


Please cite the Published Version

Harper, LD, Field, A , Corr, LD and Naughton, RJ (2020) The physiological, physical, and biomechanical demands of walking football: Implications for exercise prescription and future research in older adults. *Journal of Aging and Physical Activity*, 28 (3). pp. 478-488. ISSN 1063-8652

DOI: <https://doi.org/10.1123/JAPA.2019-0330>

Publisher: Human Kinetics

Version: Accepted Version

Downloaded from: <https://e-space.mmu.ac.uk/631101/>

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1 **Title:** The physiological, physical and biomechanical demands of walking football: implications for
2 exercise prescription and future research in older adults

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29 **Abstract**

30 The aim of this investigation was to profile the physiological, physical and biomechanical responses
31 during walking football. Seventeen male participants (66 ± 6 years) participated. Heart rate (HR), blood
32 lactate, accelerometer variables (biomechanical load [PlayerLoadTM]; changes of direction [CoD]) and
33 rating of perceived exertion (RPE) were measured. Participants mean % of HR_{max} was $76 \pm 6\%$ during
34 the sessions, with RPE across all sessions at 13 ± 2 . Blood lactate increased by $\sim 157\%$ from pre- (1.24
35 ± 0.4 mmol·l⁻¹) to post-session (3.19 ± 1.7 mmol·l⁻¹; $p \leq 0.0005$). PlayerLoadTM values of 353 ± 67 a.u
36 were observed, as well as ~ 100 CoD per session. In conclusion, walking football is a moderate-to-
37 vigorous intensity activity. The longitudinal health benefits of walking football remain to be elucidated,
38 particularly on bone health, cardiovascular fitness, and social and mental wellbeing.

39 **Keywords: soccer; exercise intensity; elderly; gerontology; physical activity**

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55 **1. Introduction**

56 The world's population is getting older, posing fiscal and societal challenges for governments,
57 particularly as older adults are at a greater risk of chronic health conditions than their younger
58 counterparts (Beard et al., 2016). Ageing can lead to cardiovascular and metabolic diseases, chronic
59 inflammation, loss of muscle mass, poor bone health, cognitive decline and neurodegenerative
60 disorders, and reduced social and mental wellbeing (Börsch-Supan et al., 2013; Cruz-Jentoft et al.,
61 2010; Ferrucci & Fabbri, 2018; Goodpaster et al., 2006). Physical activity and exercise have been shown
62 to positively affect some of these deleterious effects of ageing (Cartee, Hepple, Bamman, & Zierath,
63 2016; Fox, Stathi, McKenna, & Davis, 2007; Hamer, Muniz Terrera, & Demakakos, 2018; Lancaster
64 & Febbraio, 2014; Santos, Elliott-Sale, & Sale, 2017). One form of exercise that has been researched
65 extensively, due to its worldwide ubiquity and popularity, is association football (herein called football),
66 or soccer. The health benefits of participating in recreational football are extensive (see Bangsbo,
67 Hansen, Dvorak, & Krstrup, (2015) for a review); however, in older adults, the physical demands of
68 playing football may be a barrier to participation. Therefore, a more accessible form of the sport has
69 been designed in recent years, termed walking football.

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71 Walking football is a sport targeted towards older people (>55 years), but played by those who are
72 younger too. It is a relatively new sport, formed in the early 2010's, gaining publicity in the United
73 Kingdom in 2013 through an advert from Barclays plc. The sport is now played around the world, with
74 recreational sessions through to national and international tournaments. Walking football is usually
75 contested by two small-sided teams (5 to 7-aside), with strict rules regarding running and slide tackling.
76 This is to make the sport safer, and as such, more accessible and engaging for older populations. As
77 walking alone has many physiological and psychological benefits (Hanson & Jones, 2015; Murphy,
78 Nevill, Murtagh, & Holder, 2007), it is suggested that walking football may provide similar benefits.
79 Previous small-scale investigations have shown that walking football is a feasible and sustainable
80 exercise intervention that may improve participants' mental wellbeing (Lamont, Harris, McDonald,
81 Kerin, & Dickens, 2017; McEwan et al., 2019; Reddy et al., 2017), as well as their body composition

82 and physical fitness (Arnold, Bruce-Low, & Sammut, 2015). An ethnographic study of walking football
83 suggested that walking football also provides intangible benefits, including increasing participants'
84 'appetite for life' and enhancing their social engagement as part of a wider supportive community
85 (Loadman, 2017).

