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Kinetic and kinematic characteristics of sprint running with a weighted vest

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ABSTRACT

This study elucidated kinetic and kinematic changes between control and weighted vest sprinting with a load of 7% body mass. Fourteen male sprinters completed 60 m control and vest sprints over a long force platform system. Step-to-step ground reaction force and spatiotemporal variables were grouped, representing the initial acceleration (1st–4th steps), middle acceleration (5th–14th steps), later acceleration (15th step–step before maximum velocity reached) and maximum velocity (stride where maximum velocity reached) phase during each trial. Two-way ANOVA with post hoc Tukey HSD and a Cohen's d effect size with 95% confidence intervals elucidated the difference between trials and phases. Between control and vest trials the velocity decreased (3.41–3.78%) through trivial–small step length (1.95–2.72%) and frequency (0.87–1.54%) decreases. Vertical impulse increased (6.46–6.78%) through moderate support time increases (4.84–6.00%), coupled with no effective vertical mean force differences during the vest trial, compared to the control. There was no significant interaction between trials and phases. Therefore, although weighted vest trials did not increase vertical mean force production, vests did induce an increased vertical force application duration during the support phase step-to-step while supporting a larger total load (body mass plus vest mass).

1. Introduction

Resisted sprint training (RST) is a popular modality to overload an athlete during sprinting (Alcaraz et al., 2008; Cronin and Hansen, 2006). When coupled with a well thought out training program, RST is believed to increase sprint specific neural activation and force application, compared to control sprints (no resistance), resulting in sprint specific strength benefits that translate to improved performance after RST interventions (Behrens and Simonson, 2011; Cronin and Hansen, 2006; Martínez-Valencia et al., 2015).

Weighted vests (WVs) increase total object mass (athlete body mass [BM] plus WV mass) and apply greater force acting vertically due to gravitation, thus, athletes need to apply greater total (not object mass specific) ground reaction forces (GRFs) to overcome the inertia and/or vertical weight during WV sprinting to achieve the same magnitude of horizontal or vertical acceleration, compared to a control sprint. Therefore, benefits due to RST using WVs may be primarily specific to vertical force production, and previous research has demonstrated that larger vertical forces during the maximum velocity phase is important for control sprint performance (Nagahara et al., 2018a; Weyand et al., 2000). Optimal loads for RST to target the maximum velocity phase (high-speed training) have been reported as loads that induce $<$ 10% velocity decrement (or $<$ 13% BM) compared to the maximum velocity achieved in control sprints (Cahill et al., 2019; Macadam et al., 2019), which has been suggested to be translatable to WV sprinting. Previous studies with WV loads between 5 and 9% BM have demonstrated velocity decrements, compared to control sprints, ranging from 1.2 to 4.7% (Alcaraz et al., 2008; Carlos-Vivas et al., 2019a; Carlos-Vivas et al., 2019b; Cross et al., 2014; Simperingham and Cronin, 2014). Previous kinematic results (studies with WV loads between 5 and 9% BM) have demonstrated that WV trials increase support time (ST) (range 4.7–5.6%) and decrease flight time (FT) (range 7.9–17.4%), compared to control sprints, which change to larger extents than decreased step length (SL) (range 2.5–4.4%) and frequency (SF) (range 0.8–3.8%) trends during the maximum velocity phase (Cross et al., 2014; Macadam et al., 2019; Simperingham and Cronin, 2014). In terms of kinetics, two previous treadmill studies elucidated changes due to WVs, compared to control sprints, demonstrating no vertical peak force differences with loads of 5% BM (Simperingham and Cronin, 2014) or 9 kg absolute (Cross et al., 2014).

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Although reporting differences between WV and control trials in terms of step-to-step kinetics during overground sprinting may help to better understand the characteristics of WV sprinting and optimise intervention strategies, no previous WV research has elucidated such aspects. Therefore, the aim of this research was to clarify kinetic and kinematic differences measured by force platforms between control and WV sprints during the entire acceleration phase with a load specific to high speed training. Due to the greater force acting vertically, it was hypothesised that vertical force and impulse would be significantly different between trials.

2. Methods

Fourteen healthy, injury free male sprinters competing at regional–national level (mean ± SD: age, 19.9 ± 1.2 years; stature, 173.9 ± 6.6 cm; BM, 68.8 ± 4.4 kg; 100 m personal best, 11.15 ± 0.33 s) volunteered to participate. Informed consent was obtained prior to participation and approval was granted by the institutional research ethics committee.

