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Original Research

Conservative Clothing Effects on Body Composition Assessment by Air Displacement Plethysmography

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ABSTRACT

International Journal of Exercise Science 14(4): 687-695, 2021. Form-fitting spandex swimsuits or single-layer compression shorts are recommended during BOD POD® testing to ensure accurate results. The purpose of this study was to evaluate the effects of various outfit types on body composition measurements using the BOD POD®, and self-reported comfort level wearing each outfit. Twenty-one participants, 8 females and 13 males, (age 31.6 ± 9.8 years) wore a spandex swim cap and three different outfits during BOD POD® testing (manufacturer-recommended form-fitting spandex swimsuit, short sleeve spandex, long sleeve spandex). Measured variables include body mass, body fat percentage, body volume, and self-reported comfort level wearing each outfit. Calculated variables include BMI and body density. Mean body density when wearing the control outfit was 0.004 g/cm^3 lower than both short ($p < 0.001$) and long sleeve ($p = 0.001$) alternatives. Short and long sleeve outfits resulted in body fat percentage underestimations of 2.0% and 2.1%, respectively ($p < 0.001$). The short sleeve outfit had the highest mean comfort rating followed by the long sleeve outfit, and the lowest was the control swimsuits. The short sleeve outfit and control outfit had the largest differences in reported comfort levels ($p < 0.05$). Wearing short and long sleeve spandex outfits instead of recommended form-fitting swimsuits resulted in body density increases and body fat percentage underestimations. Participants should follow manufacturer recommendations by wearing spandex swimsuits. Participants had higher self-reported comfort levels when wearing short or long sleeve outfits.

KEY WORDS: BOD POD®, spandex, outfits, body fat percentage, body volume, body density, comfort level

INTRODUCTION

There are various techniques to measure body composition such as dual x-ray absorptiometry, bioelectrical impedance analysis, computerized tomography, magnetic resonance imagery, hydro-densitometry (underwater weighing), and air displacement plethysmography (ADP). The BOD POD®, which uses ADP, may be the most versatile technique for measuring body composition due to its accuracy, relatively quick testing time, and ability to accommodate a wide range of participants including pregnant women and children (11). Prior research has also shown the BOD POD® to have excellent repeatability (1, 7, 18). Moreover, the BOD POD® is a safe and relatively comfortable method that does not expose participants to any radiation unlike dual x-ray absorptiometry and does not require participants to submerge underwater like underwater weighing (11).

The BOD POD® utilizes the ADP technique to estimate body volume based on measuring pressure and calculating air volume in the BOD POD® chamber with and without the subject. ADP relies on the pressure/volume relationship based on Boyle's Law, or $P_1V_1 = P_2V_2$, where P = pressure, V = volume, and temperature being constant. Boyle's Law states that pressure and volume are inversely related when temperature is constant, or isothermal (12). The BOD POD® relies on isothermal conditions. Under these conditions, compressed air will decrease the volume in proportion to the increased pressure. To avoid air being trapped within hair and/or clothing, spandex swim caps and form-fitting spandex swimsuits are recommended. If a person wears loose clothing, air becomes trapped between the clothes and the person's body. This trapped air within the loose clothing is more compressible, and this will lead to a lower air pressure measurement, and thus a higher air volume calculation in the BOD POD® chamber. Since body volume is calculated by subtracting the occupied from the empty BOD POD® chamber air volume, body volume will be underestimated when loose clothing is worn (5, 13, 17, 19).

In a prior study comparing participants' body fat percentages while wearing recommended swimsuits, hospital gowns, and while nude, body fat percentage was underestimated by 8-9% while wearing a hospital gown compared to the recommended swimsuit and nude conditions (19). Other research has evaluated the effects of spandex bicycle shorts and cotton gym shorts on body composition using BOD POD® testing, which showed similar results of body fat percentage being underestimated when compared to control swimsuits (10).

To our knowledge, there have been no studies that compared the effects of short and long sleeve spandex outfits to recommended swimsuits on body composition using the BOD POD®. If outfits are not provided by testing facilities, athletes or participants may not arrive in the recommended clothing. Because of this, prior studies allowed subject testing in spandex shorts or common athletic shorts (2, 20). Some participants may not feel comfortable wearing minimal, form-fitting clothing and may prefer to wear less revealing or longer spandex clothing. Yet, participants' comfort levels were not assessed in past research, and thus we aimed to include this as a secondary research objective. Because of the different outfit types that participants may wear during testing, it is important to determine if this will have a significant impact on body composition results. Therefore, the purpose of this study was to evaluate the effects of various outfits (manufacturer-recommended form-fitting spandex swimsuits, short sleeve spandex, and long sleeve spandex) on 1) body composition measurements using the BOD POD®, and 2) self-reported comfort level wearing each outfit. We hypothesized that the short sleeve and long sleeve spandex outfits will lead to an underestimation of fat mass and percent body fat as compared to control outfits.