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87 To date, studies assessing the demands of walking football have only used two matches (Heil, Newton,
88 & Salle, 2018) or have only measured heart rate (HR) and rating of perceived exertion (RPE) in 11
89 participants who participated in at least seven of 12 matches during a 12-week intervention (Reddy et
90 al., 2017). Therefore, there is scope to expand on these findings, as well as investigate other measures
91 of exercise intensity. The monitoring of internal training loads, using methods including HR and RPE,
92 is commonplace in exercise prescription for the general population, to ensure that training sessions have
93 been correctly designed and conducted (Roy, 2015). In sporting domains, particularly at the professional
94 level, there has been a substantial increase in the use of wearable devices, allowing for the measurement
95 of external loads (see Chambers, Gabbett, Cole, & Beard, (2015) for a review). Consequently,
96 individuals are monitored through the use of an accelerometer-based variable termed PlayerLoad™
97 (PL). This metric is a software derived movement parameter (Catapult Innovations, Australia),
98 calculated as the summation of forward, sideways and vertical accelerations (Boyd, Ball, & Aughey,
99 2011). It is essentially utilised as a measure of external workload (i.e., biomechanical stress) and can be
100 quantified alongside numbers of changes of direction (CoD), accelerations (ACC) and decelerations
101 (DEC). As PL and the number of CoD, ACC and DEC are related to the intensity of an exercise bout
102 (McLaren et al., 2018) and frequent CoD may have benefits for bone health in older adults (Santos et
103 al., 2017; Turner & Robling, 2003), it is pertinent to measure these parameters during walking football.

104 The aim of this present investigation was to assess the demands of walking football in older adults
105 across a greater number of matches than previously investigated, including measures of exercise
106 intensity that are physiological, biomechanical, and physical in nature. We also aimed to assess the
107 variability of response in these measures, in order to investigate if there were noticeable fluctuations in
108 exercise intensity between matches.

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130 **2. Methods**

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132 2.1 Study design and participants

133 Following institutional ethical approval, informed consent was obtained from 17 male participants (66
134 \pm 6 years) who had volunteered to partake in the research. All participants were over the age of 55, had
135 at least one year of walking football experience, and were already participating regularly in walking
136 football sessions. No other inclusion/exclusion criteria were applied (except for blood lactate, which is
137 described below). Participants were observed between November 2018 and May 2019 for a total of 25
138 sessions of walking football. Measures of HR, blood lactate, accelerometry data and RPE were
139 collected during this period. Table 1 outlines at which of the 25 sessions these different measures were
140 collected. Sessions typically began at the same time of day (~11 am) and were ~60 min in duration,
141 although two matches were commonly played simultaneously on different pitches. This was often
142 dependant on the number of players that attended a given session, as were the session structure, which
143 comprised a number of different formats (i.e., 5, 6, & 7-a-side) and matches (i.e., 1-3). All matches
144 were played on an indoor artificial grass pitch, whereby teams were counterbalanced for age and
145 subsequently selected at random. Matches were played under official FA rules (FA.com), which were
146 officiated by a qualified walking football referee. As matches were played on an enclosed indoor pitch,
147 no throw-ins were required, except for goalkeepers who were instructed to throw under-arm and were
148 rotated approximately every 5 min. Participants continued with their habitual daily living (i.e.,
149 customary diet and physical activity) between sessions. Owing to the observational nature of the
150 research, no intervention or feedback was sought or provided during the entirety of data collection.

