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**Impact of harness attachment point on kinetics and kinematics during sled
towing**

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1 **ABSTRACT**

2 Resisted sprint training is performed in a horizontal direction, and involves similar
3 muscles, velocities and ranges of motion (ROM) to those of normal sprinting.
4 Generally, sleds are attached to the athletes via a lead (3m) and harness; the most
5 common attachment points are the shoulder or waist. At present, it is not known how
6 the different harness point's impact on the kinematics and kinetics associated with
7 sled towing (ST). The aim of the current investigation was to examine the kinetics
8 and kinematics of shoulder and waist harness attachment points in relation to the
9 acceleration phase of ST. Fourteen trained males completed normal and ST trials,
10 loaded at 10% reduction of sprint velocity. Sagittal plane kinematics from the trunk,
11 hip, knee and ankle were measured, together with stance phase kinetics (third foot-
12 strike). Kinetic and kinematic parameters were compared between harness
13 attachments using one-way repeated measures analysis of variance. The results
14 indicated that various kinetic differences were present between the normal and ST
15 conditions. Significantly greater net horizontal mean force, net horizontal impulses,
16 propulsive mean force and propulsive impulses were measured ($p > 0.05$).
17 Interestingly, the waist harness also led to greater net horizontal impulse when
18 compared to the shoulder attachment ($p = 0.000$). In kinematic terms, ST conditions
19 significantly increased peak flexion in hip, knee and ankle joints compared to the
20 normal trials ($p < 0.05$). Results highlighted that the shoulder harness had a greater
21 impact on trunk and knee joint kinematics when compared to the waist harness
22 ($p < 0.05$). In summary, waist harnesses appear to be the most suitable attachment
23 point for the acceleration phase of sprinting. Sled towing with these attachments
24 resulted in fewer kinematic alterations and greater net horizontal impulse when

25 compared to the shoulder harness. Future research is necessary, in order to explore
26 the long-term adaptations of these acute changes.

27

28 **Keywords:** acceleration, biomechanics, resisted sprint training

29 **Word count:**

30

31 INTRODUCTION

32 Sprinting is essential for success in many sports (11, 12, 13, 27). In field sports
33 where the need to reach the ball first, or be in position for a play to develop is
34 decisive, speed is a crucial factor (22, 29). Sprint velocity is a product of stride length
35 and stride frequency. To increase velocity, one or both of these components must be
36 increased (22, 33). Stride length and stride frequency can be increased by exerting
37 larger forces or increasing the rate of force development (RFD) during the stance
38 phase (15, 24, 35). It is generally accepted that while maximum velocity is important
39 in field sports, the ability to accelerate is seen as being of greater significance (10,
40 27).

41

42 The kinematic and kinetic characteristics of the acceleration and maximal velocity
43 phases of sprinting are quite different. The acceleration phase requires a greater
44 forward trunk lean (16). Kugler et al. (20) proposed that if the force vector points
45 further forward (trunk lean) then the ratio of vertical to propulsive force will be biased
46 towards forwards propulsion. In this instance, greater ground reaction force (GRF)
47 can be applied without the negative effects associated with high vertical force
48 application, such as short contact times. In contrast, at maximum velocity, athletes
49 must preserve optimal postural stability, minimising braking and increasing vertical

50 forces. Greater vertical ground reaction forces are essential in allowing faster
51 sprinters to reduce foot contact time during the stance phase (36).

52

53 The development of various resisted sprint training modalities, such as sled,
54 parachute, and bungees, are providing coaches with alternative or additional sport
55 specific training strategies to more traditional methods. During ST, the external
56 resistance is provided by the mass of the sled and the coefficient of friction between
57 the sled and the surface (8). Resisted sprint training is performed in a horizontal
58 direction, and involves the relevant muscles, velocities and ranges of motion similar
59 to those of normal sprinting (1, 19).

60

61 Sled loading strategies, as well as the sets and repetitions used to implement ST,
62 remain equivocal (1, 9, 23, 26, 28). There are several different methods by which
63 sleds can be loaded; sled loading based on an absolute load or relative load relating
64 to body mass have been commonly employed, however these methods do not take
65 the athlete's strength capabilities into consideration (14, 34). As such, loading sleds
66 based on a reduction of sprint velocity is the preferred method (2, 7, 25, 34).
67 Previous investigations have implemented various sled loadings ranging from a 5 kg
68 absolute load to 32.2% body mass (23, 37). Many researchers have found lighter
69 sled loads to be the most effective as they have been shown to have less impact on
70 contact time variables, joint angles and ROM (17, 26, 28). Several researchers have
71 used sled loadings based on a 10% decrement in sprint velocity to improve
72 performance (7, 25, 33). Whilst information on loading strategies is undergoing a
73 process of confirmation, there is a dearth of literature relating to the practicalities of
74 ST, notably with regard to attachments for harness systems.