Previous research used weighted garments with approximately 5–9% BM without reducing velocity > 10%, compared to a control (Alcaraz et al., 2008; Simperingham and Cronin, 2014), thus, 7% BM (4.8 ± 0.3 kg) was incorporated for this research. After a self-selected warm up, participants completed one maximum effort 60 m control and WV trial in order, from a crouched start using starting blocks. Trials were separated by a minimum of ten minutes for recovery. The WV used was trunk mounted (C3JWT419, Mizuno, Osaka, Japan), loaded to 7% BM (within ± 200 g) with weights positioned evenly around the anterior and posterior sides. Trials were performed on an indoor athletic track over a 50 m long force platform system (sampling frequency set at 1000 Hz) consisting of 54 force platforms (TF-90100, TF-3055, TF-32120, Tec Gihan, Uji, Japan).

A 50 Hz low-pass fourth-order Butterworth filter was used on raw GRF signals (Clark et al., 2017; Nagahara et al., 2020; Nagahara et al., 2017). Foot strike and toe-off instants were determined by exceeding or falling beneath a 20 N threshold of vertical GRF. Step-to-step velocity, SL, SF, ST and FT were calculated in line with previous studies (Nagahara et al., 2017; Nagahara et al., 2018a; Nagahara et al., 2018b). During each steps support phase, the mean propulsive, braking, anteroposterior and vertical forces were calculated. Time integration of propulsive, braking and vertical forces were used to calculate the propulsive, braking and vertical impulses during the support phase step-to-step. Net anteroposterior impulse was calculated as the sum of propulsive and braking impulses. In addition, the effective vertical mean force was calculated to control for body weight and vest weight, and time integration of the effective vertical mean force was used to calculate the effective vertical impulse.

$$EffectiveVerticalMeanForce = MF - (WVW + BW)$$

Where MF was the mean vertical force during the support phase step-to-step, the WVW was weighted vest weight and the BW was body weight. All kinetic variables were divided by BM only (WV mass excluded). All step-to-step sprint characteristics were calculated during each trial and were grouped to represent the initial acceleration phase (1st step–4th step average), middle acceleration phase (5th step–14th step average), later acceleration phase (15th step–step before maximum velocity reached average) and the maximum velocity phase (single stride where maximum velocity reached), according to previous research (Nagahara et al., 2020; Nagahara et al., 2014).

A Two-way ANOVA with Tukey's HSD post hoc analysis was calculated between trials and phases for each sprint characteristic, significance level set at $P < .050$. Tukey's HSD results were interpreted as a significant difference when the Q value (quotient of standard error and mean difference) was greater than the critical Q statistic. Cohen's d effect size (ES) ± 95% confidence intervals (CIs) further clarified the sprint characteristic changes between control and WV trials during each phase (initial, middle, later and maximum velocity) (Buchheit, 2017; Cohen, 2013). The ES results were interpreted using qualitative terms [< 0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), 1.2–2.0 (large), 2.0–4.0 (very large) or > 4.0 (nearly perfect)] (Hopkins et al., 2009).

3. Results

The two-way ANOVAs demonstrated significant differences ($P < .001$) between phases for every sprint characteristic measured. In terms of the interaction (phase vs. trials), there were no significant effects (range $P = .575$–1.00) for any sprint characteristic measured. The significant main effect between trials (control vs. WV) were found in velocity, SL, ST, propulsive and braking impulses (Figs. 1–3). Further results between trials are reported in Supplementary Table 1.

4. Discussion

The purpose of the present study was to elucidate the differences between WV and control sprinting, and there was no significant interaction (phase vs. trials) for any two-way ANOVA results, suggesting that any differences between phases or between trials found were not dependant on the other variable. Therefore, the discussion hereafter focuses on the results for the differences between trials (not the interaction or between phases). The velocity moderately–largely decreased (mean difference range 3.41–3.78%) during WV trials, compared to the control, suggesting that a WV load of 7% BM may practically overload an athlete during sprinting. The current finding is supported from similar mean differences (velocity decrement range 1.2–4.7%) found in previous WV research using loads between 5 and 9% BM (Alcaraz et al., 2008; Carlos-Vivas et al., 2019a; Carlos-Vivas et al., 2019b; Cross et al., 2014; Simperingham and Cronin, 2014). Results suggested that the velocity decrements in the WV trial were primarily caused by small SL decrements (Fig. 1), as velocity is a product of SL and SF. In addition, results suggest that WVs may influence the ST more than the FT step-to-step, and further trends between trials for each phase (Supplementary Table 1) demonstrated that mean differences for SL, SF and ST were similar to previous WV research (Cross et al., 2014; Macadam et al., 2019; Simperingham and Cronin, 2014).

