al. 2015; Ménétrier et al. 2015; Mills et al. 2015; Miyamoto and Kawakami 2015; Priego et al. 2015; Priego Quesada et al. 2015; Stickford et al. 2015; Zaleski et al. 2015).

Appendix 2: Multi-axial Extension and Recovery Testing of a Compression Garment Fabric

Garment pre-treatment and cutting of fabric samples. Unworn upper-body compression garments to be used for fabric testing (for garment descriptions see MacRae et al. 2012) were subjected to six consecutive gentle wash cycles as outlined in procedure 8A in ISO 6330 (International Organization for Standardization 2000) and air dried in ambient laboratory conditions. This pre-treatment protocol has been shown to achieve reasonable stability in properties of a range of fabrics (Gore et al. 2006). An Electrolux Wascator FOM71MP-Lab (James Heal and Co Ltd., Halifax, England) automatic washing machine was used with Heal's ECE formulation non-phosphate reference detergent (B). Standard ballast (knitted 100 % polyester fabric) was used to make up the total dry mass of 2 kg per load of test garments. Fabric specimens were cut from garments according to BS EN 12751 (British Standards Institution 1999). Fabrics were conditioned (for 24 h) and tested in a standardised environment 20.0 ± 2.0 °C and 65.0 ± 4.0 % relative humidity (International Organization for Standardization 2005).

Multi-axial extension and recovery. The behaviour of a compression garment fabric (n = 3) during extension and recovery cycling was examined in accordance with a modified version of ISO 3379 (International Organization for Standardization 1976). An Instron Tensile Tester (Model 4464, Instron Limited, England) with a 100 N load cell was fitted with a ball burst attachment (half sphere, diameter = 50 mm) that cycled between fixed extension limits. Fabric specimens (diameter = 100 mm within clamping ring) were pre-loaded with the ball burst attachment to 0.5 N (i.e. moderate extension), and cycled to a depth of 10 mm from the pre-load zero point for 7000 cycles, with a head speed of ~1000 mm/min (~50 cycles/min). The number of cycles was selected to approximately represent one exercise session (e.g. bicycling with a cadence of 90 RPM, 7000 extension and recovery cycles is ~78 min of exercise). Load data were transferred to PC computer (PowerLab 16 SP; ADInstruments, Dunedin, New Zealand) and collected at 1000 Hz using Chart software (Chart 4.2 for Windows; ADInstruments). Means for cyclic minima and maxima were calculated at the beginning, middle, and end of cycling, each over 15-min periods (minutes 0–15, 62–77, and 127–142). Note that the tensile tester required 142 min to complete the 7000 cycles (cf. the estimate of 78 min for exercise with a pedalling cadence of 90) because it was not practicable to have a head speed equivalent to 90 cycles/min. Linear mixed models with a compound symmetry covariance matrix was used for statistical analysis (SPSS 16.0, SPSS Inc). Bonferroni correction for multiple comparisons was used when required.

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