Analysis of Thermal Sensation and Wearing Comfort before and after Bikram Yoga Activity

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Abstract

This study evaluated the effect of functional characteristics of the fabric for Bikram yoga clothing and fit measured in clothing pressure on the wearer's physiological response and perceptive sensation before and after exercise in hot conditions and during a resting period in standard conditions. The test garment consisted of two tops (T1, T2) and two pants (P1, P2) each with different functional characteristics of fabric. Using various combinations of the test garments, assessment of the thermal sensation and comfort was performed before/after yoga and after resting. This study revealed that thermal sensation and wearing comfort significantly changed based on the functionality of the fabric of top garment before the exercise period. In addition, the results showed that based on clothing pressure, the feeling of comfort was different between before yoga and after resting. The appropriate choice of fabric material was important when constructing Bikram yoga clothing worn in hot conditions; however, level of clothing pressure was also found to be an essential design factor for comfort during rest after exercise.

Key words: Bikram yoga clothing, Fabric characteristics, Clothing pressure, Thermal sensation

I. Introduction

Yoga is known to increase muscle strength and maximal aerobic capacity along with improvement of exercise tolerance. (Dash & Telles, 2001; Mandanmohan et al., 2003; Ray et al., 2001; Tekur et al., 2008; Tracy & Hart, 2013). Bikram yoga is one of the various yoga styles composed of a series of 26 postures that are repeated twice and each yoga session lasts for 90 minutes in a 34°C temperature and relative humidity of 40% (Chaya & Nagendra, 2008; Pate & Buono, 2014). The human body typically emits heat and sweat during intense activity and this physiological change is essential knowledge in the context of sports activity (Hayes & Venkatraman, 2016). In the human-clothing-environment system, the clothing helps to achieve thermal balance for the human body. Especially for activities performed in a hot environment like Bikram yoga, yoga clothing can be an important beneficial or detrimental variable because the clothing can provide efficiency against perspiration but it can also pose discomfort due to limitation in body motion and unwanted skin exposure during performance (Green, 2014).

In general, if an article of clothing provides good evaporation during exercise in a hot and moist environment, then it is considered to be advantageous for the comfort (Mert et al., 2016). Clothing properties influence skin temperature and sweat production. The important clothing properties for moisture transport in fabric are fiber type, clothing construction, weight or thi-
ckness of the materials, and presence of chemical treatments (Adanur, 2017; Chaudhari et al., 2004; Choi et al., 2004). Through fiber and fabric type approach of exercise clothing, the athletic apparel market selects for fabric with numerous functionalities, especially when discussing thermoregulatory parameters because evaporation rate is a critical concern for sportswear and performance apparel (Gavin et al., 2001; Hayes & Venkatraman, 2016). For exercise like Bikram yoga that is performed in a hot environment with great perspiration rate, the primary functionalities of the selected fabric should have great absorption and evaporation of the absorbed moisture to maintain standard and dry conditions between the skin and the clothing. Meanwhile, in the clothing construction area, fit and style that prevents hindrance of poses should be considered for yoga clothing due to the characteristics of yoga requiring wide and flexible movement range of the joints.

Davis et al. (2017) study compared garments with natural fiber and synthetic fiber in moderate intensity exercise performed in the heat. This study showed that the synthetic fabric construction decreased regional microenvironment temperature, reduced overall body exertion and thermal sensation. But there was no effect in thermoregulation, ratings of perceived exertion, and clothing comfort for synthetic fabric construction. Gavin et al. (2001) also demonstrated that clothing fabric characteristics have no significant differences in the physiological, thermoregulatory, and comfort sensation responses during moderately warm condition. This similar result was also found in Brazaitis et al. (2010). However, there were other contrasting studies that showed positive effects of fiber and fabric construction. For example, Gonzales et al. (2011) showed increased thermal comfort during cycling in a hot and moist environment when wearing polyester jerseys with larger knits. Regarding fit and style, Mert et al. (2016) investigated the effects of garment’s fit and style on thermal comfort, showing that higher skin temperature was observed in a loose fit garment than in tight garments at the thigh, but the fit and style had no impact on core temperature and total water loss. Meanwhile, tighter fitting garments are preferable to keep the body warm in windy conditions since less air gap is more effective in preventing convection Chen et al. (2004). These various researches show contrasting results of whether fabric and fiber elements or fit and style elements truly have a significant effect but carry considerably convoluted inclinations on different physiological, thermoregulatory, or comfort conditions. However, these studies overall comparatively evaluated the characteristics of different clothing material by only the fiber type, which resulted in the neglect of the change in functionality of fabric based on different fabric composition or construction. Other limitations were also present, such as not using loose fit garment during their study and that proper quantified clothing pressure was not provided even when using tight garment.

