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Effects of Bikram Yoga Clothes on EEG Beta Spectrum

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Abstract
This study analyzes how the beta index, which is closely related to alertness, caution, concentration, anxiety, and tension in brain activity, varies before and after practicing yoga. Electroencephalogram (EEG) and subjective evaluations were conducted on healthy female yoga trainers with over three years of experience; participants wore yoga clothes with differing characteristics in a hot environment. Repeated ANOVA measurements were conducted on the data by deriving the difference between the corresponding sample t-test pre- and post-yoga . After yoga, concentration increased, while alertness, anxiety, and excitement decreased depending on the yoga clothes. The clothing combination that offered higher pressure and greater absorption, and enhanced concentration while lowering excitation and anxiety increased beta waves the most. The design characteristics of yoga clothes influence beta power for concentration and arousal after yoga practice. Through EEG measurements, it was possible to explore the mental states resulting from wearing clothes suitable for yoga.

Keywords
beta wave, EEG, fabric absorption, yoga clothes, clothing pressure, Bikram yoga.

1. Introduction

Clothes provide physical, physiological, and psychological comfort [1]. Functional clothing can define specific user requirements; it is designed or engineered to meet the performance requirements of the user under specific conditions. A variety of functional clothing products are available in the market as sports clothing, medical clothing, protective clothing, and so on [2]. Take, for instance, the clothes worn during Bikram yoga (a form of hot yoga), which is performed in a hot environment and is touted to provide the practitioner with good mental health as well as optimal physical performance, mobility, and physiological responses. Yoga incorporates physical exercise with deep relaxation, specific breathing, and meditation exercises [3]. It is known to enhance not only physical abilities but also emotional stability and concentration [4, 5]. In particular, Bikram yoga includes a breathing therapy called Kapalbhati, which increases mental activity and induces a calm alert state [6].

With the development of science and technology, electroencephalogram (EEG) testing has become widely adopted as a neurophysiological evaluation method for determining the degree of higher-order cognitive functions such as attention concentration. EEG is induced and amplified through electrodes attached to the skull, and the electric potential is recorded; this electrical signal is converted to the frequency axis and expressed. Studies that have measured mental and emotional states during yoga through EEG measurements reported that brain activity increases with breathing, meditation, and motion [7]. Furthermore, the alpha wave related to the respiratory system, mental relaxation, and tranquility increases after yoga [7-9]. There are also reports that the beta wave is closely related to concentration, alertness, stimulation, and caution when sitting upright after yoga or performing moderate physical activities [5]. Yoga assists their sense of acceptance and focus [10]. Another study found various cognitive benefits, inlcuding increased memory and attention-switching capacity in older adults in relation to cognitive benefits [11]. If there are articles of clothing that can add value to these fundamental yoga effects in terms of their influence on mental traits or activity, this will support yoga clothes' true function. In short, yoga clothes should be developed using multidimensional analysis in order to optimise comprehensive functionality. As the purpose of performing yoga is mental and physical health, a new approach is needed to evaluate yoga clothes.

Exercising in a hot environment generates heat, leading to higher core and skin temperatures and, ultimately, perspiration. Therefore, functional clothing must be able to manage sweat while facilitating evaporation [12, 13]. Studies of comfort clothing for hot environments have mainly focused on methods for alleviating thermal stress based on fibers and materials [14, 15] or on evaluating performance enhancement and ease of movement [16, 17]. However, research on these properties in yoga clothing are limited, and there are even fewer studies of the psychological effects of yoga clothing. There are no studies that have evaluated EEG with yoga clothes set as a variable. However, such attempts are significant considering the psychological efficacy of yoga. As mentioned earlier, several studies have examined the generation of alpha waves in relation to relaxation and calm during yoga, but relatively few have examined beta waves in relation to concentration, arousal,

