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RELATIONS OF BODY VOLUMINOSITY AND INDICATORS OF MUSCULARITY WITH PHYSICAL PERFORMANCE OF POLICE EMPLOYEES: PILOT STUDY

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ABSTRACT

Background. Activities like running, push-ups and sit-ups may be impacted by a higher body volume and size whether it is due to the amount of fat mass (FM) or skeletal muscle mass (SMM). The purpose of this study was to investigate the differences in physical performance among muscularly developed police employees with higher body mass index (BMI) levels.

Methods. Twenty ($n = 20$) male police employees were divided in 3 groups by BMI but defined by significantly different skeletal muscle mass index (SMMI): muscular ($n = 7$, BMI < 25 kg/m^2, SMMI ≥ 13.16 kg/m^2), very muscular ($n = 7$, BMI = 25–27.5 kg/m^2, SMMI = 13.17–14.10 kg/m^2), and highly muscular ($n = 6$, BMI > 27.5 kg/m^2, SMMI ≥ 14.10 kg/m^2). Body composition components (FM, SMM, percent of fat mass [PFM], percent of skeletal muscle mass [PSMM], SMMI) were assessed by multichannel bioelectrical impedance. The differences in performance of the 50-meter sprint run (RU50), 1-minute push-up (PU), 1-minute sit-up (SU), and 800-meter run (RU800) between BMI groups were statistically tested by a univariate analysis of variance with a Bonferroni post-hoc test.

Results. Highly muscular participants performed fewer SU than muscular (8.14 repetitions, $p = .004$) and very muscular (6.42 repetitions, $p = .021$) participants, and run slower on RU800 test (52.57 s, $p = .034$ and 51.71 s, $p = .038$, respectively).

*Conclusion***.** Physical performance may be negatively impacted in highly muscular police employees once BMI gets above 27.5 kg/m^2 and SMMI above 14.10 kg/m^2.

Keywords: body composition, running, push-ups, sit-ups.

INTRODUCTION

Body mass index (BMI) is an anthropometric measure often used as a rough estimate of general health status and as a surrogate measure of body composition in police studies (Boyce, Jones, & Lloyd, 2008; Dopsaj & Vuković, 2015; Kukić & Dopsaj, 2016; Orr, Dawes, Pope, & Terry, 2017). Several studies conducted with police employees have shown associations between BMI and physical performance, injury rate and health status (Dawes Elder, Hough, Melrose, & Stierli, 2013; Dawes, Orr, Siekaniec, Vanderwoude, & Pope, 2016; Deschamps, Paganon-Badinier, Marchand, & Merle, 2003; Gershon, Lin, & Li, 2002; Orr et al., 2017). Although the success in police occupations requires good physical performance (Carbone, Carlton, Stierli, & Orr, 2014; Carlton, Gorey, & Orr, 2016), it may be negatively affected by a higher BMI, over 25 kg/m^2 (Dawes, Orr, Elder, & Rockwell, 2014; Dawes et al., 2016). Therefore, BMI may be an easy and cost-effective method of predicting individuals at risk of lower physical performance on physical fitness tests. However, it is not clear how performance would be affected if the higher BMI was due to a greater skeletal muscle mass (SMM) as opposed to a greater fat mass (FM).

Studies on various athletes of both genders (Dopsaj et al., 2017; Milić et al., 2017) and on police officers (Dawes et al., 2017; Kukic, Dopsaj, Dawes, Orr, & Cvorovic, 2018; Mitrović, Djordjević, Dopsaj, & Vučković, 2015) indicate that better performers normally possess leaner bodies with well-developed muscle mass and low amounts of fats. However, none of these studies investigated the effects of body muscularity on physical performance if the subjects were highly muscular (Dopsaj & Đorđević-Nikić, 2016; Kukić & Dopsaj, 2016; Rakić, Marković, Dopsaj, Mlađan, & Subošić, 2013), with increased BMI, but still with low amounts of fats. Moreover, studies on police officers as standard indications of body composition use simple measures such as body mass (BM), BMI, FM, SMM or measures of FM and SMM in ratio to BM (Dawes et al., 2017; Dawes et al., 2014; Kukić & Dopsaj, 2016; Orr et al., 2017). The flaws of using BMI have been repeatedly reported in literature (Davillas & Benzeval, 2016; Kyle et al., 2001; Provencher et al., 2018; Rothman, 2008), while Kukic et al. (2018) pointed out the possible sources of misinterpretations when using BMI, percent of fat mass (PFM), and percent of skeletal muscle mass (PSMM).