75

76 Lawrence et al. (21) investigated the effects of different harness attachment points
77 (shoulder and waist) on walking sled pulls. They reported differences in joint
78 moments between the different attachments, concluding that the shoulder harness
79 would challenge the knee extensors, and the waist harness the hip extensors. Over
80 time, it is expected that the different harness attachments would lead to positive
81 strength adaptations related to the aforementioned joints, thereby allowing coaches
82 to tailor the sled pulls specifically to areas of weakness.

83

84 Generally, sleds are attached to the athletes via a lead (3m) and harness system,
85 the most common being a shoulder or waist attachment point. At present, it is not
86 known how the different harness attachment points impact on ST kinematics and
87 kinetics. Therefore, the purpose of this study was to investigate the sprint kinematics
88 and kinetics of ST during the acceleration phase when sleds were loaded to cause a
89 10% reduction in sprint velocity. Subjects completed sprint trials under different
90 conditions (normal sprinting, shoulder attachment and waist attachment). It was
91 hypothesised that 1) differences between the kinetic parameters would be negligible
92 between conditions, 2) both sled trials would be significantly different from the
93 normal sprint condition in terms of lower limb and trunk kinematics, and 3) the
94 attachment point would impact trunk, hip, knee and hip joint kinematics differently.
95 The findings will allow coaches to alter their use of ST to better suit the acceleration
96 phase.

97

98 **METHODS**

99 **Experimental Approach to the Problem**

100 This study used a cross-over design to compare the effects of different harness
101 attachments during ST. Fourteen resistance trained males performed a series of 6 m
102 sprints in three different conditions (normal, with shoulder and waist attachments).
103 The key dependant variables were the sagittal plane kinematic measures of the
104 lower extremities and trunk, the kinetic data obtained from the force platform and
105 various contact time measures.

106

107 **Subjects**

108 Fourteen resistance trained males (age: 26.7 ± 3.5 years; mass: 84.2 ± 12.3 kg;
109 stature: 174.4 ± 6.4 cm) participated in this study. All subjects were resistance
110 trained (2 years minimum) with ST experience. The sample size was calculated
111 based on previous acute ST investigations (14, 21). All subjects gave written and
112 informed consent before attending the testing sessions. The project was reviewed
113 and approved by the institutional ethics committee of the University of Central
114 Lancashire, in accordance with the principles of the Declaration of Helsinki. No
115 external funding was provided by any of the harness or sled manufacturers used in
116 this study.

117

118 **Procedures**

119 One week prior to testing, all subjects completed a familiarization session. During
120 this session subjects were able to practice ST using the different harness attachment
121 points. The same sled was used during all of the loaded trials. The sled was
122 attached to the subjects using a 3m non-elasticated attachment cord, and either a
123 double shoulder strap or single waist belt. Using a 6 m sprint as a baseline, sleds
124 were loaded so that sprint velocity was reduced by 10% (waist condition), as

125 recommended by Kawamori et al. (17). Sprint velocity was monitored using infrared
126 timing lights (Smartspeed Ltd., United Kingdom).

127

128 Targeting occurs when participants deliberately lengthen or shorten the stride prior to
129 force plate contact (32). These stride alterations have been shown to significantly
130 impact on sagittal plane joint kinematics (6). Research shows that participants are
131 able to run across an embedded force plate without significantly adjusting their stride
132 mechanics (32). No studies have looked at how sprinting over an embedded force
133 plate impacts on lower body kinematics. However, in the current study measures
134 were taken to ensure that no force plate targeting took place. Firstly, the
135 familiarization session was used to determine an individual starting position for each
136 subject. Starting positions were adjusted so that each participant's right foot
137 contacted the force plate on their third step. Starting positions of the ST trials were
138 also adjusted accordingly and practiced until participants consistently landed on the
139 force plate. In order to standardise starting positions, trials began in a 3 point
140 position. Each participant chose to start with his left foot leading in the 3 point
141 starting position. Regardless of the starting point, subjects sprinted a total distance of
142 6 m.