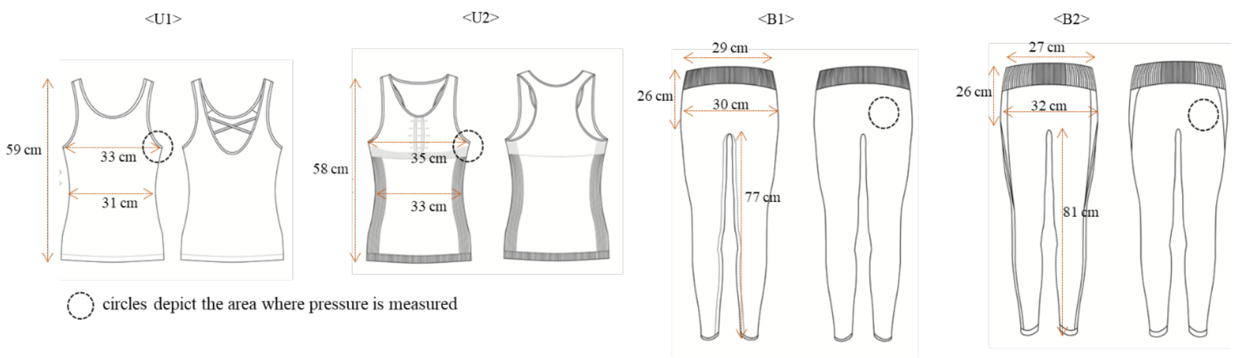

Fig. 1. Clothing pressure measurement at chest (for the top) and at the hip (for the pants)

and stimulation, and very few such studies have been related to clothing. By specifically analysing indicators related to beta waves in the context of yoga's various requirements as it is performed by modern people, we aimed to examine whether and how clothing can provide efficacy of attention.

The aim of this study was to (1) evaluate the psychological effects of clothing conditions (clothing pressure, Qmax, and absorption) when performing yoga in a hot environment through EEG measurements, (2) examine their relationship with subjective evaluations, and (3) investigate the conditions for yoga clothes that provide high-level functionality and comfort optimised for attention and mental focus. Comprehensively, the purpose of this study is to identify the design elements of yoga clothes that have a beneficial effect on mental concentration when performing yoga in a hot environment.

2. Materials and Methods

2.1. Yoga wear for the experiment

This study investigated the characteristics of market-bought yoga garments, referred to as test garments, by quantitatively measuring the material traits that affect the thermoregulation and fit of yoga clothes. This test garment had been recommended as being the most popular Bikram yoga wear by a yoga wear brand. The test garments used in this study consist of two tops (U1 and U2) and two legging-style pants (B1 and B2). The material traits evaluated include fiber formation, density, thickness, Qmax warm/cool feeling (Thermolabo II KES-F7, KATO Tech Co., Ltd., Japan), and absorption (International Organization for Standardization [ISO] 9073-6, 2000). Clothing pressure was measured by averaging the pressure measured at the chest for the top and at the hip for the pants using an inflatable air pack, as shown in Figure 1. Measurements of clothing pressure were taken from the areas with the largest circumference on the upper and lower body. The traits of yoga clothes are shown in Table 1. Four sets ("G": gear) of yoga clothes were used: (1) G1 = U1 and B1, (2) G2 = U2 and B1, (3) G3 = U1 and B2, and (4) G4 = U2 and B2. Figure 2 shows the pressure distribution of tight fitting experimental clothes using a 3D virtual try-on program, CLO 3D ver.5.2 (CLO Virtual Fashion LLC., Korea). At this time, the 2D pattern applied to the simulation was made in the size of the yoga clothes purchased, and the material was measured by CLO Fabric kit 2.0 (CLO Virtual Fashion LLC., Korea). Since the actual measurement of garment pressure from the air pack sensor was performed only at a specific point, the distribution of virtual garment pressure was checked to relatively compare the overall pressure distribution according to the yoga clothes.

2.2. Participants

The judgment sampling method was used to recruit healthy female yoga instructors in their 20s with an average of three years of experience. Eight subjects voluntarily participated in the experiment. Average measurements of the subjects were as follows: 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, and weight: 55.1 ± 8.5 kg. Prior to the experiment, approval from the National Ethics Committee (201807-SB-101-01) and informed written consent from the participants were obtained.

2.3. EEG measurement

Upon arrival at the laboratory, participants first underwent stabilisation by sitting in a chair and resting for a while before undergoing subjective evaluation in a standard condition (25°C, 40% RH). Subjective evaluation was conducted by asking the participants to rank coolness and comfort 15 minutes after wearing the experimental clothes in both standard and hot environmental chambers (34°C, 40% RH, 0.5m/s). Each rank was weighted accordingly to derive the final score for each experimental garment. The first rank was given 6 points, the second rank 5 points, and so forth. In addition, in the hot environment, the researcher asked the subjects to respond multiple times to each experimental clothing item by selecting discomfort zones caused by sweating on the chest, back, buttocks, thighs, and calves. Afterwards, participants were given a random experimental garment