Several studies have identified a BMI's inability to differentiate between body weight induced changes caused by FM and SMM, either over time or due to the effects of exercise and diet programs (Demling & DeSanti, 2000; Kyle et al., 2001; Provencher et al., 2018; Rothman, 2008). For example, Kyle et al. (2001) conducted a study on 433 subjects, aged 18 to 94 years and showed no changes over time in BMI, even though FM and PFM significantly increased, while SMM, PSMM and skeletal muscle mass index (SMMI) significantly decreased. When applied exercise training and a casein-based diet regime, Demling and DeSanti (2000) reported minimal changes in BMI, even though police officers significantly decreased PFM by 8% and increased lean body mass (LBM) by 4 kg. More importantly, a significant correlation ($r = .065$) was found between the muscle gain and increase in strength measured by chest press, shoulder press and leg extension (Demling & DeSanti, 2000). Furthermore, Provencher et al. (2018) highlighted the potential misinterpretation of obesity prevalence in National Football League (NFL) athletes, whereby obesity rates were 53.4% according to BMI $\geq$ 30 but only 8.5% according to PFM measures. The reason for this discrepancy in results was due to NFL athletes having high amounts of SMM and low amounts of FM.

The theory of geometrical similarities assumes that all human bodies have the same shape and that, therefore, they differ only in size (Jaric, Mirkov, & Markovic, 2005). This means that all lengths are proportional to a characteristic length measured on a subject (e.g., body height [BH]), and all areas (e.g., SMM) are proportional to BH2 (Jaric et al., 2005; Kukic et al., 2018). Accordingly, BMI could be considered a general indicator of body size but without giving a specific information on the source of the size (Provencher et al., 2018; Rothman, 2008). In contrast, FM, SMM can easily be misinterpreted if used as absolute measures because bigger bodies (taller subjects) may naturally possess a bigger amount of FM or SMM. Finally, PFM and PSMM are in somewhat contrast tissues of human body, meaning that increase in PSMM will lead to decrease in PFM and vice versa (Kukic et al., 2018).

Considering this, whether BMI is high due to the amount of FM versus the amount of SMM may be inconsequential as certain activities like running, push-ups, sit-ups and vertical jump may be impacted by a higher BMI regardless of the subject's body composition (Dawes et al., 2016; Mitrović et al., 2015). Mitrović et al. (2015) showed that increased BMI (over 30 kg/m2) in special unit police officers (assumingly muscular) was negatively associated with a 3000m-run velocity. In contrast, Dawes et al. (2014) also showed a negative association between BMI and 1.5 km running performance and VO2max but in officers with increased amount of FM. Increase in BM typically leads to a lower relative oxygen consumption (Mitrović et al., 2015), while increase in SMM increases the metabolic demands (Bassett & Howley, 2000; Lyons, Allsopp, & Bilzon, 2005), based on the type of applied training (Son, H. J. Kim, & C. K. Kim, 2014). In that regard, if an increased BMI, whether due to an increased FM or SMM, can negatively affect performance, the use of the BMI as an indicator of potential physical performance might gain additional support for its use. In contrast, body-size-independent indicators of muscularity may potentially be more precise than commonly used SMM and PSMM and therefore could be used in associating physical performance to body muscularity. Thus, the aim of this study was to investigate the differences in physical performance among police employees based on their BMI but in relation to their level of muscularity defined by body-size-independent indicator of muscularity. It was hypothesized that the participants with higher BMI levels due to greater muscle mass will perform more poorly in upper-body endurance, sprinting ability and middle-distance running; and that body-size-independent indicator of muscularity will be more precise than SMM and PSMM.

METHODS

This study was an observational, cross-sectional study design, consisting of four mandatory field physical abilities tests and laboratory body composition measurements. The participants' body composition was assessed by a multi-frequency bioelectric impendence, which allowed their FM and SMM to be extracted separately. This way it was precisely defined that all participants possess the same PFM but different degree of muscularity. Once participants completed the physical fitness tests, they were divided in three BMI groups and their physical performance was compared between the groups, assuming that those with higher BMI values will perform lower on physical performance tests. The ethical approval (No. 47015) for this study was obtained from the ethics committee of the Faculty of Sport and Physical Education, University of Belgrade.