Therefore, the purpose of this study is to evaluate both the effect of functional characteristics of the fabric of Bikram yoga clothing and effect of fit measured in clothing pressure on the wearer’s physiological response and perceptive sensation before, after exercise in hot conditions, and after rest in standard condition. In this study, the physiological response was represented through the amount of perspiration, while clothing comfort and thermal sensation represented the perceptive sensation. Finally, by analyzing the parameters of physiological response and perceptive sensation reaction of garments and how these variables interact, this study attained the appropriate clothing components for exercise in a hot condition. The results of this study would be expected to provide valuable information to designers of Bikram yoga clothing and to consumers.

II. Methods

1. Fabric and Garments

Most of the yoga garments purchased from the current market are tight fitted garments. There were limitations to control the variable of the study since ready-to-wear yoga clothing has various fabric construction and size. To address this issue, ready-to-wear yoga garment purchased at an athletic apparel brand for yoga was analyzed with fabric characteristics mostly used
for the fabric thermal evaluation. Additionally, the quantitative measurements of fit for each variable used for the explanation of the result was provided through measuring clothing pressure. The test garment used in this study, which were ready-to-wear yoga garments, consisted of two tops (T1; Nylon 84%, Polyurethane 16%, T2; Viscose rayon 92%, Polyurethane 8%) and two pants of leggings style (P1; Nylon 72%, Polyurethane 29%, P2; Nylon 92%, Polyurethane 8%) as seen in <Table 1>. The functionality of fabric of the test garment that were evaluated included density, thickness, stretch properties (implementation of ASTM D2594 - 04 500 g weight) [American Society for Testing and Materials [ASTM], 2004], efficiency of thermal heat transfer upon initial contact measured in Qmax warm/cool feeling (Thermolabo II KES-F7, KATO Tech Co., Ltd., Japan), absorption (International Organization for Standardization [ISO], 2000), and drying rate (ISO, 2014). Each measurement was performed in five trials and average was used for analysis. Meanwhile, to examine the level of fit, clothing pressure was measured using an air pack type pressure sensor AMI3037-2 (AMI Techno, Co, Ltd., Japan). Total of four body area were measured with shoulder and the girth of chest for upper body and the mid-buttocoks and mid-calves for lower body. Four different test garments, categorized as T1P1, T1P2, T2P1, T2P2, were used as a result of the combination of two upper (T1, T2) and two lower garments (P1, P2). Latin square design was used to reduce systematic error by order effect. The participants engaged in the study once per day followed by a couple of days of rest before being tested again and four days worth of experiments were obtained.

2. Measurement Protocol

Eight participants in their twenties with yoga training license and average of 3.8 years of yoga experience voluntarily participated in this study (bust girth: 83.4±3.5 cm, waist girth: 67.5±2.5 cm, hip girth: 91.5±2.6 cm, height: 160.9±5.2 cm, weight: 55.1±8.5 kg). Prior to the experiment, for the subjects' safety and the protection of their rights, approval from the National Ethics Committee (201807-SB-101-01) was obtained. The protocol of the experiment is outlined in <Table 2>. First, participants rested for about five minutes in a standard conditioned room (25°C, 40% RH), then participants wore test garments and clothing pressure was measured in standard condition. Then, participants entered a climate chamber set to the environment for Bikram yoga (34°C, 40% RH) and adjusted to the new condition for about five minutes. Before exercise in this