143

144 Subjects were asked not to participate in any physical activity 24 hours before the
145 testing session. No food was allowed to be consumed during testing, though water
146 was allowed. The testing session began with a standardised warm-up consisting of
147 jogging (5 minutes), dynamic stretching (5 minutes) and a number of sprints building
148 up to maximum intensity (2 x 75%, 2 x 90% and 2 x maximum).

149

150 Previous research has shown that ST trials can impact on the kinematics of any
151 subsequent normal sprint trials (17). Thus, the normal sprint trials were completed
152 before either of the sled conditions (shoulder or waist). Once the normal sprint trials
153 had been recorded, the ST trials were randomised. Testing procedures were
154 identical to those described previously in the familiarisation section. All subjects had
155 2 minutes recovery between each of the sprint trials. Five trials were collected for
156 each of the conditions. Again, subjects sprinted a distance of 6 m in a 22m lab. An
157 embedded force platform, sampling at 1000Hz, was positioned at approximately 3m
158 from the start (model 9281CA; dimensions = 0.6 x 0.4m, Kistler Instruments Ltd). In
159 order for the trials to be deemed successful, the whole foot had to contact the force
160 platform. Trials were discarded in cases where any part of the foot did not land the
161 force platform. Sprint times were generated for every trial, and any trials in which
162 sprint velocity deviated more than $\pm 5\%$ of the initial trial in that condition were not
163 used in the final analysis. In this instance, an extended recovery period of 4 minutes
164 was implemented and trials were repeated.

165
166 An eight camera motion analysis system (Qualisys Medical AB, Goteburg, Sweden)
167 was used to capture kinematic data at 250Hz. The system was calibrated before
168 every testing session. In order to determine stance leg kinematics (foot, shank, thigh
169 and trunk segments) retro-reflective markers were placed on the following bony
170 landmarks; the right calcaneus, 1st metatarsal head, 5th metatarsal head, medial
171 malleolus, lateral malleolus, medial epicondyle, lateral epicondyle, acromion process
172 (both), T12 and C7 (4). The pelvis segment was defined, using additional markers on
173 the anterior (ASIS) and posterior (PSIS) superior iliac spines. Hip joint centre was
174 determined based on the Bell et al., (3) equations via the positions of the PSIS and

175 ASIS markers. During dynamic trials the foot segment was tracked using the
176 calcaneus, 1st and 5th metatarsal heads. Rigid cluster tracking markers were also
177 positioned on the right shank and thigh segments (5). The ASIS, PSIS and greater
178 trochanters were used as tracking markers for the pelvis. The trunk was tracked
179 using markers at both acromion processes, as well as the T12 marker. A static
180 calibration was completed and used as reference for anatomical marker placement
181 in relation to the tracking markers, after which all non-tracking markers were
182 removed.

183
184 Motion files were exported as C3D files and quantified using Visual 3-D (C-Motion
185 Inc., Germantown, USA) and filtered at 12Hz using a Butterworth 4th order filter.
186 Three dimensional kinematics of the lower extremities and trunk were calculated
187 using an XYZ cardan sequence of rotations (X represents the sagittal plane, Y
188 represents the coronal plane and Z the transverse plane). The relevant segments
189 (thorax, thigh, shank and virtual foot) and reference segments (pelvis, thigh and
190 shank) were used to calculate joint angles of the trunk, hip, knee and ankle joints
191 respectively. All kinematic waveforms were normalised to 100% of the stance phase
192 and then processed trials were averaged. Various kinematic measures from the
193 trunk, hip, knee and ankle joints were investigated: angle at foot-strike, angle at toe-
194 off, peak angle, ROM from foot-strike to toe-off, and the relative ROM (the angular
195 displacement from foot-strike to peak angle). Resultant velocity at toe-off was
196 calculated using the vertical and horizontal centre of mass. These variables were
197 extracted from each of the 5 trials for each joint, data was then averaged within
198 subjects for a comparative statistical analysis.