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INSERT TABLE 1

152 2.2 Measures

153 Throughout each session, HR was collected using Polar M200 HR monitors (Polar Electro, Kempele,
154 Finland). Researchers downloaded the session data onto a PC via brand specific software (Polar
155 Flow™, Polar Electro, Kempele, Finland). Once exported and analysed, mean (HR_{mean}) and peak

156 (HR_{peak}) HR values were obtained for each participant during each individual session. In addition,
157 Tanaka, Monahan, & Seals, (2001) equation ($208 - 0.7 \times \text{age}$) was employed to predict the theoretical
158 maximum HR (HR_{max}) for each participant. Medical screening was conducted to determine eligibility
159 for blood sampling, with the following exclusion criteria employed: i) were taking blood thinning
160 medication, ii) had a health condition affecting blood flow iii) had a blood-borne virus.

161 . For blood lactate, capillary samples were taken pre and immediately post session from the fingertip,
162 stored in tubes (20µl) containing heparin so as to prevent the blood coagulating and analysed within ~2
163 h of extraction (Biosen C-Line; EKF-diagnostic GmbH, Wales; coefficient of variation [1.5%]).
164 Preceding each test, the machine was calibrated in line with manufacturer guidelines.

165 A Global Positioning System tracking device (OptimEye S5, Catapult Innovations, Australia) which
166 housed a tri-axial accelerometer (Kionix KX94, Kionix, Ithaca, New York, USA), recorded
167 accelerometry data at 100-Hz sampling frequency. This device was positioned along the thoracic
168 spine and stabilised within a neoprene vest (Catapult Innovations, Scoresby, Australia) to limit
169 movement. Where possible, participants maintained the use of the same device throughout sessions,
170 as intra-device has demonstrated excellent reliability (CV = 0.01% to <3.0%) (Nicoletta, Torres-
171 Ronda, Saylor, & Schelling, 2018). However, because the number of participants was greater than the
172 number of devices, the device retention rate for participants was $84.0 \pm 13.3\%$ across all applicable
173 sessions. Data were downloaded using the manufacturers software (version 5.14, Catapult Sprint,
174 Catapult Sports, Australia). Accordingly, tri-axial PL values were obtained and calculated from the
175 summation of the vertical anterior-posterior (PL-AP), medial-lateral (PL-ML) and vertical (PL-V),
176 planes of motion. This parameter is essentially, the instantaneous rate of change of acceleration of the
177 above three vectors divided by a scaling factor of 100. This is used to measure external load for a
178 given activity and is expressed in arbitrary units (a.u.) (White & Macfarlane, 2015).

179 Additionally, inertial movement analysis (IMA) data was retrieved during analysis, which consisted of
180 number of ACC, DEC, and CoD. Thresholds for ACC, DEC, and CoD were characterised as low (1.5-
181 $2.5 \text{ m}\cdot\text{s}^{-2}$), medium ($2.5\text{-}3.5 \text{ m}\cdot\text{s}^{-2}$) and high ($>3.5 \text{ m}\cdot\text{s}^{-2}$) intensity. The change in direction is quantified
182 in degrees ($\pm 180^\circ$) relative to the accelerometer orientation and measured in $\text{m}\cdot\text{s}^{-1}$. This metric is often

183 defined as an instant one-step movement (i.e., CoD) and used to detect the magnitude and direction of
184 a given acceleration. Accelerometry data was collected for the entire 60 min session and stationary
185 periods (i.e., rest between matches) were omitted from analyses for accelerometry-based data.
186 Following each session, RPE was taken as a subjective measure of exercise intensity using the Borg 16-
187 point linear scale (6-20) (Borg, 1982) as it is a valid and sensitive measure of exercise intensity,
188 including in older adults (Chung, Zhao, Liu, & Quach, 2015; Shigematsu, Ueno, Nakagaichi, Nho, &
189 Tanaka, 2004).

190 2.3 Statistical analysis

191 Unless stated otherwise, data are reported as mean and standard deviation (SD). Data analysis was
192 completed using commercially available software (Microsoft Excel[®]) and SPSS version 24 for
193 Windows (IBM[®] SPSS[®] Statistics; SPSS Inc., Chicago, IL, USA). A paired-sample t-test was employed
194 to determine whether differences existed between pre- and post-session for blood lactate. Coefficient
195 of variation (CV) was completed to ascertain absolute reliability between sessions with <10%
196 considered good (Atkinson & Nevill, 1998) and 95% confidence intervals (CI) were also reported.
197 Statistical significance was established at $p \leq 0.05$ prior to analyses.