Participants. The sample of convenience included 20 healthy, physically active male employees of Abu Dhabi Police who completed the test as a mandatory annual assessment. The sample was divided into three groups relative to BMI (see Table), with all groups having a low PFM < 13% (Riebe, Ehrman, Liguori, & Megal, 2018, p. 472) and above average PSMM > 49.79% (Kukić & Dopsaj, 2016; Rakić et al., 2013). Since all the three groups possessed above average PSMM with statistically different skeletal muscle mass index, they were considered muscular but with different degrees of muscularity. Accordingly, the groups were named as follows: Muscular (n = 7), with BMI < 25 kg/m^2, and SMMI ≤ 13.16 kg/m^2; Very muscular (n = 7), with BMI = 25–27.5 kg/m^2, and SMMI = 13.17–14.10 kg/m^2; and Highly muscular (n = 6), with BMI > 27.5 kg/m^2 and SMMI ≥ 14.10 kg/m^2. The main characteristics of the sample relative to group were: Muscular (age = 29.29 ± 1.82 years, body height (BH) = 182.57 ± 5.35 cm, body mass (BM) = 77.96 ± 7.36 kg); Very muscular (age = 28.57 ± 3.55 years, BH = 182 ± 9.22 cm, BM = 86.73 ± 10.13 kg); and Highly muscular (age = 28.30 ± 3.93 years, BH = 182.67 ± 7.09 cm, BM = 99.28 ± 9.13 kg). All participants were informed about the purpose of the testing data collection and they all signed a written informed consent about the use of data in research purposes. This research was carried out in accordance with the conditions of the Declaration of Helsinki, recommendations guiding physicians in biomedical research involving human subjects (Christie, 2000).

Body composition assessment. Body composition analysis and the four physical performance tests were conducted on a same day, with body composition being measured first. The multi-frequency bioelectrical impendence analysis (BIA) machine InBody 720 (Biospace Co. Ltd, Seoul, Korea) was used for full body composition evaluation. The BIA method has been shown to be a reliable (ICC = 0.97) and valid (r = .90 for men and r = .93 for women, compared to dual-energy x-ray absorptiometry [DXA]) method when used as a field test (Aandstad, Holtberget, Hageberg, Holme, & Anderssen, 2014). Furthermore, hydration was shown to have a minimal effect on accuracy of BIA in college athletes (Kemble et al., 2010). The body composition analysis was conducted according to previously reported protocols (Dopsaj et al., 2017; Kukić & Dopsaj, 2017). Three direct (BM, FM, and SMM) and 3 indirect measures (PFM, PSMM and SMMI) were chosen for the analysis. It was important to show that the groups were not different by the absolute and relative amount of FM in order to define the whole sample as muscular. PFM and PSMM were chosen as volume-independent variables because they show FM and SMM relative to body weight, while SMMI was chosen because it represents body size-independent SMM, calculated as: SMM (skeletal muscle mass, in kg) • BH^2 (body height, in m), expressed in kg • m^{-2} (Dopsaj et al., 2017; Jaric et al., 2005; Kukic & Dopsaj, 2017).

Assessment of physical abilities. Physical performance was assessed using the official Abu Dhabi police test battery for the annual physical fitness assessment, consisting of the following measures: 50 m sprint run (RU50), 1-min push-up (PU), 1-min sit-up (SU), and the 800 m run (RU800).

RU50: Participants were allowed to rehydrate immediately after the body composition assessment. After a 10-minute warm-up, participants approached the starting line and performed a 50 m sprint run one by one as fast as physically able. One tester was at the start line giving the signals 'ready', 'steady', and 'go'. On the 'go' command, the tester at the start line moved their hand down sharply as a signal for the two testers positioned at the finish line, to start the stopwatch. Mean of two measured times were recorded as a valid result. The same testers assessed each participant individually.

PU and SU: After all participants completed the RU50, they were given 10 minutes rest allowing them enough time to get ready for the PU and SU test. The PU test was conducted first and then, following a 10-minute rest period, the SU test was completed. A trained testing team counted the repetitions. Both tests (PU and SU) were conducted according to previously explained protocols and required participants to perform as many repetitions as possible in 1 minute (Čvorović et al., 2018; Dawes et al., 2016).