	Code	Fiber content (%)	Density (loop/5.0 cm)		Thickness (mm)	Qmax (W/cm²)	Absorption (mm/10 minutes)		Clothing pressure (kPa)
			Wale	Course			Wale	Course	
Tops	U1	Nylon 84, Polyurethane 16	124	308.8	0.82	0.125	53	81	0.59
	U2	Viscose rayon 92, Polyurethane 8	96.4	121.6	0.78	0.108	29	48	0.44
Pants	B1	Nylon 72, Polyurethane 29	133.8	287.4	0.80	0.105	0	0	0.53
	B2	Nylon 92, Polyurethane 8	87.6	141.6	0.89	0.091	47	56	0.89

Table 1. Physical traits and clothing pressure of yoga wear materials

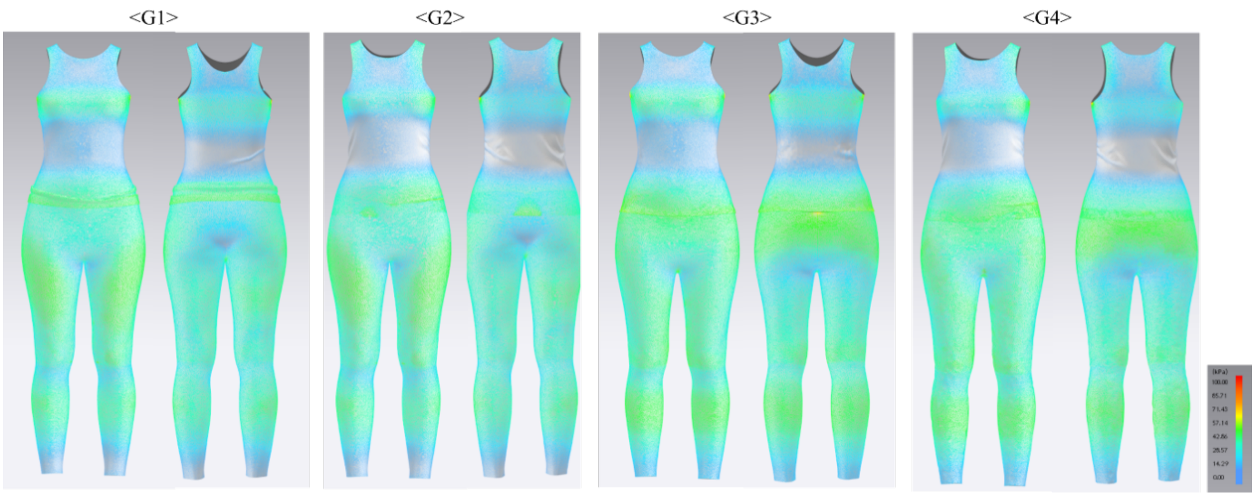

Fig. 2. pressure distribution of tight fitting experimental clothes using a 3D virtual try-on program CLO 3D ver.5.2

