Wearing ballistic and weighted vests increases front kick forces

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A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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ABSTRACT

Background and Study Aim: Front kicks are often used in hand-to-hand military combat training. To mimic real-life combative environments, personal protective equipment (PPE) that includes a ballistic vest should be worn during training. The aim of this study was the effects of ballistic and weighted vests on front kick kinetics.

Material and Methods: Five male soldiers (22.2 ±1.5 y, 78.8 ±5.8 kg, 180.6 ±4.8 cm) performed six individual front kicks during three conditions: bodyweight with no vest (*NV*), with a 12 kg ballistic vest (*BV*), and with a 12 kg weighted vest (*WV*). Peak force (N), time to reach peak force (s), and impact force (N) were measured during each kick. Data were analyzed using paired sample t-tests and Cohen's *d*.

Results: Peak force of *BV* 6061 ±1176 N and *WV* 6298 ±1355 N was greater than *NV* 5201 ±1176 N ($p<0.01$; $d = 0.7$ and 0.9, respectively). Time to reach peak force was longer for *BV* 14.25 ±4.24 ms compared to *WV* 13.00 ±3.96 ms ($p<0.01$; $d = 0.3$), but neither were different than *NV* 14.02 ±6.71 ms ($p = 0.822$, $p = 0.330$, respectively). Impact force was greater for *WV* 3833 ±790 N and *BV* 3761 ±930 N compared to *NV* 3405 ±62 N ($p<0.01$; $d = 0.4$ and 0.6, respectively).

Conclusions: As both vests result in similar kinetics, soldiers can use a *WV* or *BV* during hand-to-hand combat training to adapt to greater front kick impact forces that likely occur during combat.

Keywords: biomechanics • hand-to-hand combat • military • personal protective equipment

Conflict of interest: Authors have declared that no competing interest exists

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Hand-to-hand combat – physical confrontation between two or more persons at very short range without the use of firearms or other distance weapons.

Combat – *noun* a physical struggle between opposing individuals or forces [22].

Close combat – physical confrontation between two or more opponents at short range involving weapons (knife, stick, firearms and other distance weapons).

Personal protective equipment – protective clothing, helmets, thorax-protection system or other equipment designed to reduce the likelihood of serious injury from the impact of small arms fire and fragments.

Front kick – is a kick executed by lifting the knee straight forward, while pulling the foot to the hamstring, and then straightening the leg in front of the target area.

Impact force – the force generated at the start of contact or collision. In close combat this is the impact of a kick or punch as they hit the body or solid pad.

Impact force – *noun* a force that is a result of colliding with another body, e.g. when a runner's foot hits the ground [22].

INTRODUCTION

In combat environments, military personnel wear personal protective equipment (*PPE*) that typically consists of a helmet and thorax-protection system (i.e. a vest with ceramic plates). Together, *PPE* is designed to reduce the probability of serious injury resulting from small arms fire and fragments [1]. During combat, soldiers rarely remove their *PPE*, meaning that ballistic vests of up to 12 kg [2] are worn at all times. To mimic real-life combative scenarios, combat training should be performed while wearing *PPE*, but the physiological, kinetic, and kinematic effects of wearing *PPE* have not been heavily investigated.

Previous research has shown that *PPE* decreases performance during simulated marching or repeated military work tasks [3, 4], but less research has been conducted on the effects of *PPE* during hand-to-hand combat training. As this type of training is common among military personnel [5, 6], it would be advantageous to understand whether *PPE* affects performance. During combat training, different punch and kick variations are utilized [5, 7], one of the most common types being the front kick [8, 9]. For this reason, many researchers have investigated the kinetics and kinematics of front kicks [10-15], and although these studies provide valuable data regarding front kick reaction time [16], velocity [12], and forces [11, 17], they have all been conducted in the absence of *PPE*. As the kinetics of a front kick are influenced by kicking technique [18], it is possible that wearing a *PPE* can shift the body's center of mass, alter movement kinematics, and result in different kinetics. Therefore, we applied in our research a 12 kg ballistic vest (*BV*). As *BV*s can be costly, bulky, and difficult to maintain, front kick kinetics were also determined while wearing a cheaper, commercially available weighted vest (*WV*) with equal mass, to determine if *WV*s may be substituted for *BV*s during training. Based on previous research [1, 14, 19], we hypothesized that front kicks performed with both a *BV* and *WV* would result in greater impact forces compared to front kicks performed without vest (*NV*).