RU800: After the SU test, participants were allowed to rest for 15 minutes and were given the opportunity to hydrate before the RU800 test. The test was conducted on a 200 m circuit running track, whereby the participants were instructed to run 4 laps as fast as possible. The time was measured using a stopwatch, with the precision of 1 second.

Statistical analysis. Descriptive statistics (i.e. means and standard deviations (SD)) were calculated using Microsoft excel. To investigate the differences between defined BMI groups, a univariate analysis of variance (One-way ANOVA) with Bonferroni post-hoc analysis was used for all variables. The significance level was set at $p < .05$ a priori. For the ANOVA statistical analysis, SPSS software (IBM software SPSS 20.0) was used.

RESULTS

Physical performance outcome measures, the number of SU performed and the time needed to complete the RU800 were significantly affected by the increased BMI (Table). Descriptive statistics and the ANOVA results (Table) showed that BM was significantly different between the BMI groups, while there were no differences in their BH. Furthermore, significant differences in body composition occurred only in SMM and SMMI, while FM, PFM, and PSMM were the same across the groups, suggesting that participants were significantly different only by the total and relative (hence the quality) amount of SMM.

The Bonferroni post-hoc analysis revealed that significant differences in BM (21.32 kg, $p = .001$) and

Table. **Descriptive statistics for mean and standard deviation for each group, with the ANOVA values for *F* and *p***

Variables	Muscular ($n = 7$) Mean ± SD	Very muscular ($n = 7$) Mean ± SD	Highly muscular ($n = 6$) Mean ± SD	*F*	*p*
Age	29.29 ± 1.82	28.57 ± 3.55	28.30 ± 3.93	0.627	.546
BH (cm)	182.57 ± 5.35	182 ± 9.22	182.67 ± 7.09	0.016	.984
BM (kg)	77.96 ± 7.36	86.73 ± 10.13	99.28 ± 9.13	9.234	.002*
BMI (kg/m²)	23.96 ± 1.35	23.64 ± 0.32	30.91 ± 1.58	55.824	<.001*
FM (kg)	8.49 ± 2.66	9.83 ± 2.53	11.27 ± 1.85	2.171	.145
PFM (%)	10.91 ± 3.34	11.36 ± 2.56	11.33 ± 1.53	0.062	.940
PSMM (%)	50.88 ± 1.97	51.25 ± 2.20	52.18 ± 1.68	0.732	.495
SMM (kg)	39.70 ± 4.52	44.46 ± 5.49	51.80 ± 4.90	9.551	.002*
SMMI (kg/m²)	11.88 ± 0.9	13.38 ± 0.60	15.51 ± 0.96	30.791	<.001*
50 m (s)	7.09 ± 0.34	6.89 ± 0.34	7.40 ± 0.47	2.780	.090
PUSH UP (No)	41.43 ± 5.41	43.14 ± 4.34	42.67 ± 2.16	0.297	.747
SIT UP (No)	45.14 ± 2.97	43.43 ± 1.90	37.00 ± 5.80	8.173	.003*
800 m (s)	201.57 ± 13.62	202.43 ± 17.56	254.17 ± 61.56	5.212	.016*

Note. BH – body height, BM – body mass, BMI – body mass index, FM – fat mass, PFM – percent of fat mass, PSMM – percent of skeletal muscle mass, SMM – skeletal muscle mass, SMMI – skeletal muscle mass index, 50 m – a 50 m-sprint run test, PUSH UP – maximal number of push-ups in 1 minute, SIT UP – maximal number of sit-ups in 1 minute, 800 m – a 800 m run test.

SMM (12.10 kg, p = .001) existed between the normal and highly muscular groups (Figures 1 and 2).