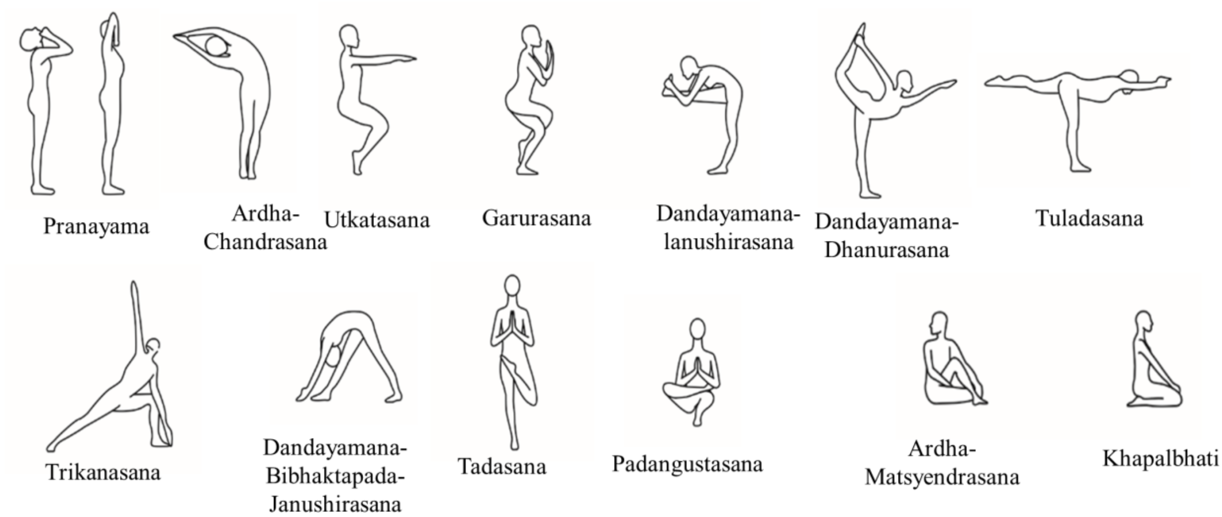

Fig. 3. Set of yoga poses

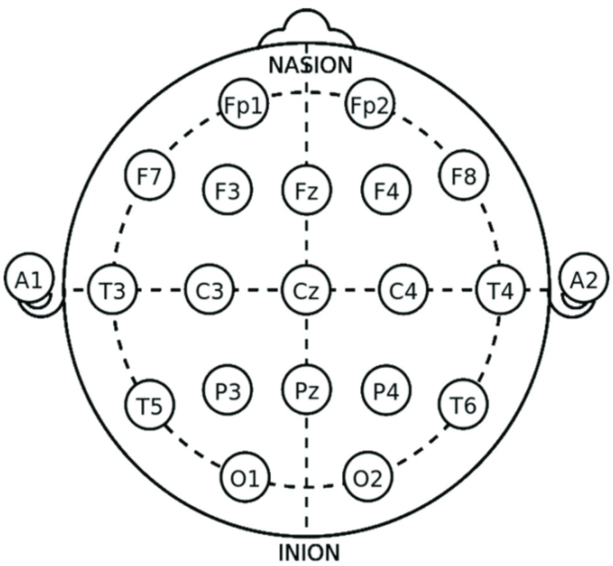

Fig. 4. Attachment of channel electrodes for EEG measurement

and asked to enter a hot environmental chamber. Participants returned for three more days, at intervals of two days, to conduct identical evaluations for the other three sets of clothing. After relaxing for 5 minutes in a comfortable state in the hot environmental chamber, EEG was measured. Readings were taken before (participants sat quietly for 3 minutes) and after practicing Bikram yoga for 20 minutes. For yoga, participants watched and followed a 20-minute video. From among a set of 26 Bikram yoga poses, 16 were selected. Participants were asked to perform the set of 16 poses twice as shown in Figure 3. The last pose, Kapalabhati, is the rhythmic breathing done with the belly at a speed of approximate 90 breaths per minute.

Twenty-one channel electrodes were attached in reference to the 10-20 international system of electrode placement for EEG measurement [18], and brain waves were measured for 3 minutes while checking the inflow of artifacts in real time during the experiment as shown in Figure 4 (QEEG-32FX, Laxtha, Korea). The regions of the scalp on which electrodes were placed were the frontal (Fp1, Fp2, F3, F4, Fz), central (C3, C4, Cz), parietal (P3, P4, Pz), occipital (O1, O2), and temporal (T3, T4) regions.

2.4. EEG signal processing

The analog brain potential signal measured through a sensor was sampled at 250 Hz and converted into a 24-bit digital signal. This signal was transferred using serial communication and was stored on a computer. Brain waves were categorised as delta (2-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-45 Hz) by frequency. However, variables like skull thickness and level of tension vary considerably from person to person; therefore, relative indices were used in the analysis to compensate for this. In other words, relative band power, which is the rate (%) of each bandwidth in terms of EEG strength, was converted and used in the analysis [19, 20]. As mentioned in the introduction, beta waves were elicited to measure attention and waking evaluation. The beta indices—relative low beta (RLB: 12–15 Hz / 4–50 Hz), relative middle beta (RMB: 15–20 Hz / 4–50 Hz), and relative high beta (RHB: 20–30 Hz / 4–50 Hz)—were analysed using the Wolfram cloud-based time-series bio-signal data analysis program, BioScan-Cloud (BioBrain Inc., Daejeon, Korea). To compensate for individual factors such as cranium thickness and tension during measurement, the data were converted into relative band power, which is the ratio of each bandwidth (%) of the EEG power to the total bandwidth (4–50 Hz) [20, 21].

2.5. Statistical analysis

The EEG data from the hot environment were examined using a paired *t*-test. The mean difference between the paired *t*-test results of matching samples pre- and post-yoga was derived using a statistical analysis program (SPSS 20.0, IBM, New York, USA). Repeated ANOVA measurements were performed for the pressure between the experimental yoga wears, and the statistical significance was defined as $p < 0.05$.