199

200 Contact time was determined as time over which 20N or greater of vertical force was
201 applied to the force platform (30). The durations of the braking and propulsive
202 phases were based on anterior and posterior horizontal GRF. Peak GRF was
203 determined for the following components: vertical, braking, propulsive. Vertical
204 impulse was calculated as the area under the vertical ground reaction force-time
205 curve minus body weight impulse over the time of ground contact. The braking and
206 propulsive impulses were determined by integrating all the negative and positive
207 values of horizontal GRF, respectively, over the time of ground contact (17). Net
208 horizontal impulse was calculated as propulsive impulse minus the absolute value of
209 braking impulse. Similarly, mean values of vertical and net horizontal GRF were
210 obtained by dividing respective impulse values by the contact time, whereas mean
211 braking and propulsive GRF were calculated by the time duration of braking and
212 propulsive phases, respectively (17). All GRF measures were expressed relative to
213 total body mass.

214

215 **Statistical Analysis**

216 Descriptive statistics were calculated and presented as mean \pm SD. One-way within
217 subjects analysis of variance (ANOVA) was used to compare the means of the
218 different conditions (normal, waist and shoulder) with the different outcome
219 measures (velocity, contact time, kinematics, kinetics). The significance level was set
220 at $p \leq 0.05$. Post hoc pairwise comparisons were conducted on all significant main
221 effects using a Bonferroni adjustment to control for type I error. Effect sizes were
222 calculated using partial Eta² (η^2). All statistical analyses were undertaken using
223 SPSS (Version 22, IBM SPSS Inc., Chicago, USA).

224

225 **RESULTS**

226 Table 1 presents the stance phase velocity and contact time data. The kinetic
227 measures are presented in Table 2. Tables 3-6 present the sagittal plane kinematic
228 parameters from the trunk, hip, knee and ankle joints. Figure 1 presents the mean
229 sagittal plane angular kinematics during the stance phase.

230

231 The mean sagittal kinematic waveforms were qualitatively similar (Figure 1),
232 although statistical differences were observed at the trunk, hip, knee and ankle joints
233 (Tables 3-6).

234

235 @@@Figure 1 inserted near here@@@

236

237 The results indicate that a significant main effect was observed for sprint velocity
238 ($p < 0.01$, $\eta^2 = 0.87$). Post hoc analysis revealed that sprint velocity was significantly
239 reduced during the waist ($p = 0.000$) and shoulder ($p = 0.000$) trials compared to the
240 normal trials. There was no significant difference between the ST conditions ($p =$
241 0.616).

242

243 Similarly, a significant main effect was observed for the contact time of the stance
244 leg ($p < 0.01$, $\eta^2 = 0.66$). Post hoc analysis revealed that contact times of the stance
245 leg were significantly shorter in the normal condition compared to the waist ($p =$
246 0.000) and shoulder ($p = 0.000$) attachments. There was no significant difference
247 between ST conditions ($p = 0.073$). Results highlighted a significant main effect for

248 the duration of the propulsive phase of the stance ($p < 0.01$, $\eta^2 = 0.48$). Post hoc
249 tests indicated that the propulsive phase was significantly longer during the waist (p
250 $= 0.024$) and shoulder ($p = 0.002$) attachment trials compared to the normal sprint
251 trials. There was no significant difference between ST conditions ($p = 0.841$).

252

253 @@@Table 1 inserted near here@@@

254

255 The results (Table 2) show that there was a significant main effect for net horizontal
256 mean force ($p < 0.001$, $\eta^2 = 0.547$). Post hoc tests revealed that the normal condition
257 resulted in significantly lower net horizontal mean force than the shoulder attachment
258 ($p = 0.020$) and the waist condition ($p = 0.001$). There was no significant difference
259 between the ST conditions ($p = 0.056$). Similarly, there was a significant main effect
260 for the net horizontal impulse between conditions ($p < 0.001$, $\eta^2 = 0.742$). Post hoc
261 tests indicated that both ST conditions were significantly greater than the normal
262 sprint trials ($p = 0.000$). The net horizontal impulses produced during the waist
263 attachment condition were significantly larger than the shoulder condition ($p =$
264 0.045). There was a significant main effect for the propulsive mean force ($p < 0.05$,
265 $\eta^2 = 0.329$). Post hoc tests revealed that the waist condition led to significantly
266 greater mean propulsive GRF than the normal condition ($p = 0.004$). There was no
267 significant difference between the ST conditions ($p = 0.056$). Finally, a significant
268 main effect was observed for propulsive impulse measures ($p < 0.001$, $\eta^2 = 0.746$).
269 Post hoc tests revealed that the normal condition resulted in significantly lower
270 propulsive impulse measures than the shoulder attachment ($p = 0.000$) and the waist

271 condition ($p = 0.000$). There was no significant difference between the ST conditions
272 ($p = 0.063$).