The most sensitive variable was SMMI since significant differences were shown between all

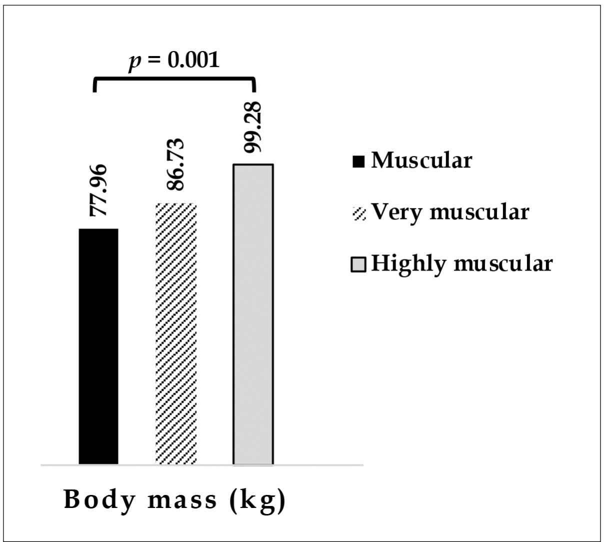

Figure 1. **Differences in BM between the BMI group**

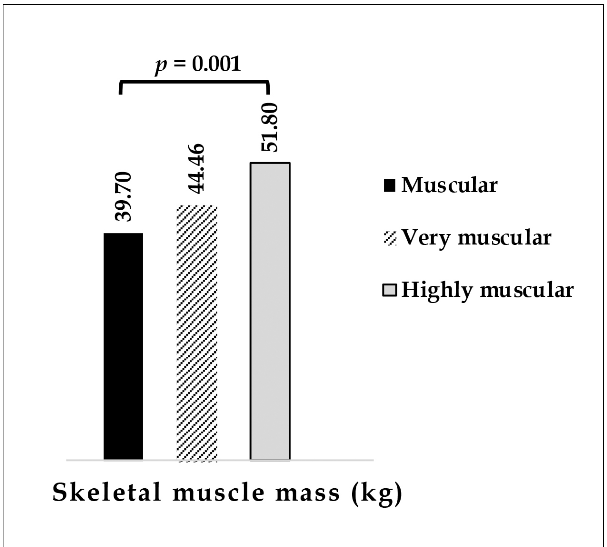

Figure 2. **Differences in SMM between the BMI groups**

groups (Figure 3). Mean differences between the muscular and very muscular and muscular and highly muscular groups were 1.49 kg/m^2 (p = .011), and 3.62 kg/m^2 (p < .001) respectively, while the mean difference between the very muscular and highly muscular was 2.13 kg/m^2 (p = .010).

The performance of 1-minute SU and RU800 was negatively influenced by higher BMI (Table).

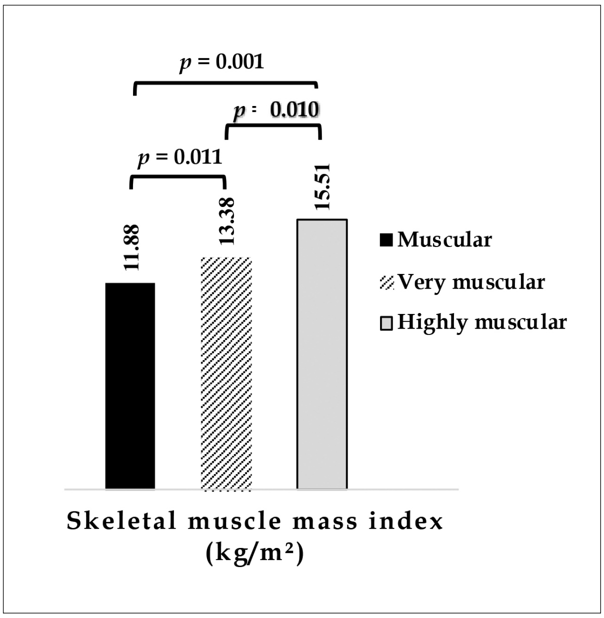

Figure 3. **Differences in SMMI between the BMI groups**

Significant differences were observed between the muscular and highly muscular as well as between the very muscular and highly muscular (Figures 4 and 5). The highly muscular group performed significantly less SU than the muscular and very muscular groups, with the mean differences of 8.14 repetitions (p = .004) and 6.42 repetitions (p = .021). Similarly, they needed more time to complete the RU800 test than muscular and very muscular groups, with mean lower time of 52.57 s (p = .034) compared to 51.71 s (p = .038).