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207 **3. Results**

208 Analysis was conducted individually for HR values (participants n = 11; sessions n = 11 [6-11 sessions
209 per participant), blood lactate (participants n = 9; sessions n = 11 [4-10 sessions per participant]),
210 accelerometer variables (participants n = 7; sessions n = 16 [6-9 sessions per participant]) and RPE
211 (participants n = 7; sessions n = 25 [13-16 sessions per participant]).

212 3.1 Heart rate

213 Participants' average response over 11 sessions are displayed in Figure 1A for HR_{peak} (155 ± 16 bpm;
214 CV = 3.3%; CI% = 2.2, 7.1) and Figure 1B for HR_{mean} (124 ± 13 bpm; CV = 7.4%; CI% = 4.9, 16.2);
215 both variables demonstrated good reliability (CVs <7.5%). Participants mean % of HR_{max} was 76 ± 6%,
216 with a range of 63-86% of their theoretical maximum HR. In comparison, an increased range was
217 observed (77-106%) for peak % of HR_{max} for which mean values were 95 ± 8% (Table 2).

218 *****INSERT TABLE 2*****

219 *****INSERT FIGURE 1*****

220 3.2 Blood lactate

221 Mean changes in blood lactate are outlined in Figure 2, with a ~157% increase observed from pre- (1.24
222 ± 0.4 mmol·l⁻¹) to post-session (3.19 ± 1.7 mmol·l⁻¹; *p* <0.0001) across 11 sessions.

223 *****INSERT FIGURE 2*****

224 3.3 Accelerometry variables

225 3.3.1 *PlayerLoad (PL)*

226 Average PL values of 353 ± 67 a.u were observed with contributions from the PL-AP (84 ± 17 a.u),
227 PL-ML (104 ± 16 a.u) and PL-V (164 ± 35 a.u) planes of motion. When expressed as relative
228 contributions, PL-AP%, PL-ML% and PL-V% were established as 24 ± 2%, 30 ± 2% and 46 ± 2%,
229 respectively. Typical error reported as CVs ranged from 4.3 to 44.2%. Means, CVs and CIs for PL
230 variables are displayed in Table 3.

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***** INSERT TABLE 3*****

3.3.2 Change of direction (CoD)

Participants completed 85 ± 23 CoD at lower intensities, with much fewer observed for medium- (8 ± 4) and high-threshold (2 ± 1) actions. As a collective, CVs ranged from 49.5 to 149.7%; these are displayed in Table 4 along with CIs.

3.3.3 Decelerations (DEC) and accelerations (ACC)

We observed an average of 24 ± 9 DEC_{LOW} and 9 ± 5 ACC_{LOW} across the sessions, with medium thresholds being alike for DEC (4 ± 2) and ACC (3 ± 2) and high thresholds for DEC (1 ± 1) versus ACC (1 ± 2). The absolute reliability for the DEC and ACC metrics ranged from 38.6 to 139.9 % (CVs) as outlined in Table 4.

***** INSERT TABLE 4*****

3.3 Ratings of perceived exertion (RPE)

Average RPE across all sessions was 13 ± 2 (range = 8–18). Good absolute reliability was detected for RPE (CV = 7.8 %; CI% = 4.6, 24.2) and individual RPE values across each session are presented in Figure 3.