273

274 @@@Table 2 inserted near here@@@

275

276 The results (Table 3) show that in the sagittal plane there was a significant main
277 effect for the magnitude of ROM for the trunk ($p < 0.001$, $\eta^2 = 0.493$). Post hoc tests
278 revealed that trunk ROM was significantly lower during the shoulder condition
279 compared to the normal ($p = 0.000$) and waist ($p = 0.000$) conditions. A significant
280 main effect was observed for the relative ROM of the trunk ($p > 0.001$, $\eta^2 = 0.410$).
281 Post hoc tests indicated that relative trunk ROM was significantly greater in the
282 shoulder condition compared to the normal sprinting condition ($p = 0.001$).

283

284 @@@Table 3 inserted near here@@@

285

286 The results (Table 4) show that in the sagittal plane there was a significant main
287 effect for hip joint angle at foot-strike ($p < 0.001$, $\eta^2 = 0.47$). Flexion at the hip joint
288 was significantly greater at foot-strike during the waist ($p = 0.015$) and shoulder ($p =$
289 0.004) attachment trials compared to the normal trials. There was no significant
290 difference between the ST trials ($p = 1.000$). Similarly, the results indicate that there
291 was a main effect for hip joint angle at toe-off ($p < 0.05$, $\eta^2 = 0.38$). Extension was
292 greater in the normal trials compared to the waist ($p = 0.015$) and shoulder ($p =$

293 0.035) attachment trials. There was no significant difference between ST trials ($p =$
294 1.000). Finally, a significant main effect was found for peak hip flexion ($p < 0.001$, η^2
295 = 0.47). The peak hip joint angle was significantly lower in the normal sprint trials
296 compared to the waist ($p = 0.015$) and shoulder ($p = 0.004$) attachment conditions.
297 There was no significant difference between the ST sled trials ($p = 1.000$).

298

299 @@@Table 4 inserted near here@@@

300

301 The results (Table 5) show that in the sagittal plane there was a significant main
302 effect for knee joint angle at foot-strike ($p < 0.001$, $\eta^2 = 0.73$). Post hoc tests
303 revealed that knee joint flexion was significantly greater at foot-strike during the waist
304 ($p = 0.000$) and shoulder ($p = 0.000$) attachment sled trials compared to the normal
305 sprint trials. There was no significant difference between ST conditions ($p = 0.441$).
306 The results indicate that there was a significant main effect for knee joint angle at
307 toe-off ($p < 0.05$, $\eta^2 = 0.36$). Knee joint extension was greater in the normal trials
308 compared to the waist ($p = 0.018$) and shoulder ($p = 0.016$) attachment trials. There
309 was no significant difference between ST trials ($p = 1.000$). A significant main effect
310 was found for peak knee joint angle ($p < 0.001$, $\eta^2 = 0.73$). Post hoc analysis
311 revealed that all of the conditions were significantly different from one another. Knee
312 flexion in the normal trials was lower than the waist ($p = 0.001$) and shoulder ($p =$
313 0.000) attachment trials. Knee flexion was significantly greater in the shoulder
314 attachment condition compared to the waist attachment trials ($p = 0.037$). Finally,
315 there was a significant main effect for the magnitude of ROM at the knee joint
316 ($p < 0.05$, $\eta^2 = 0.29$). Post hoc tests indicated that knee joint ROM was significantly

317 smaller in the normal condition compared to the shoulder attachment condition ($p =$
318 0.036). There was no significant difference between the normal and waist
319 attachment trials ($p = 0.461$).

320

321 @@@Table 5 inserted near here@@@

322

323 The results (Table 6) show that in the sagittal plane there was a significant main
324 effect for ankle joint angle at foot-strike ($p < 0.001$, $\eta^2 = 0.4$). Post hoc tests indicated
325 that dorsi-flexion was significantly greater at foot-strike during the waist ($p = 0.041$)
326 and shoulder ($p = 0.006$) attachment trials compared to the normal sprint trials.
327 There was no significant difference between the ST conditions ($p = 0.494$). Finally, a
328 significant main effect was found for peak ankle dorsi-flexion ($p < 0.001$, $\eta^2 = 0.46$).
329 Peak ankle dorsi-flexion was significantly lower in the normal trials compared to the
330 waist ($p = 0.034$) and shoulder ($p = 0.002$) attachment conditions. There was no
331 significant difference between the ST trials ($p = 0.248$).