The aim of this study was the effects of ballistic and weighted vests on front kick kinetics.

MATERIAL AND METHODS

This quantitative study was based on an intrapersonal comparison using a quasi-experimental design. The research was approved by the Ethics Committee of the Faculty of Physical Education and Sport (No. 025/2016, 5 February 2016) together with an informed consent, which was signed by all the participants. All procedures were performed in accordance with the Declaration of Helsinki.

Participants

Five male soldiers of the Military Department at the Faculty of Physical Education and Sport, Charles University in Prague (22.2 ±1.5 years, 78.8 ±5.8 kg, 180.6 ±4.8 cm) participated in the study. The soldiers were able to execute a front kick with proper technique, regularly participating in close combat training at the Department of Military Physical Education within the Faculty of Physical Education and Sport at Charles University. All of the soldiers were healthy for the duration of the experiment and did not suffer from any health problems during measurements.

Experimental protocol

All measurements were conducted in a single laboratory visit. After a 10-minute dynamic warm-up consisting of various lower limb, trunk, and upper body exercises, each participant executed pre-test front kicks of progressively increasing intensity with *NV*, *BV* and *WV* to familiarize themselves with the feeling of kicking against the force plate. During familiarization, each participant started their kicks with a self-selected distance from the force plate and a researcher noted the distance from which the front kicks felt most natural for each participant. These individualized distances were then recorded and used to ensure the same starting position for each trial. All front kicks began with a front posture and were was executed so that the foot made contact at a mid-range height, typical of the abdomen or solar plexus. The order of testing conditions was randomized, and participants executed a single set of 6 front kicks with *NV*, *BV*, or *WV*. Between each kick, participants were given 30 s of rest, and after the 6th kick of the first condition, 6 min rest was given. Participants then repeated the same protocol for the remaining two randomized conditions.

Measuring device and the gear of participants

The kinetics of each front kick was measured using a triaxial force plate (Kistler 9281) measuring at 1000 Hz [20]. In the pre-analytical phase, the lower limit of the magnitude of acting force

Figure 1. Force plate.

was set to 100 N to reduce noise on the force plate and to mark the beginning and the end of the interaction between a participant's foot and the force plate. The plate was adjustable along the vertical axis to ensure that the height of the plate was individualized to each participant's "mid-range" height [11, 17] for the purposes of the experiment (Figure 1).

All participants wore standardized military field clothing and field shoes designed for the Armed Forces of the Czech Republic. A ballistic vest (a protective modular vest CZ 4M with a ballistic resistance level of IV and 12 kg of weight) and a weighted vest (Piran Sport, adjusted to the weight of 12 kg) were used for the purposes of this study (Figure 2).

Measurement procedure and data collection

Three variables were compared between each of the two conditions (*NV*/*BV*, *NV*/*WV*, *BV*/*WV*). Peak force ($\overrightarrow{F_{peak}}$) was determined as the sum of force exerted in all three directions x, y, z [11] (Eq. 1).

$$|\overrightarrow{F_{peak}}| = \max\left(\sqrt{\overrightarrow{F_x^2} + \overrightarrow{F_y^2} + \overrightarrow{F_z^2}}\right) \quad \text{(Eq. 1)}$$

Figure 3 shows an example force-time curve for a single front kick. All the physical quantities were analyzed from the very first interaction of a participant's foot with the force plate (t_0) to reaching the peak force (F_{peak}).

The time to reach peak force (t_{max}) was determined as the time period between the beginning of the interaction of a participant's foot with the force plate and the time of peak force (t_{peak}) (Eq. 2).

$$t_{max} = t_{peak} - t_0 \quad \text{(Eq. 2)}$$

Impact force ($\overrightarrow{F_{mean}}$) was the third measured variable in this study. The formula for calculating impulse ($\vec{I}$) was used to derive the average impact force acting during the time to reach peak force (Eq. 3).

Figure 2. Weighted and ballistic vests.