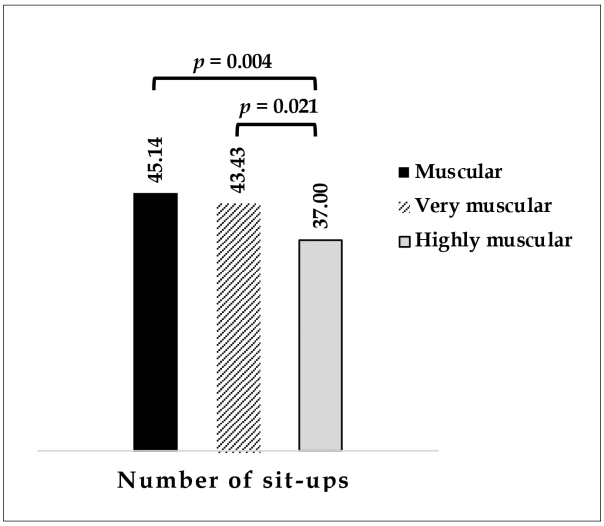

Figure 4. **Differences in number of executed SU between the BMI groups**

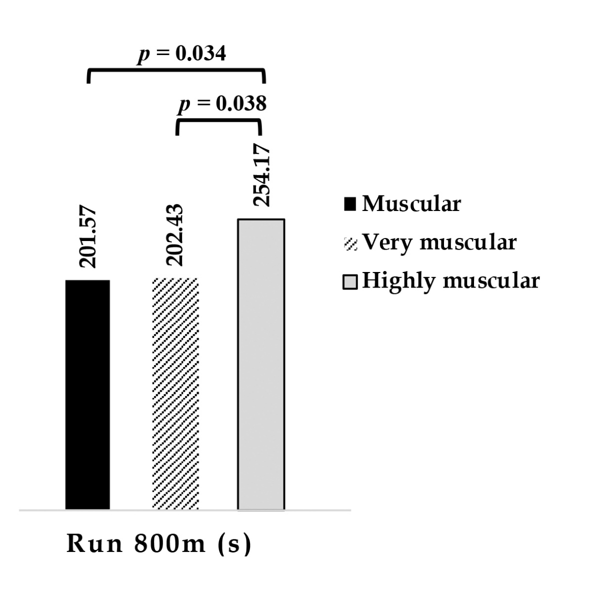

Figure 5. **Differences between the BMI groups in time needed to complete the RU800**

DISCUSSION

The aim of this study was to investigate the differences in physical abilities among muscularly developed police employees with different BMI, and that body-size-independent indicator of muscularity will be more precise than SMM and PSMM.

The main findings of this study suggest that BMI levels of up to 27.5 kg/m^2 if based and SMMI up to 14.10 kg/m^2 may not negatively impact on performance given that the performance was similar to the group with BMI ≤ 25 kg/m^2. However, increasing BMI levels above 27.5 kg/m^2 based on SMMI > 14.10 kg/m^2 (such as body builders) may lead to lower physical performance in SU and RU800. Note that the groups did not differ significantly in PSMM and PFM but they did in SMMI, indicating that the amount of contractile potential on each squared meter of the body size (Dopsaj et al., 2017) was higher respective to BMI group which could be the reason for the equal performance in RU50 and PU (Dawes et al., 2016).

In regard to the RU800 performance, Salvadego et al. (2013) reported lower relative oxygen consumption in participants with increased muscle mass and BMI = 30.1 kg/m^2 (PFM = 12%), relative either to BM or SMM. Thus, a lower performance of highly muscular group in RU800 could be due to decreased oxygen consumption relative to body weight, regardless of body size. Several studies have shown that BMI, FM, and PFM are negatively associated with running performance, estimated VO_2max and occupational task performance (Dawes et al., 2018; Dawes et al., 2016; Mitrović et al., 2015). A study conducted on 72 special force police officers showed negative causal relationship between BMI and running velocity on a 3000m run test and hence aerobic capacity (Mitrović et al., 2015). The authors of this study found that hyper muscular police officers (BMI ≥ 30 kg/m^2, with low levels of FM) run, on average, 0.364 m/s (p = .021) slower than the officers with a normal BMI (BMI ≤ 25 kg/m^2) with a significant prediction coefficient of determination (R^2 = .167, p < .001). Results obtained on RU800 in this study were in somewhat similar since the sample in Mitrović et al. (2015) consisted of officers from a special antiterrorist unit, whose members were physically highly trained, therefore potentially muscularly highly developed officers.