Table 1. Yoga clothing design and fabric property for experiments (The circled marks indicate the location of clothing pressure measurement)

<table>
<thead>
<tr>
<th>Fiber contents</th>
<th>Point of measurement for yoga clothing</th>
<th>Tops</th>
<th>Pants</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Chest girth: 66 cm</td>
<td>T1</td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td>Waist girth: 62 cm</td>
<td>T2</td>
<td>P2</td>
</tr>
<tr>
<td></td>
<td>Front length: 59 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>Chest girth: 70 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waist girth: 67 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front length: 58 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>Waist girth: 59 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hip girth: 60 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crotch depth: 26 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outseam: 77 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>Waist girth: 53 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hip girth: 63 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crotch depth: 24 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outseam: 81 cm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
climate chamber, thermal sensation and wearing comfort were subjectively evaluated and weight was measured while wearing the prototype. Among the 26 Bikram yoga poses, 16 yoga poses were selected for this study and the subjects were asked to repeatedly perform these 16 poses for two times <Fig. 1>. Immediately after the exercise, participants' weights were measured again to analyze the absorbed perspiration amount of the yoga garment along with evaluation of thermal sensation and wearing comfort. After the tests, participants rested for 15 minutes in a standard condition (25°C, 40% RH), then participants were again asked to answer a survey about thermal sensation and wearing comfort during their resting period. This survey that was performed before exercise, after exercise and resting period was based on subjective evaluation of a 7-point Likert scale, consisting of thermal sensation (1 = Extremely hot, 4 = Neutral, 7 = Extremely cool) and wearing comfort categories (1 = Extreme discomfort, 4 = Neutral, 7 = Extremely comfort). Participants were asked to select areas of discomfort due to sweat that were distinguished to chest, back, and abdomen for upper body and hips, groin, thighs, and calves for lower body. The results of the survey were demonstrated in body mapping as seen in <Fig. 2> and the color darkened as the response rate increased.

3. Statistical Analysis

All measured data for functionality of fabric of test garments, including density, were presented in mean with standard deviation. The amount of body perspiration was calculated by subtracting the weight after exercise from the weight before exercise. Paired t-test

<table>
<thead>
<tr>
<th>Table 2. Experimental protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard condition</td>
</tr>
<tr>
<td>25°C, 40% RH</td>
</tr>
<tr>
<td>⋅ Adjust for 5 minute</td>
</tr>
<tr>
<td>⋅ First evaluation of test garment (A)</td>
</tr>
<tr>
<td>⋅ Weight measurement</td>
</tr>
</tbody>
</table>

| Fig. 1. Bikram yoga movement for experiment. |

- Pranayama |
- Ardha-Chandrasana |
- Utkatasana |
- Garurasana |
- Dandayamana-Dhanurasana |
- Dandayamana-Janushirasana |
- Tuladasana |
- Trikanasana |
- Tadasana |
- Padangustasana |
- Ardha-Matsyendrasana |
- Khapalbhathi |
was performed as data analysis for amount of perspiration and clothing pressure for each top and pants. Friedman one-way analysis of variance was used to analyze subjective thermal sensation and wearing comfort data and spearman correlation analysis was performed to analyze the correlation between wearing comfort and clothing pressure. SPSS Statistics version 23.0 (IBM software, NY, USA) was utilized for all statistical analysis performed in this study and the level of significance was set to $p < .05$. Through power analysis with G power 3.1 (Erdfelder et al., 1996) of the parametric test of eight subjects, which were assigned at effect size of 0.5, 53% power level was shown.