Post hoc analysis in this study revealed no significant differences in any propulsive, braking or anteroposterior variables between trials for any phase (Fig. 2, Supplementary Table 1), thus, the discussion focuses on the interpretation of the results for the vertical GRF variables. The method for calculating vertical GRF is important to consider due to the influence of WV mass, and only one previous WV study has highlighted that different interpretations of results may occur due to methodology differences (Simperingham and Cronin, 2014). The vertical mean force was expressed relative to BM in this study, which may be considered as the practical/actual force produced by the athlete or the passive/supportive force used to overcome or support the added influence of WV weight during WV trials. The effective vertical mean force was further calculated to control for the influence of body weight and WV weight, thus, may be considered as the mechanically reasonable force or the active force. Although no significant vertical mean force or effective vertical mean force differences were found between trials in the present study (Fig. 3), the mean difference trend (Supplementary Table 1) of moderate effective vertical mean force decreases (range 3.13–10.97%) were opposite to the trend of trivial–small vertical mean force increases (range 0.75–1.62%), due to controlling for the influence of added WV weight during WV trials. These conflicting trends highlight that any weighted garment study reporting vertical GRFs needs to clarify the underlying reason for any interpretation, in relation to the method used. Based on the current results, although the active force (effective vertical mean force) showed a trend of decreased magnitudes during WV trials, the passive force (vertical mean force) did not differ between trials, suggesting that participants produced only enough vertical force to support the larger total mass during WV trials, compared to the control.