METHODS

Participants

Twenty-one (13 male, 8 female) participants (mean age = 31.6; SD = 9.8 years) were included in this study. Convenience sampling was used by posting flyers around San José State University and the local community. Eligibility for the study was determined via screening surveys. Participants were included if they were 18 years or older, able to speak, read, and understand English, and willing to wear form-fitting swimsuits, short-length spandex outfits, and long-length spandex outfits. Participants were excluded if they reported claustrophobia due to the confined space of the BOD POD® chamber. After screening, the purpose, possible risks, and benefits related to the study were explained and discussed with the participant. All participants provided written informed consent prior to participation and the Institutional Review Board at San José State University approved the protocol, and this research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (15).

Protocol

Based on instructions from the BOD POD® operators manual (P/N 210-2400, rev. U, 07/2019, p. 35-36), participants removed all jewelry, eyeglasses, and other types of accessories and were asked to avoid eating, drinking, and exercising for at least two hours prior to testing. After eligibility was determined and participants signed the consent form, their height was measured to the nearest 0.1 cm using a stadiometer (Seca Corp., Chino, CA, USA). All protocol outfits were provided for the participants (Figure 1). All spandex outfits provided were similar in style and material (13-15% spandex) and included a spandex swim cap (COSMED Mayim). The control outfit were form-fitting spandex swimsuits (COSMED BOD POD iSwim). The short sleeve outfit consisted of a short sleeve spandex shirt (AthLio men's cool dry short sleeve compression shirt or Neleus women's compression workout athletic shirt) and spandex shorts (Devops men's compression shorts underwear or Persist women's high waist yoga shorts). The long sleeve outfit was a long sleeve spandex shirt (AthLio men's cool dry long sleeve compression shirt or Neleus women's dry fit athletic compression long sleeve t-shirt) and long spandex pants (Devops men's compression pants athletic leggings or Colorfulkoala women's high waisted full-length yoga pants). Participants were asked to void their bladder before changing into the first outfit. For each protocol outfit, prior to entering the BOD POD® (COSMED USA, Concord, CA, USA), the participant had their body mass measured by a calibrated digital standing scale (COSMED USA, Concord, CA, USA). Body volume was measured wearing each outfit using the BOD POD® v4.5+ software. The BOD POD® was warmed-up and calibrated using a 50.280 L cylinder prior to testing and followed the manufacturer's guidelines and published standardized procedures during testing (3, 6). Predicted thoracic gas volumes were used for each participant based on prior research, which showed no significant differences when using measured and predicted thoracic gas volume (14). Participants were first measured in the form-fitting spandex swimsuits (control outfit), followed by the short sleeve spandex outfit, and lastly the long sleeve spandex outfit. To ensure reliability, the BOD POD® measures body volume twice for each outfit, and a third measurement is taken only if the first two volumes differ by more than 150 mL. In this study, the authors used the Siri equation, body fat % = (495 / body density) – 450) to estimate percent body fat after calculating body density based on mass and BOD POD® estimate of body volume (16). To assess self-reported comfort levels, participants were asked "How comfortable were you wearing each outfit? Please rate your comfort with 1 being least comfortable and 10 being most comfortable." Participants rated their comfort after changing into their own clothes after testing was completed with all three outfits.

Figure 1. Protocol outfits with spandex swim caps used for A) females and B) males.

Statistical Analysis
It was calculated a priori that a sample size of 20 subjects would be needed to detect a significant difference in percent body fat between outfit types. This number of participants was determined using a power analysis for an effect size of 0.3 SD and power (1 – β) of 0.80 using the GPower

v3.1 software (5). A post-hoc analysis confirmed that the study was adequately powered ($1 - \beta = 0.99$). Data were analyzed using SPSS version 25.0 (IBM Corp, Armonk, NY 2019). Repeated measures ANOVA analyses (rANOVA) were performed for continuous and parametric data. Friedman tests were performed for non-parametric or rank data. To determine if differences between study outfits were present, post-hoc pairwise comparison tests using the Bonferroni correction were used if rANOVA was significant; post-hoc pairwise comparisons using Dunn's tests were used if the Friedman test was significant. Statistical significance was established prior to data collection at $p \leq 0.05$.