III. Results

1. Interview Procedures

The analysis of the functional characteristics of the fabric used in the test garment is shown in <Table 3>. The density was high for T1 for upper body clothing. The thickness was 0.78-0.89 mm, and the stretch properties of T1 was the highest while the stretch properties of T2 was the lowest. Qmax, absorption and drying rate of T1 were also found to be superior to those of T2. Overall, T1 was shown to have higher functionality of

<table>
<thead>
<tr>
<th>Code</th>
<th>Fiber contents (%)</th>
<th>Density (loop/5.0 cm)</th>
<th>Thickness (mm)</th>
<th>Stretch properties (%)</th>
<th>Qmax (W/cm²)</th>
<th>Absorption (mm/10 minutes)</th>
<th>Drying rate (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Nylon 84, Polyurethane 16</td>
<td>124.0</td>
<td>308.8</td>
<td>0.82</td>
<td>208</td>
<td>372</td>
<td>0.125</td>
</tr>
<tr>
<td>T2</td>
<td>Viscose rayon 92, Polyurethane 8</td>
<td>96.4</td>
<td>121.6</td>
<td>0.78</td>
<td>60</td>
<td>68</td>
<td>0.108</td>
</tr>
<tr>
<td>P1</td>
<td>Nylon 72, Polyurethane 29</td>
<td>133.8</td>
<td>287.4</td>
<td>0.80</td>
<td>124</td>
<td>160</td>
<td>0.105</td>
</tr>
<tr>
<td>P2</td>
<td>Nylon 92, Polyurethane 8</td>
<td>87.6</td>
<td>141.6</td>
<td>0.89</td>
<td>176</td>
<td>76</td>
<td>0.091</td>
</tr>
</tbody>
</table>
fabric than T2. For pants, P1 showed greater density, Qmax, and drying rate than P2, while absorption for P2 was measured higher than that of P1.

2. Clothing Pressure

As seen in <Fig. 3>, measurement of the clothing pressure of each test garment revealed that T1 measured 0.85±0.33 kPa for shoulder and 0.59±0.30 kPa for chest, while T2 was 0.37±0.26 kPa for the shoulder and 0.44±0.17 kPa for the chest. Statistically, T1 showed significantly higher clothing pressure in the shoulder area than T2 (p=.012), and T1 clothing pressure was greater for chest area as well, although there was no statistically significant difference. Thus, the design of T1 adhered more closely to the human body than T2. For pants, P1 buttocks measured to be 0.53±0.18 kPa and 0.77±0.21 kPa for calves, while P2 had 0.89±0.21 kPa for buttocks and 1.14±0.31 kPa for calves, which proved P2 generally had a tighter style. The only statistically significant variance was in the buttocks area in which P2 measured higher than P1 (p=.042). The thickness of fabric that was measured in this study did not have a significant impact on the stretch of the fabric. In addition, it was difficult to find consistent regularity between stretch and clothing pressure. Therefore, it seemed clear that the clothing pressure was the complicatedly affected variable that depended on the stretch of the fabric and the construction of clothing pattern based on size. Thus the clothing pressure would need to be considered when the fit of the compression garment is studied.

3. Absorbed Sweat Rates of Clothing

By measuring the weight before and after yoga, the difference between the weights was calculated and this value represented the amount of perspiration that the garment absorbed. This result is shown in <Table 4>. The weight increased after yoga for each of the test garments, indicating that all of the garments except absorbed sweat. When analysis of the relationship between the change of weight and the amount of perspiration was conducted, there was a positive relationship amongst the sweat rate, amount of the sweat absorbed and the garment weight during the exercise within 40 minutes at the climate chamber. However, the fallen sweat (non-acclimatized) on the floor and the rapid evaporation from the garment were not able to be considered in this analysis (Kakitsuba, 2004; Raccuglia et al., 2018). Therefore, it can be explained that when wearing T2P1 and T2P2, there was a statistically significant increase.
Fabric evaluation suggested that the wearer of T2 produced more sweat than the wearer of T1 regardless of the lower body clothing since T2 had slower heat transfer, absorption and drying rate than T1.

4. Perceptive Thermal Sensation and Wearing Comfort

The evaluation of the test garments before exercise in hot conditions is shown in <Fig. 4>. The general responses for evaluation of thermal sensation were at moderate level satisfaction with no significant statistical difference between the test garments. For wearing comfort, participants generally responded with ratings indicating slight comfort. Among these responses, comfort of the upper body was notably higher when wearing T1P1 than when wearing T2P1. The responses obtained after yoga in a hot condition is shown in <Fig. 5>. Similar to before exercise, thermal sensation was generally found to be at a neutral level and did not have a significant difference between the test garments, while wearing comfort was also found to be at a slightly comfortable level.