The response to greater vertical load can theoretically be an

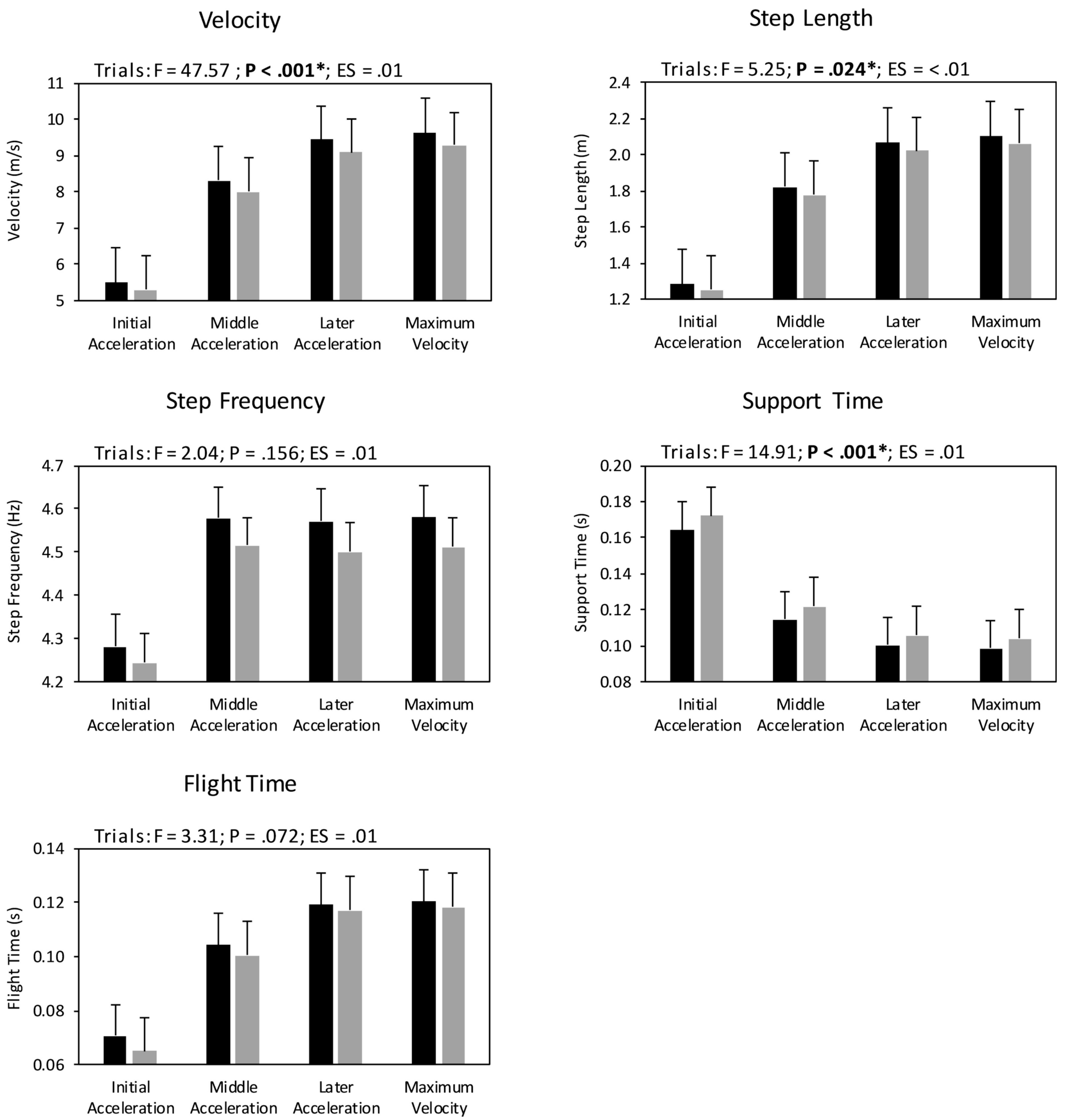

Fig. 1. Kinematic variables group mean (bars) plus standard deviation (black error lines) for control (black) and weighted vest (grey) trials during the initial acceleration, middle acceleration, later acceleration and maximum velocity phase. The two-way ANOVA results between trials (between phases and interaction excluded) are shown in text: F value; P value; effect size. Significance indicated with an asterisk.

increased vertical force during ground contact and throughout the support phase step-to-step to overcome added WV resistance. Applying greater GRF may be considered as a practically beneficial effect of RST, however, results demonstrated no significant mean force changes (Figs. 2–3). These mean force results were consistent with similar WV treadmill studies that demonstrated no significant peak vertical force differences between WV and control trials (Cross et al., 2014; Simperingham and Cronin, 2014). Taken together, a WV may not increase acute force production capability during sprinting. Despite no significant vertical mean force differences between trials in the present study, there was a trend of trivial–small increases (mean difference range 0.75–1.62%) during the WV trial (Supplementary Table 1). These possibly small increases may possibly be inferred as an acute vertical mean force effect due to WVs, however, this speculation should be interpreted with caution due to the non-significant differences and trivial–small effect sizes. In terms of impulse results, theoretically to maintain maximum effort sprinting during RST a certain magnitude of FT is required, thus the BM specific vertical impulse should be increased through larger vertical mean force or longer ST. Tukey's HSD tests revealed significant vertical impulse increases in every phase during the