*****INSERT FIGURE 3*****

257 4. Discussion

258 The aim of this study was to investigate the physiological, biomechanical and physical demands of
259 walking football, in participants who had been playing the sport for one year or more. The average RPE
260 across the 25 sessions was 13 ± 2 , equating to the verbal anchor 'Somewhat Hard' on the 6-20 Borg
261 Scale. However, as shown in Figure 3, there was some intra-session and inter-individual variability,
262 with ratings ≥ 15 (Hard) in 11 of the 25 sessions, and ratings of ≤ 11 (Light) in 13 of the 25 sessions.
263 These RPE values are similar to a previous investigation on walking football (Reddy et al., 2017). The
264 American College of Sports Medicine position stand on the quantity and quality of exercise for
265 developing and maintaining cardiorespiratory, musculoskeletal and neuromotor fitness states that an
266 RPE of 13 equates to a moderate intensity, with participants working at 64-76% and 46-63% of their
267 $\%HR_{\max}$ and $\% \dot{V}O_{2\max}$, respectively (Garber et al., 2011). Within this study, we observed participants
268 exercising at an average of 76% of their theoretical HR_{\max} during the sessions. Four participants were
269 exercising at an average of $\geq 80\%$ of their theoretical HR_{\max} ; however, as we were unable to measure
270 HR_{\max} directly, the accuracy of the equation used and individual variation in HR_{\max} should be considered
271 (Tanaka et al., 2001). Nonetheless, the two measures of internal load (i.e., $\%HR_{\max}$ and RPE) seemed
272 to be fairly well aligned.

273 Our observed HR values are comparable to those previously reported in recreational small-sided
274 football training (i.e., 6v6) across a range of ages (Bangsbo et al., 2015). Evidence suggests that
275 football-based training performed at such intensities provides significant benefits to the cardiovascular
276 system (Bangsbo et al., 2015). Cardiovascular disease is a leading cause of mortality, particularly in
277 older adult males, and as such, data from our and previous investigations (Loadman, 2017; Reddy et
278 al., 2017) suggests walking football is a socially enjoyable mode of exercise that could potentially
279 reduce the risk of cardiovascular disease. However, longitudinal studies are required to confirm this
280 supposition.

281 In absolute terms, HR_{mean} for the eleven sessions was 124 ± 13 bpm. Previous research has investigated
282 the effects of a 2-week interval walking (3 mins high intensity [$90\% \dot{V}O_{2\text{peak}}$], 3 mins low intensity
283 [$60\% \dot{V}O_{2\text{peak}}$] alternating for 60 min) intervention in a similar age group to our study (65 ± 2 years), in

284 which comparable HR_{mean} values were reported during the high intensity periods (119 ± 3 bpm) to those
285 of the present study (Karstoft et al., 2017). The comparable HR_{mean} data may suggest that walking
286 football sessions have a relative intensity of $\sim 90\% \dot{V}O_{2\text{peak}}$, which would support the notion that walking
287 football for older adults can be considered an intermittently vigorous-intensity activity (Reddy et al.,
288 2017). This is also supported by our RPE values, as participants often rated sessions ≥ 15 (Hard; Figure
289 3). As we only collected RPE at the end of a session, the participant's rating may have been reflective
290 of the last 10-15 minutes of the session, rather than the session as a whole. However, the participants
291 were verbally instructed to consider the whole session when providing their rating.

292 The benefits of walking alone on risk factors for cardiovascular disease are well established, with the
293 potential to improve aerobic capacity, reduce systolic and diastolic blood pressure, and positively alter
294 body composition (Hanson & Jones, 2015; Murphy et al., 2007). Furthermore, there may be additional
295 benefits of intermittent, or interval walking, which walking football can be considered a type of. Indeed,
296 Karstoft et al., (2017) observed significant improvements in glycaemic control in type 2 diabetics
297 following an intermittent walking intervention compared to a volume-matched continuous walking
298 intervention, and Nemoto, Gen-no, Masuki, Okazaki, & Nose, (2007) found significantly greater
299 increases in aerobic capacity and upper leg muscle strength in an intermittent walking group compared
300 to a moderate-intensity continuous walking training group. Other authors have also observed reductions
301 in lifestyle disease risk factors and improvements in peak aerobic capacity following long- (Masuki et
302 al., 2015) and short-term (Murphy, Nevill, Neville, Biddle, & Hardman, 2002) intermittent walking
303 interventions. However, future studies comparing walking football to traditional interval walking are
304 required.