RESULTS

Body composition measurements and statistics are listed in Table 1. The outfits had a significant effect on mean body density, $F(2,40) = 17.653$, $p < 0.001$. When wearing the control outfit, body density was 0.004 g/cm^3 lower on average than both short and long sleeve alternatives. Post-hoc tests using the Bonferroni correction showed the body density when wearing the control outfit was significantly different from the short ($p < 0.001$) and long sleeve ($p = 0.001$) outfits. Differences were seen in body volume between each outfit, $F(2,40) = 4.084$, $p = 0.024$. Post-hoc pairwise comparisons showed that participant's body volume was significantly lower when wearing the short sleeve outfit (0.143 L lower) compared to the control ($p < 0.05$), but the short and long sleeve outfits only differed by -0.01 L, which was not significant. There was also a significant difference in mean body mass, $F(2,40) = 124.884$, $p < 0.001$. Post-hoc tests showed significant differences between the control outfits compared to both short and long sleeve outfits amounting to increases of 0.1 kg and 0.2 kg, respectively ($p < 0.001$). Differences were observed in body fat percentage, $F(2,40) = 18.743$, $p < 0.001$. Post-hoc tests showed significant differences between the control outfits vs. both short, and long sleeve spandex outfits ($p < 0.001$) which amounted to body fat percentage underestimations of 2.0% and 2.1%, respectively. No significant differences were seen for body mass index (BMI).

Table 1. Body composition statistics.

Variable	Control Outfit	Short Sleeve Outfit	Long Sleeve Outfit	rANOVA *p*-value
BMI (kg/m^2)	30.2 ± 5.1 [1]	30.1 ± 5.2	30.3 ± 5.1 [1]	0.442
FM (%)	31.4 ± 12.6 [1,2]	29.4 ± 12.4 [1]	29.3 ± 11.7 [2]	< 0.001 *
FFM (%)	68.6 ± 12.6 [1,2]	70.6 ± 12.4 [1]	70.7 ± 11.7 [2]	< 0.001 *
Fat Mass (kg)	28.0 ± 12.9 [1,2]	26.4 ± 12.7 [1]	26.4 ± 12.4 [2]	< 0.001 *
Fat Free Mass (kg)	59.7 ± 13.3 [1,2]	61.5 ± 13.2 [1]	61.5 ± 12.2 [2]	< 0.001 *
Body Mass (kg)	87.6 ± 16.6 [1,2]	87.8 ± 16.7 [1]	87.9 ± 16.6 [2]	< 0.001 *
Body Volume (L)	85.3 ± 16.8 [1]	85.2 ± 16.9 [1]	85.2 ± 16.9	< 0.024 *
Body Density (g/cm^3)	1.029 ± 0.027 [1,2]	1.033 ± 0.027 [1]	1.033 ± 0.026 [2]	< 0.001 *

*significant differences ($p \leq 0.05$) were based on repeated measures ANOVA (rANOVA); Groups with common superscript numbers were significantly different based on pairwise post-hoc analyses using the Bonferroni correction at $p \leq 0.05$.

Based on the Friedman test, differences were seen in comfort level ratings for each outfit, $\chi^2(2) = 14.95$, $p < 0.001$. Figure 2 shows that the short sleeve outfit had the highest mean comfort rating (8.3 ± 2.0), followed by the long-sleeve outfit (7.9 ± 2.6), and last was the control swimsuits (5.5 ± 2.9). Overall, based on Dunn's pairwise comparison post-hoc tests, control outfit comfort ratings were lower than both short sleeve ratings ($p = 0.003$) and long sleeve ratings ($p = 0.01$).

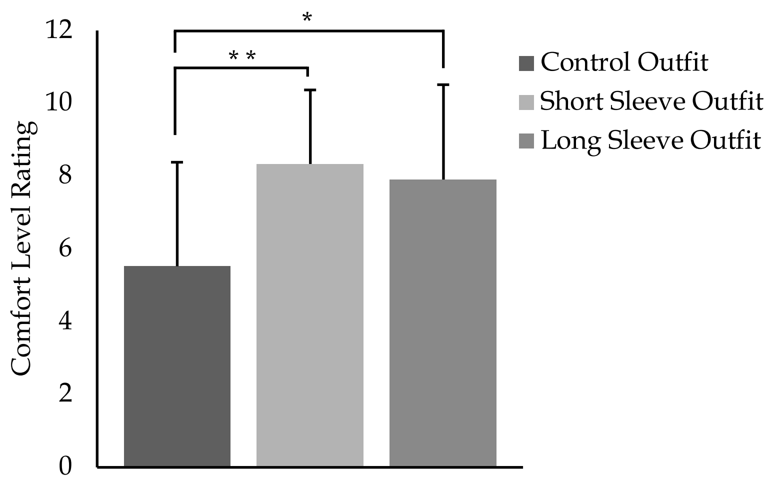

Figure 2. Mean and SD of self-perceived comfort ratings for each outfit ($n = 21$). Ratings range from a minimum of 1 (least comfortable) to a maximum of 10 (most comfortable). $^*p \leq 0.05$, $^{**}p \leq 0.01$ based on pairwise Dunn's tests.