332

333 @@@Table 6 inserted near here@@@

334

335 **DISCUSSION**

336 The aim of this investigation was to examine the kinematics and kinetics of ST when
337 different harness attachment points were used (shoulder and waist). Sleds were
338 loaded to cause a 10% reduction in sprint velocity over a 6 m distance. To the
339 authors knowledge this is the first study to use a motion capture system to measure

340 the sagittal plane kinematics of ST. This study will have practical implications to
341 strength and conditioning coaches looking to improve acceleration performance.

342

343 Results show that there were significant kinetic differences between the ST
344 conditions and the normal sprint trials, supporting the rejection of the first hypothesis.
345 These findings are contradictory to those of Kawamori et al. (17) who measured
346 various GRF variables with a similar 10% BM sled loading. Both ST conditions were
347 significantly different from the normal condition in numerous parameters: net
348 horizontal mean force, net horizontal impulse, and propulsive impulse. Again, in
349 contrast to Kawamori et al. (17) the ST conditions in this study resulted in longer
350 ground contact times and propulsive phase contact times compared to the normal
351 sprint trials. The increased propulsive contact times were not surprising as more
352 propulsive force was required to overcome the extra resistance provided by the ST.
353 However, the increased net horizontal force and propulsive impulse measures could
354 be explained by longer ground contact times thus allowing more time to push in a
355 horizontal direction.

356

357 Previous studies have reported that a 10% sled loading (BM or velocity reduction)
358 had no significant acute impact on sprint kinematics (27, 28). However, we
359 hypothesised that sprint kinematics during ST would be different from the normal
360 sprint condition. The results of the present study supported our hypothesis. There
361 were significant differences between normal sprint trials and both ST conditions in
362 the sagittal plane at the hip, knee and ankle joints. Peak hip flexion, flexion at foot-
363 strike, and flexion at toe-off were greater during the ST trials. Similarly knee joint
364 flexion was significantly greater for the ST conditions. Dorsi-flexion was significantly

365 greater in the ST conditions at foot-strike as were the peak angles recorded. These
366 findings contradict the theory that the 10% loading is the ideal because kinematics
367 are not significantly altered (26, 28). It is beyond the scope of the present study to
368 suggest what the longer-term implications of these alterations might be.

369

370 Finally, the third hypothesis was also accepted. Both harness attachment points
371 altered kinematics differently. During ST, the harness attachment points affected the
372 athletes differently to those reported previously in heavy walking sled pulls (21).
373 Trunk ROM was significantly lower during the shoulder attachment condition
374 compared to the other conditions (Table 3). In contrast, trunk relative ROM was only
375 significantly greater in the shoulder condition compared to the normal trials. The
376 shoulder attachment lead to significantly greater peak knee flexion when compared
377 to the waist harness (Table 5). The knee joint ROM in the shoulder condition was
378 significantly greater than the normal condition, whereas differences between the
379 waist condition and the other conditions were negligible (Table 5).

380

381 Unexpectedly, the ST harness attachment points also impacted stance phase
382 kinetics differently. The waist harness led to significantly greater net horizontal
383 impulse compared to the shoulder attachment condition. Furthermore, the waist
384 condition resulted in significantly greater propulsive mean GRF when compared to
385 the normal sprint condition. Importantly, none of the ST contact time measures were
386 significantly different. Previous researchers (18) have highlighted net horizontal
387 impulses and propulsive force as being key to achieving high acceleration, as such it
388 would appear that the waist harness is more suitable when training for the
389 acceleration phase of sprinting. It seems apparent that the kinematic alterations

390 caused by the waist harness made the line of action more horizontal, resulting in
391 greater net horizontal impulse.