305 Walking football has the potential to be of greater benefit than intermittent walking interventions due
306 to the frequent changes of direction required to react to the movement of opposition players and the
307 ball. We observed an average of just under 100 changes of direction at a speed of $1.5 \text{ m}\cdot\text{s}^{-2}$ or above per
308 walking football session, and ~ 45 accelerations and decelerations at speeds $\geq 1.5 \text{ m}\cdot\text{s}^{-2}$. Previous
309 interventions with continuous walking have observed no discernible improvements in bone mineral
310 density (Gába et al., 2016; Palombaro, 2005), which is unsurprising as walking is a part of normal day-

311 to-day activities, and does not provide a large ground/joint reaction force. However, frequent changes
312 of direction may elicit a greater strain magnitude and osteogenic stimulus than linear movement alone
313 (Hart et al., 2017). There is currently a lack of evidence and consensus about the optimal exercise
314 modalities to slow down age-related loss of bone and increase bone strength. However, it has been
315 suggested that multidirectional activity may be of benefit (Santos et al., 2017). Nevertheless, it is also
316 recommended that the exercise be of high intensity and impact in nature (Santos et al., 2017), and so
317 whether walking football meets all these criteria remains to be elucidated. Furthermore, we observed
318 very high CVs for CoD, ACC and DEC, suggesting that there are large inter-session differences in these
319 metrics. The variability in the accelerometry variables across sessions may be due to intra- and inter-
320 device variability, different sizes of teams, participants spending longer in the goalkeeper role (which
321 requires less movement) and the dynamic, random nature of football in general. Therefore, it is
322 important to account for potential differences in the biomechanical load of walking football sessions
323 when prescribing walking football as an exercise intervention. Nonetheless, the HR response to the
324 sessions demonstrated relatively low variability (CV: <7.5%) and so it would appear that walking
325 football consistently imposes a moderate-to-vigorous intensity stimulus.

326 Limitations such as, but not limited to, individual variances, inter-unit reliability and placement, and
327 disparate sampling frequencies must be taken into account when comparing individual accelerometry
328 data (Malone, Lovell, Varley, & Coutts, 2017). In acknowledgment of these potential errors,
329 Casamichana, Castellano, & Dellal, (2013) observed PL values that ranged from 219.5 ± 63.7 to 257.7
330 ± 39.8 a.u in third division Spanish players over 16 min of 5 vs 5 small-sided soccer matches. As such,
331 our PL data (353 ± 67 a.u) suggests that 60 min of walking football equates to the same relative
332 biomechanical load as approximately 25 min of a 5 vs 5 small-sided soccer match. Additionally, we
333 observed increases in PL-ML (~9 %) and concurrent reductions in PL-V (~10 %) contributions
334 compared to 90 min of simulated soccer (Page, Marrin, Brogden, & Greig, 2015). This is unsurprising
335 given that running is prohibited in walking football, although it may suggest that the reduced impact
336 may provide a safer alternative towards mitigating age-related losses in bone mineral density, when
337 compared to regular football in older populations (Hagman et al., 2018).

338 Just reacting to the changes in the movement of opponents and the ball may offer benefits for the
339 neuromuscular system. Falling in older adults is often precipitated by the inability of the neuromuscular
340 system to react quick enough to an unexpected stimulus (Sawers & Bhatt, 2018). Reactive stepping
341 interventions and perturbation-based balance training in older adults have been shown to reduce the risk
342 of falling by 40-50% (Mansfield, Wong, Bryce, Knorr, & Patterson, 2015; Okubo, Schoene, & Lord,
343 2017; Weerdesteyn et al., 2006). As quick stepping in different directions is required during trips and
344 falls, exercise stimuli that can improve sensorimotor skills and create stored motor programmes that
345 can be utilised during fall situations may be of benefit (Okubo et al., 2017). Therefore, the requirement
346 to respond stochastically to a dynamic game of walking football may potentially protect older adults
347 from risk of falling. Falling itself is a leading cause of bone fractures in older adults, creating a large
348 financial burden (Stevens, Corso, Finkelstein, & Miller, 2006), and potentially leading to a reduction in
349 physical activity following a fall due to fear of future falls. As long-term bed rest due to fracture
350 recovery can accelerate sarcopenia and loss of bone (Cruz-Jentoft et al., 2010; Leblanc, Schneider,
351 Evans, Engelbretson, & Krebs, 2009), future studies assessing the impact of walking football on fall
352 risk and bone metabolism are warranted.