DISCUSSION

The manufacturer's recommendations for BOD POD® test clothing include form-fitting spandex swimsuits, or single layer compression shorts without any padding (and sports bras for women). This is to help reduce isothermal air trapped within hair and clothing fibers. Due to gas laws previously discussed, this air will be more easily compressed during measurements leading to a smaller body volume, thus increasing body density when measured by ADP (4, 13, 19). Our results showed mean body density increased when wearing the short and long sleeve outfits compared to the control outfit. With the contributing values to body density being body volume and body mass, we also saw that body volume was lower when wearing the short and long sleeve spandex outfits. This may be due to larger areas of participant's bodies being compressed by the form-fitting clothing (8), body hair being compressed (9), or unaccounted isothermal air within the clothing (19). The other contributing factor to body density was body mass, which increased while wearing the short and long sleeve outfits compared to the control. This may be explained by the increased amount of clothing material worn due to different outfit lengths.

The observation of higher body density values when participants wore short and long sleeve spandex outfits raised the expectation that there would also be a lower body fat percentage when wearing these outfits. This was confirmed in our results, which showed that body fat percentage when wearing short and long sleeve outfits was lower than the control swimsuits. This indicates that the outfits worn during testing influence body fat percentage measurements which, in research or training programs, may mislead someone into thinking their body fat percentage has increased or decreased depending on the outfits they wore. The results of the data collected from the BOD POD® show that both short and long sleeve spandex outfits significantly underestimated body fat percentage compared to the recommended form-fitting spandex swimsuits (control outfits). The secondary data analysis of self-reported comfort levels showed short and long sleeve outfits were rated higher than the control swimsuits. This indicates participants were more comfortable on average when wearing the less revealing spandex outfits. This could be related to the physical comfort of the swimsuits, and the limited sizes available that may not have been ideal fits for participants. Other participants may not have been comfortable standing in front of a researcher when wearing the more revealing, control swimsuits.

Our study yielded similar findings reported by others. One study looked at different short types (spandex bicycle shorts and cotton gym shorts) compared to spandex swimsuits. They found that spandex bicycle shorts produced body fat percentage measurements 1.5% lower on average than when wearing the swimsuits ($p < 0.05$) (10). Of note, it was not specified the type or if tops were worn during measurements. Another recent study also aimed to compare how traditional and non-traditional clothing affects body composition in female college students by looking at capri-length spandex and spandex shorts (8). The findings of this study illustrate that although capri-length spandex is like recommended spandex shorts, this can falsely increase body density and lead to inaccurate results. The study reported that an increased density translated to a 0.84% underestimation of body fat on average when wearing the longer capri-length spandex (8). To our knowledge, there are no previous data reporting comfort levels wearing outfits which gave us no previous data to compare to.

This study had several limitations. Because the sample size targeted was based on detecting differences between body fat percentage wearing each outfit, there may not be enough power for subgroup analyses (e.g., male vs. female) or for other variables, including body volume. The small sample size could have also overestimated the magnitude of the effects of the outfits based on our specific population studied. Another possible limitation includes participants wearing their undergarments under all 3 test outfits. These were the only clothing items not provided by the researchers and thus could have differed from participant to participant. Also, an ordering effect cannot be excluded in our comfort measurements because the least conservative outfit was worn first, and the most conservative outfit was worn last. Future studies should randomize the order of the outfits worn to assess comfort levels. To improve results in the future, a larger sample size of both males and females should be utilized, and ideally undergarments should not be worn by participants during testing. A limitation regarding the self-perceived comfort levels was that participants may have interpreted the questionnaire differently in terms of their definition of comfort. Participants may have assumed this was physical comfort with how the outfits felt, and others may have assessed their mental comfort wearing the outfits in front of a researcher. Regardless, comfort should be considered when measuring body composition to ensure participants are as comfortable as possible.

We can conclude from our study that wearing short and long sleeve spandex outfits instead of recommended form-fitting spandex swimsuits resulted in a significant body fat percentage underestimation of 2.0% and 2.1%, respectively. Therefore, we recommend participants follow manufacturer recommendations by wearing spandex swim caps and form-fitting spandex swimsuits in BOD POD® body composition analyses.

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