<Fig. 6> reveals that there was no notable difference between the thermal sensation of the test garments after rest in the standard environment. Also, while wearing comfort for the top increased to a slightly comfortable level, peculiarly for T2P1 than for T1P1, this was the opposite result from before yoga. Further evaluation will be necessary to explain the significant increase of comfort after rest for T2 because the fabric of the test garment of T2 showed lower functionality values than T1 for most categories, including Qmax, absorption, and dryness, but still showed greater comfort after rest. Meanwhile, while there were responses of cooler thermal sensation during the rest period after yoga in the standard environment than in a hot environment, there

<table>
<thead>
<tr>
<th></th>
<th>Before yoga</th>
<th>After yoga</th>
<th>Change (Before – After)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>T1P1</td>
<td>55.271 kg</td>
<td>3.259</td>
<td>55.289 kg</td>
<td>3.225</td>
</tr>
<tr>
<td>T1P2</td>
<td>55.444 kg</td>
<td>3.038</td>
<td>55.306 kg</td>
<td>3.261</td>
</tr>
<tr>
<td>T2P1</td>
<td>55.182 kg</td>
<td>3.201</td>
<td>55.244 kg</td>
<td>3.203</td>
</tr>
<tr>
<td>T2P2</td>
<td>55.493 kg</td>
<td>2.987</td>
<td>55.555 kg</td>
<td>2.984</td>
</tr>
</tbody>
</table>

***p<.001

Fig. 4. Thermal sensation and wearing comfort rating before yoga.
were generally assessments of lower wearing comfort. Also, despite the fact that the scores were not sensitively reflected on a scale since the evaluations made by participants were subjective, it was evident that thermal sensation and wearing comfort had more effect on the top than the pants.

Next, the changes in thermal sensation and wearing comfort according to the time at which yoga was performed are displayed in <Fig. 7>. All of the test garments showed an inclination to feel cooler over time, and such cool thermal sensations increased significantly after rest than before exercise when wearing T1P1 or T1P2. Meanwhile, when considering the aspect of wearing comfort, comfort tended to decrease after rest than before exercise, especially when wearing T1P1 that showed significant decrease in comfort after exercise and rest compared to before exercise. Thus, wearing T1 after the rest period led to cooler thermal sensation but lower wearing comfort, meaning that the interaction of various elements of the environment and clothing can ultimately affect thermal sensation and wearing comfort even when the functional aspect of the fabric material is superior. This interpretation will be further discussed in later pages of the discussion section.

Meanwhile, the results of body mapping the participants’ choices of their most uncomfortable region of the body after rest are shown in <Fig. 8>. It was notable that there was greater discomfort in the upper body, and areas in which there was discomfort changed along with different combinations of tops and pants. T1 sho-
wed a higher level of discomfort in the chest than in the back, while T2 had increased discomfort in the back. Upon cumulating the responses for all of the test garments and body mapping the total values, it was revealed that the chest and back regions of the top had the greatest discomfort. These results can be interpreted in the same context in which participants previously showed a more sensitive reaction in the upper body when making subjective evaluations. Smith and Haventh (2011) made a body map of the sweating pattern, which showed that the center upper and mid-chest and shoulder in the anterior body region, center-mid, lower and upper back along with upper leg in the posterior region had higher ratio values. Although this study did not exquisitely classify each region, upper body areas with greater sweat production were mainly associated with discomfort and could be interpreted in the same context as the pre-study.

Fig. 7. Thermal sensation and clothing comfort rating according to stage (before exercise, after exercise, and after relax).