392

393 Our results highlighted differences in trunk angle between ST conditions. Previous
394 investigations have also discussed the importance of trunk lean during ST. Alcaraz
395 et al. (1) suggested that shoulder attachments would increase trunk lean to a greater
396 extent than a waist harness attachment point. They reported, that due to the applied
397 load being higher than the hips (pivot point), the athletes would have to compensate
398 and increase trunk lean. It was proposed that the greater trunk lean would impact on
399 the athletes force vector so that more propulsive GRF was applied compared to
400 vertical GRF. Conversely, when sleds were attached via waist belts the load passed
401 through the hips, as such these attachments did not promote an increased trunk lean
402 (1). As such, the authors suggested that shoulder harness attachments would be
403 more beneficial when training for the acceleration phase, and waist attachments
404 could be more suited to the maximum velocity phase (1). In contrast, results from
405 this study indicated that negligible differences in peak flexion, angle at foot-strike and
406 toe-off between exist between ST conditions at the trunk. The only differences were
407 that trunk ROM was significantly lower during the shoulder attachment condition
408 when compared to the other conditions. Interestingly, the trunk relative ROM was
409 only significantly greater in the shoulder condition compared to the normal trials.
410 Importantly, kinematic differences between the waist and normal sprint conditions
411 were negligible. Therefore, our findings suggest that when the ST harness
412 attachment is further away from the hips it alters trunk kinematics to a greater extent,
413 thus reducing net horizontal impulse.

414

415 The all-male resistance trained testing population is a limitation. Previous
416 investigations have demonstrated that females exhibit distinct lower body kinematics
417 when compared with males (31). As such, the results are limited to this population
418 and may not be applicable to female athletes. Additionally, this study only looked at
419 the harness attachment implications at a set sled loading (10% reduction in sprint
420 velocity). Numerous investigations have highlighted that the kinetic and kinematic
421 alterations differ greatly dependant on sled loading (9, 17, 26, 28). Thus, the findings
422 from the present study will not be transferable to different sled loading strategies or
423 the other phases of sprinting.

424

425 **PRACTICAL APPLICATIONS**

426 The current investigation provides new information regarding the influence of
427 different harness attachment configurations on the kinetics and kinematics of ST.
428 The results indicate that ST, with the commonly prescribed loading to cause a 10%
429 decrement in sprint velocity, will alter kinematics at the trunk, hip, knee, and ankle
430 joints. Similarly, both ST conditions led to significant GRF alterations when
431 compared to normal sprinting. The kinematic and kinetic alterations observed in this
432 study differ between the waist and shoulder attachment points. Our results suggest
433 that the waist attachment point appears to be the most suitable when training for the
434 acceleration phase of sprinting. Sled towing with this attachment led to fewer
435 kinematic alterations and greater net horizontal impulses when compared to the
436 shoulder attachment trials. Future research is necessary to explore how the
437 observed harness attachment alterations impact on sprint
438 performance/kinematics/kinetics after prolonged ST training interventions.

439

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548

549 **Figure labels**

550 Figure 1. Mean trunk (a) hip (b) knee (c) and ankle (d) joint angles in the sagittal
551 plane for the normal (bold line), shoulder (dashed line) and waist (dotted line)
552 conditions.

Table 1. Velocity and contact variables (means and standard deviations) under the different conditions (normal, shoulder and waist).

	Normal	Shoulder	Waist
Velocity ($\text{m}\cdot\text{s}^{-1}$)	5.61 ± 0.34	$5.08 \pm 0.3^*$	$5.13 \pm 0.31^*$
Contact time (s)	0.17 ± 0.02	$0.19 \pm 0.03^*$	$0.19 \pm 0.22^*$
Braking phase duration (s)	0.02 ± 0.02	0.02 ± 0.01	0.01 ± 0.00
Propulsive phase duration (s)	0.15 ± 0.02	$0.18 \pm 0.02^*$	$0.17 \pm 0.02^*$

* Significantly different from normal sprinting $p \leq 0.05$

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Table 2. Kinetic variables (means and standard deviations) from the third step under the different conditions (normal, shoulder and waist).