3. Results and Discussion

3.1. Subjective evaluation of coolness (cool sensation) and comfort (total sensation)

The subjective evaluation results are presented in Table 2. In the standard environment, coolness was ranked as G4, G2, G3, and G1, and comfort as G4, G3, G2, and G1. For the hot environment, coolness was ranked as G4/G3, G1, and G2, and comfort as G4/G3 and G2/G1. In general, G4 felt cool and comfortable regardless of environmental conditions, whereas G2 and G1 did not. However, considering that coolness and comfort are identically ranked for G4 and G3 in a hot environment, it appears that the sensitivity to yoga clothes declines as temperature rises. Meanwhile, G2 and G1, which achieved low ranks in all environments, shared B1 pants. A notable trait of the B1 pants is that they have nearly zero absorption functionality. This shows that the absorption function of the pants is a critical factor that affects perceived coolness and comfort.

The results of the participants' responses to the discomfort zone are as follows: U1 chest (n=7) and back (n=4), U2 chest (n=6) and back (n=8), B1 thighs (n=5), and B2 thighs (n=1). In other words, sweat created greater discomfort with the tops than it did with the bottoms; additionally, U1 was a little more uncomfortable than U2. The thighs of both pairs of pants were uncomfortable, with B1 being more uncomfortable. B2 registered only one response and had less

Environment	Item	Clothing	Rank 1 (n)	Rank 2 (n)	Rank 3 (n)	Rank 4 (n)	Total points
Standard	Coolness	G1	0	2	4	2	32
		G2	3	0	2	3	38
		G3	3	2	0	3	37
		G4	2	4	2	0	40
	Comfort	G1	1	0	2	5	29
		G2	0	1	4	3	30
		G3	1	6	1	0	40
		G4	6	1	1	0	45
Hot Chamber	Coolness	G1	1	1	4	2	33
		G2	1	1	2	4	31
		G3	3	3	1	1	40
		G4	3	3	1	1	40
	Comfort	G1	1	1	3	3	32
		G2	0	3	2	3	32
		G3	3	2	3	0	40
		G4	4	2	0	2	40

Table 2. Subjective preference concerning coolness and comfort

Yoga wear	Brain area		Mean	Mean differences	*t*
G3	Fp1	Pre- yoga	0.078	-0.004	-5.031**
		Post- yoga	0.074		
	Fz	Pre-	0.077	-0.003	-2.358*
		Post-	0.074		
	P7	Pre-	0.079	0.006	2.524*
		Post-	0.085		

*Note: * p < .05, ** p < 0.01*

Table 3. EEG measurement of RLB waves

of a negative effect on comfort. The same tendency was observed in the subjective preference results, with G1 and G2, which both include B1, receiving fewer responses indicating discomfort. The above results are addressed in more detail in the discussion section.

3.2. Brain wave evaluation

As a result of the paired t-test of the EEG data, the t-value was less than 0.5, which means that the values of EEG waves pre- and post-yoga were significantly different. When the t-value was negative, it meant that the activity of brain waves after yoga decreased, and when it was positive, that it increased. The yoga wears that displayed statistically significant differences regarding the RLB index—the index related to alertness—are presented in Table 3. After yoga, the RLB index decreased when wearing G3 at the Fp1 and Fz areas and increased at P7 (areas of the brain [EEG measurement]). The other clothes displayed statistically insignificant differences. This suggests that only G3 significantly affects alertness; but it exhibited differences depending on the cerebral area, specifically reducing it at the forehead and enhancing it at the calvaria.

The analytical results for yoga clothes that showed significant differences for the RMB index, which is related to caution and concentration, are presented in Table 4. The average RMB values commonly increased for all clothes, except G2. Three sets of yoga clothes (G1, G3, G4) supported previous studies that suggested that wearing yoga clothes enhances concentration after yoga [5]. G2 showed no significant difference.

Finally, analysis results of the RHB index, which is closely related to anxiety and tension, are presented in Table 5. The RHB indices were statistically significant for all clothes, and generally decreased post yoga. This is in line with past studies that found that yoga generally lessens anxiety and tension. In particular, G4 showed the most significant differences in various areas of the brain, suggesting that it is the most effective clothing for reducing anxiety and tension.

The repeated ANOVA measurement results for the pressure between the experimental yoga wears are shown in Figure 5. It can be observed that the RMB significantly changed in the frontal lobe (F3, F4) and parietal lobe (C3) of the left brain. The amplitude of the RMB indices increased for G1, G3, and G4, but decreased for G2 at a statistically significant level. This implies that concentration is enhanced after yoga while wearing G1, G3, and G4, but is diminished for G2. G2 was also the clothing combination that was least preferred in the subjective evaluation conducted in a hot environment.