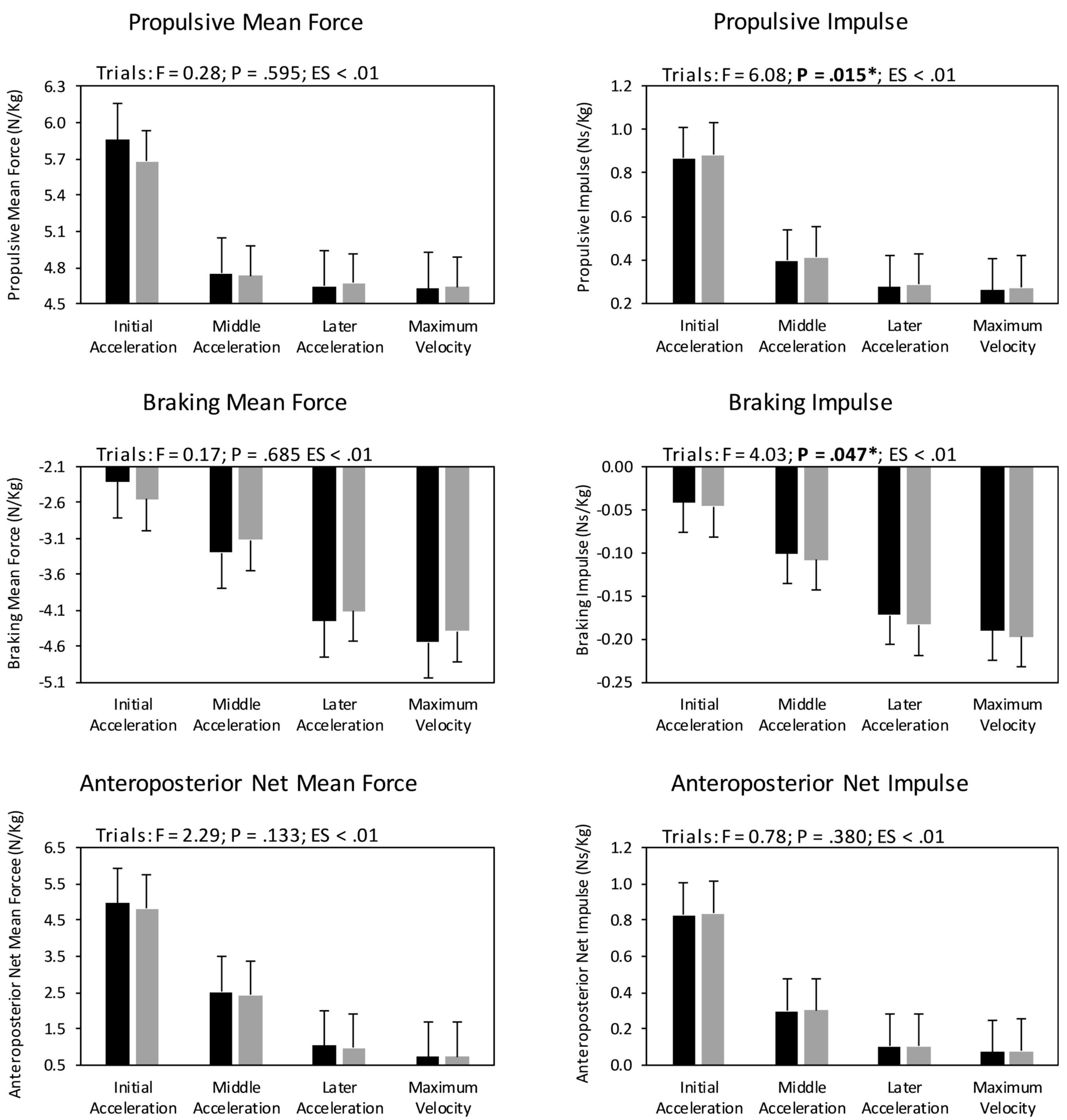

Fig. 2. Propulsive, braking and anteroposterior force and impulse variables group mean (bars) plus standard deviation (black error lines) for control (black) and weighted vest (grey) trials during the initial acceleration, middle acceleration, later acceleration and maximum velocity phase. The two-way ANOVA results between trials (between phases and interaction excluded) are shown in text: F value; P value; effect size. Significance indicated with an asterisk.

WV trial, compared to the control, though increased ST. These results demonstrated that increased vertical force application durations step-to-step were achieved, coupled with no significant effective vertical mean force differences, suggesting that vertical impulse is increased due to WVs through increased ST. Therefore, there may possibly be a practical overload training effect of WVs through supporting a greater total mass over an increased support phase duration step-to-step, which may be an area for future investigation.

One popular modality of RST is targeting resistance to horizontal acceleration, however, results suggested that WVs primarily change vertical impulse and not horizontal force characteristics. Thus, it may be speculated that WVs possibly change the vertical oscillation of the centre of mass during sprinting, and WVs may have a different training stimulus to other RST modalities such as parachute or sled towing (Alcaraz et al., 2008), which should be considered for practical training contexts. In addition, results supported the hypothesis that vertical impulse would significantly differ between trials, however, the load (7% BM) may not have been large enough to induce significant vertical or horizontal mean force differences. In conclusion, the current results suggest that WVs may be an appropriate training modality to reduce velocity, causing an