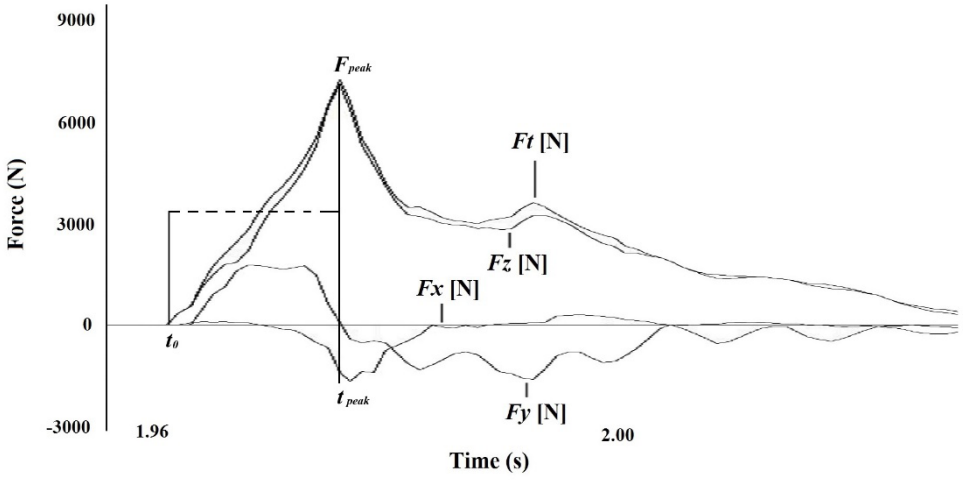

Figure 3. The time course of the kinetic force of one front kick.

$$\vec{I} = \int_{t_0}^{t_{peak}} \overrightarrow{F_{peak}} dt \qquad \text{(Eq. 3)}$$

The formula above was modified as data collection wasn't continuous, but discrete. During each time period (Δt), given by measuring frequency, impulse was calculated and the sum (net impulse) from the beginning of the interaction of a participant's foot with the force plate to reaching peak force was determined (Eq. 4). Average impact force was then derived from net impulse and the time to reach peak force (Eq. 5).

$$\overrightarrow{I_{net}} = \sum_{i=1}^{n} \left(\overrightarrow{F_{peak}}\right)_i \cdot \Delta t_i \qquad \text{(Eq. 4)}$$

$$\overrightarrow{F_{mean}} = \frac{\overrightarrow{I_{net}}}{t_{max}} \qquad \text{(Eq. 5)}$$

Statistical analysis

The mean and standard deviation of all six trials were calculated for each variable for each of the three conditions. Data were firstly subjected to Shapiro-Wilk test of normality to verify data normality. The intrapersonal comparison of results of studied indicators mentioned earlier was then realized through the parametric paired sample t-test for all three conditions (*NV/BV*, *NV/WV*, *BV/WV*). The significance level was set at . Practical significance was determined by effect size using *Cohen's d* which can be interpreted a small (0.2 to 0.5), medium (0.5 to 0.8), and large (*d*>0.8).

RESULTS

All data were normally distributed. The peak force was greater when front kicks were performed with a *BV* or *WV* compared to *NV* (*d* = 0.7 and 0.9, respectively), but there were no differences between *BV* and *WV* (*p* = 0.329) (Figure 4).

The time to reach to peak force was shorter for *WV* compared to *BV* (*d* = 0.3), but there were no differences between *NV* compared to *WV and BW* (*p* = 0.822, *p* = 0.330, respectively) (Figure 5).

Impact force was greater when front kicks were performed with a *BV* or *WV* compared to *NV* (*d*=0.4 and 0.6, respectively), but there were no differences between *BV* and *WV* (*p*=0.558) (Figure 6).

DISCUSSION

Our study indicates that wearing a 12 kg *BV* or *WV* affects the kinetics of front kicks in trained soldiers. Specifically, peak force output and impact force (i.e. impulse) were significantly greater compared to *NV*. Therefore, it may be warranted to perform hand-to-hand combat training in partial or full *PPE* to mimic real-life combative scenarios where front kick kinetics may be different to front kick training with *NV*.

The peak force of front kicks with *BV* (6061 ±1319 N) and *WV* (6298 ±1355 N) were approximately 17% and 21% greater than *NV* (5201 ±1176 N),