	Normal	Shoulder	Waist
Vertical peak force (N · kg ⁻¹)	10.28 ± 2.11	9.56 ± 2.07	9.77 ± 1.73
Vertical mean force (N · kg ⁻¹)	3.58 ± 1.20	3.14 ± 1.00	3.18 ± 0.98
Vertical impulse (m · s ⁻¹)	0.61 ± 0.16	0.60 ± 0.18	0.59 ± 0.18
Net horizontal mean force (N · kg ⁻¹)	3.23 ± 0.58	3.53 ± 0.52*	3.81 ± 0.48*
Net horizontal impulse (m · s ⁻¹)	0.55 ± 0.08	0.67 ± 0.03*†	0.71 ± 0.10*
Braking peak force (N · kg ⁻¹)	3.21 ± 1.58	3.18 ± 1.58	2.86 ± 1.64
Braking mean force (N · kg ⁻¹)	1.43 ± 0.90	1.48 ± 0.94	1.28 ± 0.91
Braking impulse (m · s ⁻¹)	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01
Propulsive peak force (N · kg ⁻¹)	6.90 ± 0.76	6.99 ± 0.81	7.16 ± 0.70
Propulsive mean force (N · kg ⁻¹)	3.81 ± 0.60	4.00 ± 0.54	4.26 ± 0.53*
Propulsive impulse (m · s ⁻¹)	0.58 ± 0.08	0.70 ± 0.07*	0.73 ± 0.09*

* Significantly different from normal sprinting p ≤ 0.05

† Significantly different from waist attachment condition p ≤ 0.05

Table 3. Trunk kinematics (means and standard deviations) under the different conditions (normal, shoulder and waist).

X (+=flexion/- =extension)	Normal	Shoulder	Waist
Angle at foot-strike (°)	7.62 ± 9.42	6.75 ± 10.19	8.63 ± 10.10
Angle at toe-off (°)	-1.83 ± 8.70	1.89 ± 10.56	1.21 ± 10.71
Peak flexion (°)	9.42 ± 10.03	11.27 ± 10.45	11.96 ± 11.67
Range of movement (°)	9.46 ± 3.71	4.86 ± 3.90*†	8.73 ± 3.86
Relative range of movement (°)	1.81 ± 1.89	4.51 ± 3.52*	3.33 ± 3.56

* Significantly different from normal sprinting $p \leq 0.05$

† Significantly different from waist attachment condition $p \leq 0.05$

Table 4. Hip Joint kinematics (means and standard deviations) from the stance limb under the different conditions (normal, shoulder and waist).

X (+=flexion/- =extension)	Normal	Shoulder	Waist
Angle at foot-strike (°)	58.81 ± 8.29	67.08 ± 8.18*	65.80 ± 9.93*
Angle at toe-off (°)	-6.43 ± 6.40	-0.47 ± 9.22*	0.36 ± 8.33*
Peak flexion (°)	58.81 ± 8.29	67.08 ± 8.18*	65.80 ± 9.93*
Range of movement (°)	65.24 ± 6.74	67.55 ± 8.84	65.44 ± 9.74
Relative range of movement (°)	65.24 ± 6.74	67.55 ± 8.84	65.44 ± 9.74

* Significantly different from normal sprinting $p \leq 0.05$

Table 5. Knee joint kinematics (means and standard deviations) from the stance limb under the different conditions (normal, shoulder and waist).

X (+=flexion/=-extension)	Normal	Shoulder	Waist
Angle at foot-strike (°)	47.41 ± 5.48	54.28 ± 6.60*	53.27 ± 6.16*
Angle at toe-off (°)	15.76 ± 5.79	18.42 ± 5.60*	18.95 ± 5.87*
Peak flexion (°)	50.01 ± 5.38	56.62 ± 5.49*†	54.81 ± 5.68*
Range of movement(°)	31.65 ± 6.57	35.86 ± 8.37*	34.33 ± 8.12
Relative range of movement (°)	2.60 ± 4.80	2.34 ± 4.90	1.53 ± 3.31

* Significantly different from normal sprinting $p \leq 0.05$

† Significantly different from waist attachment condition $p \leq 0.05$

Table 6. Ankle Joint kinematics (means and standard deviations) from the stance limb under the different conditions (normal, shoulder and waist).

X (+=dorsi-flexion/- =plantar-flexion)	Normal	Shoulder	Waist
Angle at foot-strike (°)	2.72 ± 5.89	5.85 ± 5.34*	4.76 ± 6.69*
Angle at toe-off (°)	-25.40 ± 4.01	-24.34 ± 3.44	-24.20 ± 3.05
Peak dorsi-flexion (°)	24.32 ± 4.82	27.08 ± 6.00*	26.00 ± 5.40*
Range of movement (°)	28.11 ± 5.00	30.19 ± 3.95	28.96 ± 5.22
Relative range of movement (°)	21.61 ± 6.23	21.22 ± 5.93	21.24 ± 5.82

* Significantly different from normal sprinting $p \leq 0.05$