In a load carriage study, Lyons et al. (2005) showed that body composition index, calculated as lean body mass divided by (fat mass + external load), produced a moderate correlation (r = –.52, p < .01) with the metabolic demand of heavy load-carriage. It should be noted that Lyons et al. (2005) showed that the association of SMM and physical performance increases as the task was more dependent on strength and that lean muscle mass should be considered as a selection criterion for load carriage occupations. In that regard, our results support this notation because all participants in this study were muscular above the 50th percentile when compared to the normal population (Kukić & Dopsaj, 2016; Rakić et al., 2013) and similar in musculature to professional combative athletes (Dopsaj et al., 2017). Therefore, they scored highly in strength related tests. However, Lyons et al. (2005) also showed that metabolic demands of the task increased by 51% as the load increased from 0 to 40 kg, while our results additionally suggest that metabolic demands significantly increase once BMI surpass the level of 27.5 kg/m^2 (although highly muscular), leading to a lower performance in RU800.

In other words, highly muscular, or even hyper-muscular police officers, because of the hyper level of muscles as active metabolic consumption mass may have a lower level of metabolic efficiency during the locomotion endurance tasks, such as long running. According to that phenomenon and association of body size and performance (Jaric et al., 2005; Markovic & Jaric, 2004), hyper-muscular body in police should be recognized as a whole body locomotion endurance negative effect. This could lead to a twofold conclusion. Firstly, SMM-induced higher levels of BMI might be an advantage when required to carry a daily occupational load and in sudden physically demanding tasks that require upper body strength (arresting a belligerent, lifting and carrying heavy objects). Secondly, highly increased SMM may become a disadvantage for aerobically demanding tasks (such as chasing suspect, running the stairs, etc.).

Police employees may be required to engage belligerents by using physical force for self-defense or to ensure public safety (Dawes et al., 2018). In that regard, the defensive tactics and arrest control training that mainly consists of martial arts such as judo, wrestling, jiu-jitsu and karate are of high importance for police employees (Dawes et al., 2018). More importantly, the successful application of these defensive and arrest control technics, in real life and unpredictable situations with an unknown opponent, is highly associated with muscle strength (which depends on higher PSMM and SMMI) (Dopsaj et al., 2017). Moreover, Dawes et al. (2016) found positive correlations ($p \leq 0.001$) between estimated LBM and strength tests such as PU, vertical jump, estimated peak power and bench press, suggesting that better PU performance requires a higher estimated LBM, which is partly supported by our results. All three groups from our study were muscularly developed (mean PSMM = 51.43%) and accordingly performed very well on the PU test, with no difference between the groups (although different by SMM and SMMI, Figures 2 and 3). Conversely, a lower performance in SU test achieved by highly muscular group, comparing to very muscular and muscular, is not very clear since it depends on active contractile mass (as in PU test) rather than on endurance. It could be due to the effects of body mass and body size that may occur in performance tests of supporting body weight (Jaric et al., 2005; Markovic & Jaric, 2004), whereby authors suggest that results in tests such as sit-ups should be normalized to BM • –0.33. However, even though highly muscular participants performed lower than muscular and very muscular, they still scored well on SU test comparing to Annual Fitness Assessment, where by 36 sit-ups is a pass mark for the age group 23–30 years (Abu Dhabi Police, Annual Fitness Assessment minimum standards). This again suggests that greater muscle mass leads to a better physical performance, but it also indicate that SMM may become an obstructing factor once a certain amount has been developed. Additionally, increased SMM due to excessive strength training may lead to imbalance between strength and range of motion followed by altered muscle efficacy and increased risk of injuries (Barlow, Benjamin, Birt, & Hughes, 2002; Staron et al., 1990; Tesch, 1988).

CONCLUSION

This study is the first known study to investigate differences in physical performance among police employees with an increased BMI based on higher levels of SMM; and the first one that investigates the precision of SMMI compared to PSMM. Based on the results all three groups showed very good levels of physical performance, although the highly muscular group performed significantly lower than other two groups on RU800 and SU tests. These results suggest that physical performance may be negatively impacted once BMI gets above 27.5 kg/m^2 and SMMI above 14.10 kg/m^2. By having a better understanding of how these factors interact, instructors can be more precise in designing exercise programs, while police employees can benefit by understanding how muscularity can support them in physically demanding tasks, but also how highly developed muscle mass can lead to lower physical performance in other tasks.

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Conflict of interest. There is no conflict of interest for this paper.

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