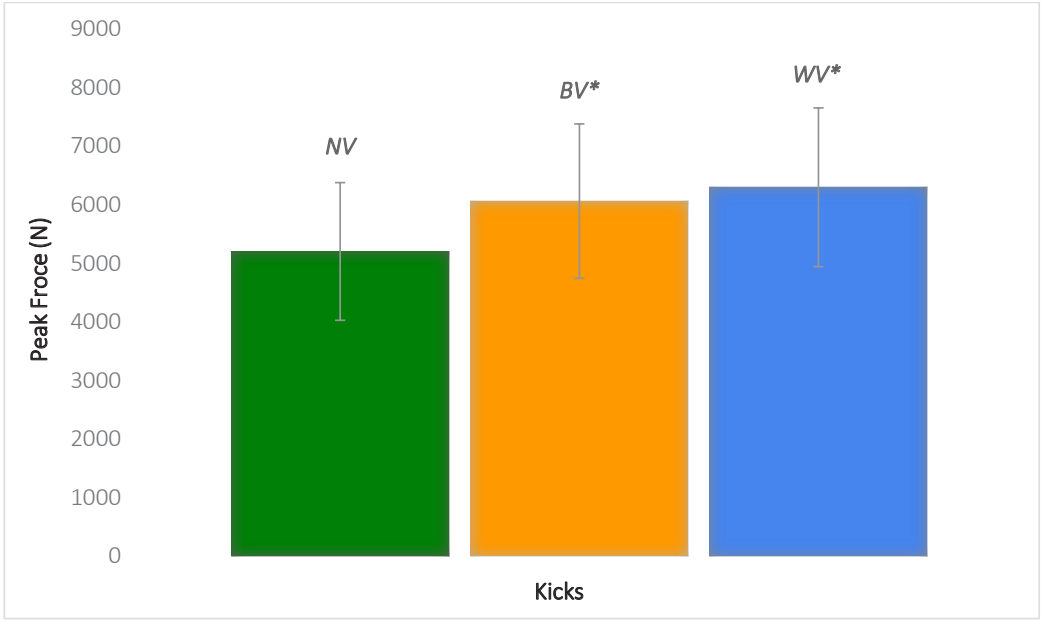

Figure 4. Peak force with a ballistic vest (BV), weighted vest (WV), and no vest (NV). *significantly greater than NV (p<0.01).

respectively. As impact force (i.e. impulse) contains both force and time components, it is not surprising that impact force was greater for the *BV* and *WV* conditions compared to *NV*. However, some may find this interesting, as peak force was achieved quicker in *WV* (13.00 ±3.96 ms) compared to *BV* (14.25 ±4.24 ms) (Figure 5), meaning that impact force could theoretically be greater in *WV* (i.e. the same amount of force in less time). The most likely explanation is that the difference in time to peak force between *BV* and *WV* wasn't enough to affect impact force. Although the time to peak force was

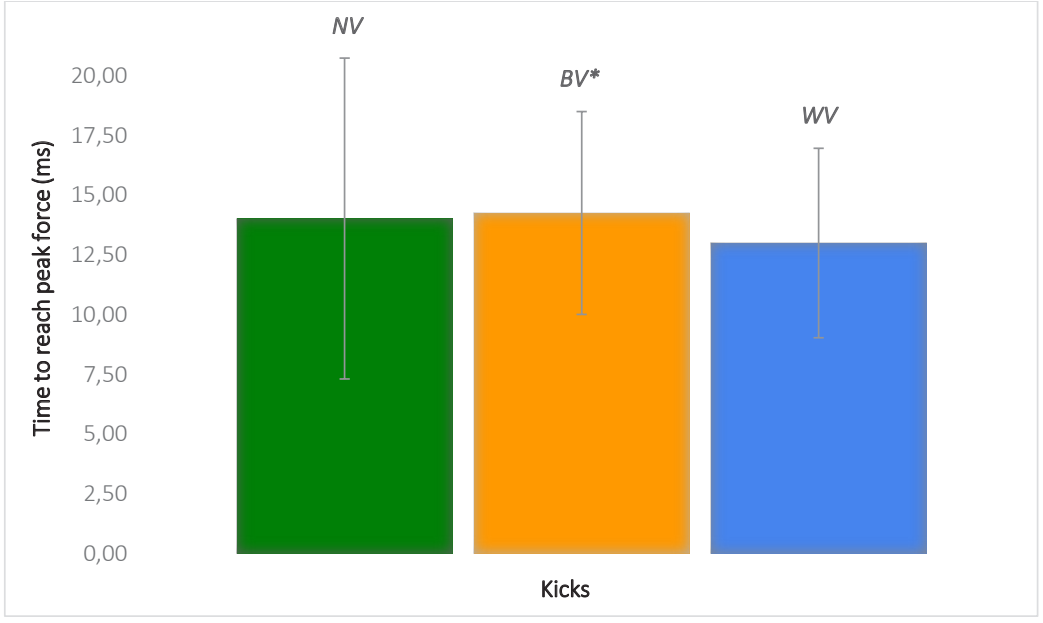

Figure 5. Time to reach peak force with a ballistic vest (BV), weighted vest (WV), and no vest (NV); *significantly less than BV (p<0.01).