Yoga wear	Brain area	Mean		Mean differences	t
G1	Fp1	Pre-yoga	0.110	0.005	2.436*
		Post-yoga	0.115		
	Fz	Pre-	0.109	0.007	2.659*
		Post-	0.116		
	F8	Pre-	0.116	0.006	2.798*
		Post-	0.122		
	C3	Pre-	0.118	0.006	2.929*
		Post-	0.124		
G3	P3	Pre-	0.118	0.007	2.625*
		Post-	0.124		
	O1	Pre-	0.110	0.007	2.590*
		Post-	0.117		
	C3	Pre-	0.114	0.011	4.198**
		Post-	0.125		
	P7	Pre-	0.117	0.008	4.322**
		Post-	0.125		
G4	F4	Pre-	0.120	0.004	4.663**
		Post-	0.124		
	F7	Pre-	0.119	0.004	3.871**
		Post-	0.123		
	C3	Pre-	0.119	0.005	3.894**
		Post-	0.124		
	Fz	Pre-	0.116	0.006	5.030**
		Post-	0.122		
	Cz	Pre-	0.115	0.004	3.271*
		Post-	0.119		

*Note: * $p < .05$, ** $p < 0.01$*

Table 4. EEG measurements of RMB waves

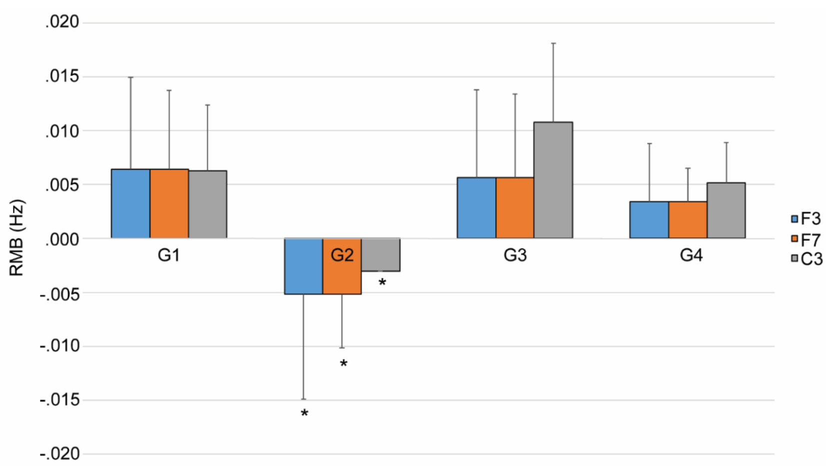

Fig. 5. ANOVA measurement results for the pressure between the experimental yoga wears

4. Discussion

Though yoga itself is known to activate brain waves, this study showed that brain wave activity can either increase or decrease after yoga depending on the yoga clothes worn. Thus, yoga clothing can be considered a major variable and has a proven neurophysiological effect on yoga activity. The standardised design properties of yoga clothing, pressure and subjective preference (depicted in Figure 6), were used to analyse how the characteristics of the yoga clothes affected subjective sensations and brainwaves. Participants preferred G3 in a hot environment for its coolness and comfort. Radar charts of G3 occupied relatively large areas, as shown in Figure 6. The graph that stands out here is G2. G2 had a negative evaluation in subjective preference and a high response frequency regarding areas that were uncomfortable with sweat; it showed a low index in all items, including absorption in the standardised score. As the chamber had no air circulation and was set to a high temperature, it appears that the subjects were more sensitive to absorption than the initial contact coolness. The moisture transmission behaviour of clothing is a thermophysiologically critical factor [22, 23]. However, as perspiration does not easily evaporate under experimental conditions, absorption becomes more important than other functions.

Yoga is associated with the perception of calmness, as it significantly increases alpha activity through physical exercise, breathing, and meditation, regardless of clothing worn, rendering the performer's temporality idle but still alert [7, 8, 24]. Furthermore, it is known that yoga activates brain waves, such as beta waves, which promote relaxation, alertness, and concentration [5, 25], as well as theta waves, which improve internal attention [26]. However, unlike previous studies, which examined a broad bandwidth, this one intricately divided the bandwidth to derive a precise analysis of how brain activity differs before and after performing yoga in dependence on the yoga clothes worn.