Fig. 8. Clothing discomfort zone by sweating body mapping.
As mentioned above, since the comfort for the upper garment that the participants sensitively responded to showed little correlation with functionality of fabric material characteristic, additional analysis between fit and comfort was performed. Specifically, the clothing pressure around the shoulders of T1 and T2 showed statistical difference and the comfort evaluation for before, after exercise and resting period were analyzed using Spearman correlation. This result is seen in Table 5. In this study, there was no significant difference in p-value because there were only eight participants and no relation was observed between comfort and clothing pressure when wearing T1 in hot condition before and after yoga, but the correlation coefficient of –0.63 was observed after resting period. Thus, this significantly negative correlation means higher clothing pressure around the shoulder leads to lower evaluation of wearing comfort for T1 after resting period. Contrarily, the negative correlation coefficient of –0.26 was observed before exercise when wearing T2, but no relation was observed during resting period. The clothing pressure of shoulder area of T1 was 0.85 kPa, which was relatively higher pressure than other areas. This high pressure gives a sensation of garment suitably adhering to the body before exercise, but high pressure is presumed to become burdensome constraint that decreases comfort of the garment during resting period after exercise. Meanwhile, clothing pressure at the shoulder for T2 was relatively low pressure of 0.37 kPa, which does not give the sensation of support for the body before exercise so negative correlation was observed, but T2 clothing pressure posed no influential variable on comfort after rest. Fig. 9 represents data standardization of variables about subjective responses of the comfort of the upper body and characteristics of fabric. The subjective evaluation of wearing comfort of the top garment T2 was greater than T1, while T1 showed higher values with size of garment and lower clothing pressure.

<table>
<thead>
<tr>
<th>Top</th>
<th>Correlations</th>
<th>Before yoga</th>
<th>After yoga</th>
<th>After rest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correlation coefficient</td>
<td>–0.146</td>
<td>–0.190</td>
<td>–0.530</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>0.729</td>
<td>0.651</td>
<td>0.177</td>
</tr>
<tr>
<td>n</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>–0.626</td>
<td>–0.217</td>
<td>–0.262</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.097</td>
<td>0.606</td>
<td>0.531</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9. Data standardization of variables about subjective responses and fabric characteristics for the upper body.
In terms of the fabric, T1 was less thick, had a low stretchable rate, as well as a low Qmax and absorption but a high drying rate. This result showed that garment containing fabric with a high drying rate and less adherence to the skin would be most effective in wearer's perception of comfort during rest period after an extensive yoga session.

**IV. Discussion and Conclusion**

Based on the overall result, wearing T1P1 before Bikram yoga exercise showed greater upper garment comfort than T2P1, but none of the clothing combination resulted in significantly greater comfort or thermal sensation after exercise. During the initial stage of the hot condition, the superior absorption and drying rate of the top garment (T1) did influence the feeling of wearing comfort, but the participants no longer perceived the functionality effects as exercise time increased. Comparison of subjective evaluations of thermal sensation of test garments between before exercise and after rest showed that participants significantly expressed cooler thermal sensation when wearing T1P1 and T1P2. Participants wearing T1P2 significantly expressed cooler lower body and overall thermal sensation. This result showed the importance of the functional characteristics of fabric for the tops when discussing thermal sensation. In terms of wearing comfort, wearing T1P1 after exercise and after rest significantly decreased wearing comfort compared to the comfort before exercise. Meanwhile, wearing T2P1 led to higher expression of wearing comfort after rest than T1P1 comfort rating after rest. This means that the low clothing pressure acted as a better beneficial factor on comfort in hot conditions than the physical functionality characteristics of the fabric material, especially after rest. This result is supported by the study of Gonzales et al. (2011) that showed how perceived hotness significantly changed as the garment size differed after 10-12 minutes of exercise and the jersey knit size has the possibility of affecting heat loss. Some of the past studies showed that difference in fiber material has no effect on thermoregulation and physiological response during exercise and recovery (Brazaitis et al., 2010; Gavin et al., 2001; Hooper et al., 2015), but the majority of these studies experienced with loose fit garment and did not appear to consider the physical burden of clothing pressure. Additionally, the study of Mert et al. (2016) analyzed the contribution of garment fit and style on thermal comfort and showed that style has no effect on core temperature or total water loss. However, fit affected total water loss and temperature, especially the skin temperature decreased when wearing tight garments. Even though the presence of air gap between clothing and the skin can prevent heat transfer and can influence change in body heat, this theory cannot be applied to the compression garment used in this study. Mori et al. (2002) compared loose cloth and tight cloth, resulting in significant increase of heart rate and nocturnal urinary melatonin excretion when wearing tight clothing due to enhancement of diurnal sympathetic nervous system activity caused by pressure on the skin produced by tight clothing. Meanwhile, popular yoga clothing among the public is body fitted clothing that provides pressure on muscles or joints, which falls under the category of Sports Compression garment. Compression garment not only increases performance, helps with recovery, and has a positive effect on multiple facets (Gill et al., 2006; Hirai et al., 2002; Hopkins & Hewson, 2001), but also has a significant impact on perception and psychological facet (Kraemer et al., 2001; Lee, Kim et al., 2017; McLaren et al., 2010; Nguyen et al., 2018). Other studies also showed that functionality of garment was dependent on the level of clothing pressure of compression garment (Lee, Hong et al., 2017; Lee, Kim et al., 2017; Liu et al., 2014). Clothing pressure is one of the most important garment parameters because it influences mechanical, physiological, and psychological responses. However, since the perception threshold of clothing pressure felt by the wearer can differ in extreme environment as experienced in this study, it was necessary to not only consider the relation of comfort and clothing functionality based on clothing pressure but also the evaluation period performed before and after exercise and after rest. The result of this study also showed that difference in sensation due
to the garments was not perceived during intense performance, but instead significant comfort perception of garment was perceived during rest in standard condition.