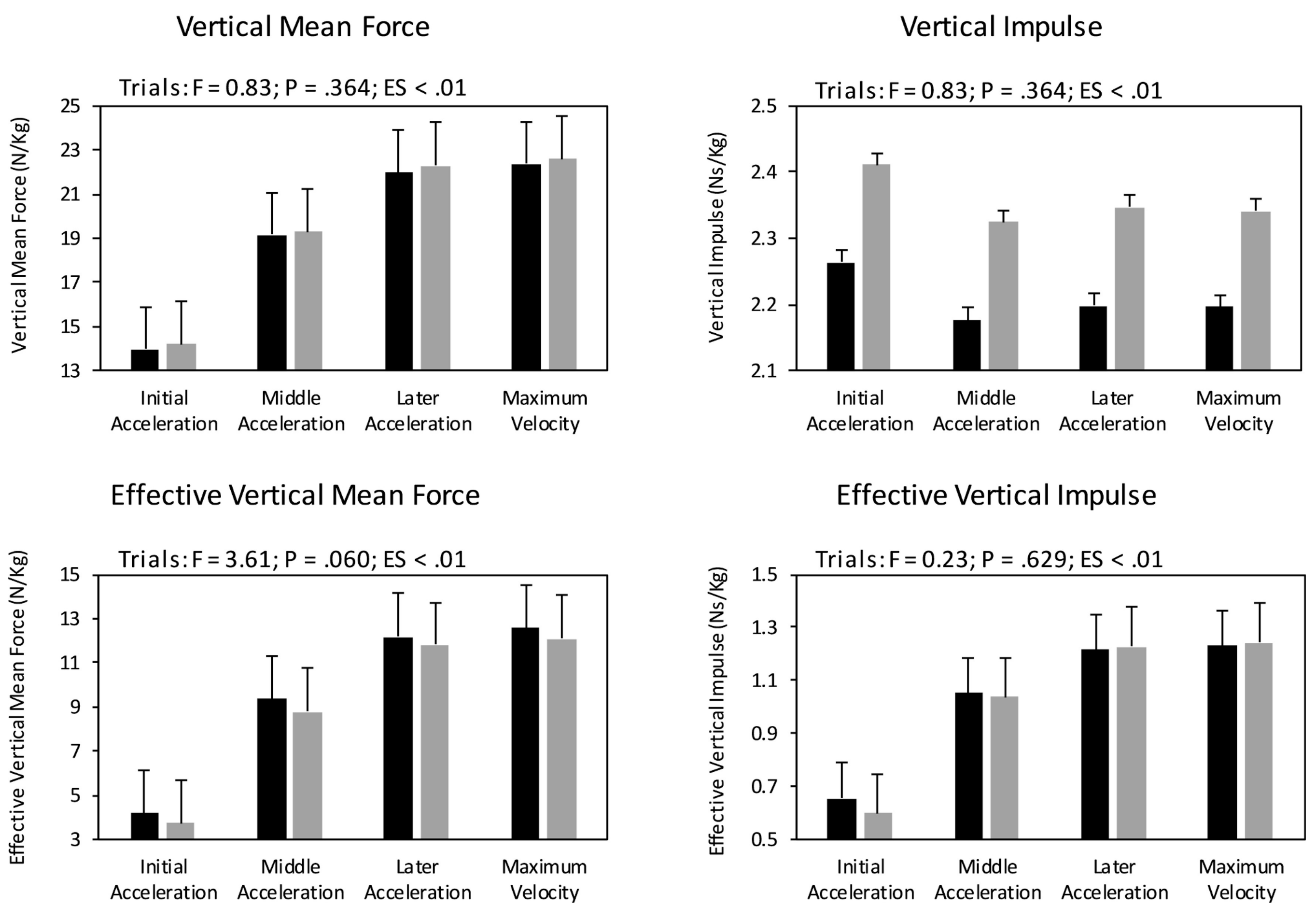

Fig. 3. Vertical force and impulse variables group mean (bars) plus standard deviation (black error lines) for control (black) and weighted vest (grey) trials during the initial acceleration, middle acceleration, later acceleration and maximum velocity phase. The two-way ANOVA results between trials (between phases and interaction excluded) are shown in text: F value; P value; effect size. Significance indicated with an asterisk.

increased vertical impulse through a lengthened ST without an increase in effective vertical mean force. Therefore, although WVs did not acutely increase vertical mean force, WVs did induce an increased force application duration step-to-step while supporting a larger total load, however, it is unknown whether these characteristics of WV sprinting may be beneficial for sprint training. Further research is needed to clarify the WV specific optimal loads for high speed training and to evaluate the effects of WV training interventions.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2021.110655.

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