G1 generally enhances concentration and caution while reducing anxiety and alertness. G2 decreased anxiety and tension, but the difference was not significant. G3 decreased alertness, anxiety, tension, and concentration. G4 enhanced the concentration while reducing anxiety and tension. Only G2 significantly reduced the RMB wave, but displayed a low preference by participants during subjective evaluation; it was the only set with low Qmax, absorption, and pressure. Analysis of G1 and G2, which both had relatively low pressure, showed that G1 increased RMB more than G2,

Yoga wear	Brain area	Mean		Mean differences	*t*
G1	F4	Pre-yoga	0.186	-0.007	-2.499*
		Post-yoga	0.179		
	F8	Pre-	0.190	0.007	7.289***
		Post-	0.183		
	Cz	Pre-	0.115	-0.004	3.271*
		Post-	0.119		
G2	Cz	Pre-	0.187	-0.004	-3.271*
		Post-	0.183		
G3	Cz	Pre-	0.183	-0.004	-3.271*
		Post-	0.176		
G4	Fp1	Pre-	0.178	0.008	3.829**
		Post-	0.175		
	Fp2	Pre-	0.170	0.008	3.068*
		Post-	0.172		
	O1	Pre-	0.178	0.007	3.991**
		Post-	0.171		
	O2	Pre-	0.177	0.005	2.801*
		Post-	0.172		
	F7	Pre-	0.182	0.006	2.891*
		Post-	0.175		
	F8	Pre-	0.184	0.009	3.113*
		Post-	0.176		
	P8	Pre-	0.184	0.009	3.198*
		Post-	0.174		
	Cz	Pre-	0.115	-0.004	-3.271*
		Post-	0.119		

*Note: * $p < .05$, ** $p < 0.01$, *** $p = 0.00$*

Table 5. EEG measurements of RHB waves

positively affecting the activation of the beta wave. Both were negatively addressed in the subjective evaluation, but G1 did not show negative results in the EEG measurements. Meanwhile, G3 and G4, which had relatively higher pressure, also lowered anxiety and excitement, implying that a certain level of clothing pressure is required for yoga. Specific clothing pressure can positively affect joint movement, blood circulation, mental support, and enhancement of concentration during exercise [27]. Erhui and Yanzhen [28] state that the pressure comfort of garments varies according to the type and intensity of body movement; thus, numerous factors must be considered when selecting the optimal pressure for functional clothes. When all factors that affect comfort are applied harmoniously, a virtuous cycle positively affects the wearer's emotions, senses, and performance. Lee et al. [27] examined how compression pants set to different levels of clothing pressure affected the EEG spectrum and found that a pressure level of 1.57 ± 0.41 kPa significantly enhanced attention and concentration, serving as an analytical basis for the phenomenon discussed above. In the repeated ANOVA measurement results for the pressure between experimental garments, the RMB increased for G1, G3, and G4 but did not significantly affect G2. G2 showed different trends in the subjective evaluation of subjects as well as in the results of EEG measurement. It was difficult to make the fabric comfortable for hot, sweaty bodies, and the pressure was the lowest as well; hence it could not provide the tension possible with tight fitting clothes. Exercising in a hot environment generates heat, leading to higher core and skin temperatures and, ultimately, perspiration. Therefore, functional clothing must be able to manage sweat while facilitating evaporation [12, 13]. These clothes should be able to reduce skin moisture through moisture transfer and improve sweat evaporation to improve thermoregulation [23]. There is an association between sweating events and brain regions involved in arousal [29]. Ftaiti et al. [30] reported that performing exhausting activity in the heat induced a change in brain activity and that beta activity was significantly decreased in hot and neutral environments because the fatigue brought on by heat affects brain activity. Since G2 was low for all indicators, it was functionally less effective at managing the physiological discomfort and fatigue caused by sweating than the experimental sets of clothing. Thus, G2 did not satisfy the physiological and physical conditions for the wearer. Generally, favorable functions of synthetic sportswear include faster heat transfer, better moisture vapour transmission, and a cooler feeling, all of which contribute to a comfortable wearing experience [31, 32].

In summary, results meaningfully changed depending on the clothing, signifying that yoga clothes affect brain waves during yoga activity and that optimal conditions do exist. The results confirm that clothing with absorption of perspiration was preferred both physiologically and subjectively. Clothing pressure also contributes to faster sweat absorption, as it increases the contact area between the clothing and the body. Since clothing environments significantly affect beta waves during yoga, it is very important to evaluate and design the high-level functionalities of yoga clothes while considering their mental and physical effects.

5. Conclusions

This study scientifically examined the effects of clothing in a special environment while performing yoga.