Therefore, for exercise in hot environments like Bikram yoga, the negative correlation of clothing pressure was found to have greater influence on perceptive wearing comfort than functionality characteristic of fabric on comfort after rest from exercise. Additionally, it was clear that in the particular environment of this study, high levels of absorption of the fabric or of the Qmax do not correlate with greater wearing comfort, indicating the significance of simultaneously considering environment-body-fabric system when developing new garments. This result needs to be considered in influencing the decision of garment choice for exercise in the future, which makes the result of this study to be a meaningful information to not only designers of Bikram yoga clothing but also to consumers. However, since this study tested with commercial yoga clothing, there was a limitation on inability to meticulously control the characteristic of fabric and clothing pressure. For the future study, the protocol used in this study can be applied to quantitatively measure physiological response and this addition can lead to a more meaningful result.

In conclusion, clothing pressure and functionality of fabric material affected wearing comfort and thermal sensation, respectively, for upper garments worn in hot condition. No significant differences in thermal sensation were subjectively felt between test garments within each time period. However, when only comparing the thermal sensation before yoga and after rest for high functional fabric test garment, participants significantly felt cooler thermal sensation after rest than before exercise. This means that the functionality of fabric needs to be considered as an important factor for thermal sensation for after the resting period.

Meanwhile, clothing pressure played a more important role than functionality of fabric in determining wearing comfort after exercise. Before exercise, wearing higher functionality fabric provided more wearing comfort. However, after exercise and rest, the lower functionality fabric provided better wearing comfort because the low functionality fabric test garment also had low clothing pressure. Thus, this showed that clothing pressure affected wearing comfort after exercise and rest. Also, in this study, clothing discomfort was shown through the body mapping of sweat produced by participants. As a result, participants felt greater discomfort in the upper body with more perspiration amount than in the lower body.

Therefore, this study evaluated how the functional characteristics of the fabric and clothing pressure affected the wearer's physiological response through the sweat ratings and perceptive sensation, including thermal sensation and wearing comfort, at three time periods: before exercise, after exercise, and after rest.

Based on the results of this study, it should be noted when constructing Bikram yoga clothing that is worn in a hot condition that the appropriate choice of fabric materials is important but level of clothing pressure is also an essential design factor for comfort, especially during rest period after exercise. For the Bikram yoga apparel industry, yoga designers need to consider that comfort level differs at each time period of exercise, including after rest.

References


Analysis of Thermal Sensation and Wearing Comfort before and after Bikram Yoga Activity


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