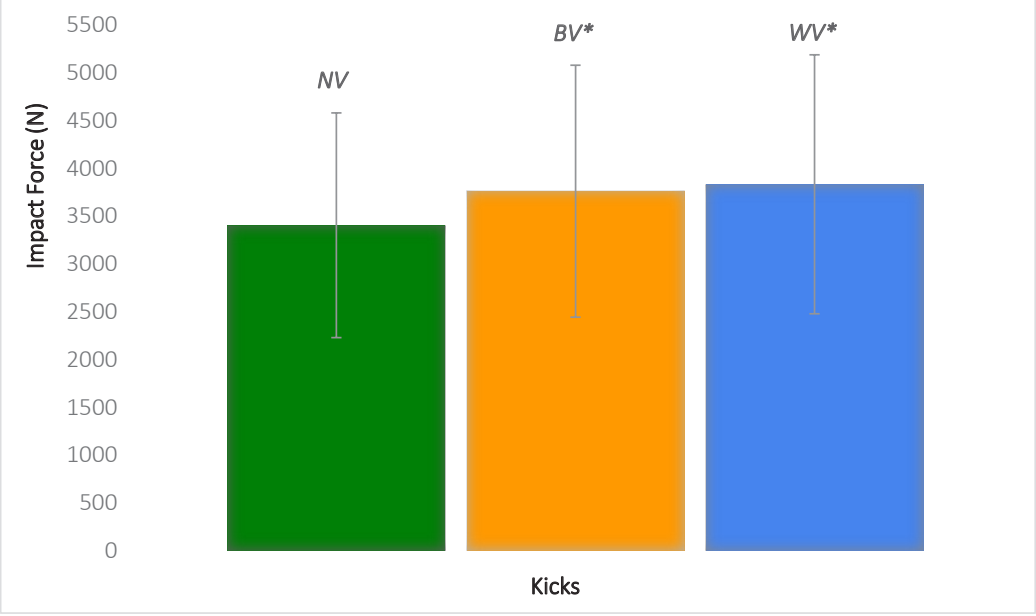

Figure 6. Results of impact force with a ballistic vest (BV), weighted vest (WV), and no vest (NV). *significantly greater than NV (p<0.01).

statistically significant between the two conditions, a small sample size coupled with a small effect size may make the time to peak force difference practically insignificant.

However, the significant difference in time to peak force may hold true and may be credited to the shape and material of the vests. Previous research has shown that the shape of a ballistic vest reduces the mobility of trunk [4, 21], which may cause a change of front kick technique [12]. If this held true in the present study, it is possible that the *WV* may have not impaired mobility and resulted in a more "efficient" foot contact. At first glance, this may seem contrary, as the *NV* condition would have the least amount of movement impairment. However, the small sample size and relatively large standard deviation for *NV* (Figure 5) may have masked a difference between *NV* and *BV*. However, the kinematics of trunk mobility and kick technique were not assessed in the present study, so this notion remains purely hypothetical.

As this was the first study to investigate the effects of *BV* (and *WV*) on front kick kinetics, it is difficult to compare our findings with those of others. Nevertheless, Kurgano and Yokokura [17] found that the peak force of font kicks performed by Japanese martial art Nishon-Kempo without wearing a vest was 4500 N. Dworak et. al. [11] found that the impact force 2900 N. Additionally, the *NV* peak force and impact force in our study (5201 ± 1176 N and 3405 ±762 N, respectively) was greater than the values presented by studies [11, 17]. Another possible explanation for greater peak and impact forces in our study is that our subjects wore solid military footwear, which allows for maximal force while minimizing the innate apprehension of suffering an injury. Therefore, more research should be conducted on front kick force with full military outfitting.

The relatively small sample size and lack of 3-dimensional kinematics are limitations of the present study and should both be addressed in future research. However, this is the first study to our knowledge that shows the effects of partial *PPE* (i.e. no helmet, weapon, etc.) on front kick kinetics in highly-trained soldiers. As our data show that the presence of a *BV* or *WV* increases kicking forces and as front kicks are used as a self-defense strategy, to kick down doors, and to disrupt enemy fighters, further research should be conducted on the topic.

CONCLUSIONS

The peak force and impact force of a front kick with *BV* and *VW* are greater than when a front kick is performed with *NV*. Therefore, soldiers should use *BV* or *WV* during training to adapt to the greater forces that likely occur during hand-to-hand combat.

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