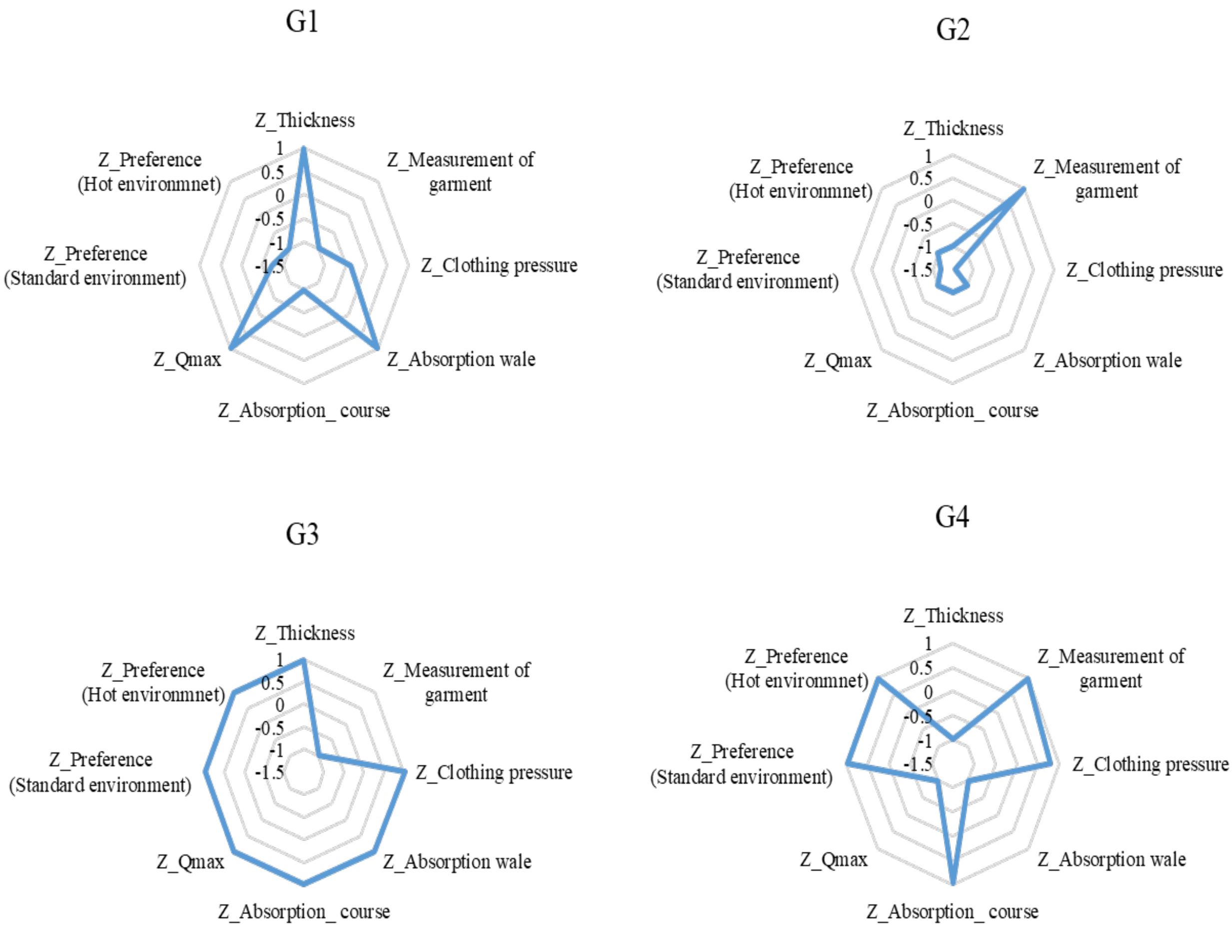

Fig. 6. The standardised design properties of yoga clothing, pressure and subjective preference

Yoga clothing affects brain potential while practicing yoga, and even subjectively disliked yoga clothes (G2) caused negative brain wave responses. While details regarding brain waves varied, almost all yoga clothes enhanced concentration post yoga (except G2). The clothing combination that offered higher pressure and absorption, and enhanced concentration while lowering excitation and anxiety, proved to be most beneficial for the mind after yoga, as measured by EEG. This study has novelty in that it quantitatively measured materials and clothing design elements and scientifically analysed EEG, unlike studies that depend only on subjective responses for the mental state according to each wearing combination. Moreover, it can be seen that the functionality of the material does not directly lead to functionality of clothing, and all conditions must be comprehensively considered for clothing to properly execute its intended functions. These results will be meaningful information not only for clothing buyers but also for designers. Additionally, products developed should also consider brain neuroscientific evaluation as such evaluation results can be utilised as highly effective marketing aspects. However, the experimental garment used in this study was a set of clothes that was available in the market, and this lack of choice limited the control conditions. Although there are limitations in evaluating products purchased from the market, it is meaningful that random variables were standardised and analysed by statistical methods. The small number of participants, even though they were professional practitioners, was another limitation of this study. Future studies should experiment with the general population.

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