353 Unfortunately, we were unable to measure step count and distance covered in the present investigation.
354 To the authors' knowledge, we are unaware of any published research reporting step count and distances
355 covered during walking football. Future research assessing these variables is necessary, as knowledge
356 about the extent to which an hour of walking football contributes to daily step count can help exercisers
357 and those who prescribe exercise. Current recommendations suggest a walking cadence of 100
358 steps·min⁻¹ to elicit moderate intensity activity (Tudor-Locke et al., 2018), so ~5500 steps during an
359 hour of walking football if accounting for a brief break during the session. However, recent research by
360 Abt and colleagues suggests that to achieve a $\dot{V}O_2$ reserve ($\dot{V}O_{2R}$) of 40%, participants need a walking
361 cadence of 138 to 140 steps·min⁻¹ (Abt, Bray, Myers, & Benson, 2019). However, this is moderated by
362 fitness status, with those of lower fitness able to achieve a similar $\dot{V}O_{2R}$ at a slower cadence. Moreover,
363 current guidelines on overall daily step count (10,000 steps a day) may not be reflected by research
364 outcomes, with more dose-response studies required in a variety of populations (Kraus et al., 2019).

365 That said, current recommendations suggest older adults should aim for 150 minutes of moderate-to-
366 vigorous physical activity per week, with 3000-6000 steps per day at those intensities (Sparling,
367 Howard, Dunstan, & Owen, 2015). Therefore, participating in walking football will not only likely help
368 older adults meet daily step count recommendations, but also help them achieve the recommended
369 amount of moderate-to-vigorous intensity activity.

370 This is the first study to measure the blood lactate response during walking football. We observed a
371 mean increase of ~157% from pre- to post-session (1.24 ± 0.4 vs 3.19 ± 1.7 mmol·l⁻¹). This relatively
372 high post-session blood lactate concentration suggests that walking football places a significant demand
373 on the anaerobic system, in particular the glycolytic pathway, supporting the notion that walking
374 football is a vigorous-intensity exercise for older adults. As expected, the observed concentrations were
375 not as high as previously observed during small-sided recreational football matches in young (early
376 30's) untrained males (Randers, Nielsen, Bangsbo, & Krstrup, 2014; Randers et al., 2010; Randers,
377 Ørntoft, Hagman, Nielsen, & Krstrup, 2018) but comparable data in older adults is not available. Due
378 to logistical constraints we were unable to measure blood lactate at regular intervals (e.g., every 15 min)
379 during the sessions, which would have allowed us to assess transient changes in blood lactate. Football
380 is intermittent in nature, and as such, the flux of the anaerobic and aerobic energy systems will be in
381 constant change, mimicking that of high intensity interval training (HIIT) protocols. In older adults,
382 HIIT has been shown to improve metabolic (Søgaard et al., 2018) and cardiovascular health (Izadi,
383 Ghardashi Afousi, Asvadi Fard, & Babaei Bigi, 2018), as well as muscle mitochondrial content
384 (Wyckelsma et al., 2017). However, high dropout rates have been observed during HIIT programmes
385 (Reljic et al., 2019). Therefore, the physiological and psychological benefits of walking football
386 compared to traditional HIIT warrants further investigation, including adherence to the program of
387 exercise, and affective responses during sessions.

388 Future intervention studies investigating walking football may benefit from collaborating with
389 professional football clubs, as this has been shown to assist in attracting hard-to-reach males and
390 increasing adherence to an exercise program (Curran, Drust, Murphy, Pringle, & Richardson, 2016;
391 Hunt et al., 2014; Pringle et al., 2013). This was particularly successful in the large-scale European Fans

392 in Training (EuroFIT) programme (Wyke et al., 2019). A similar programme utilising walking football
393 as an intervention may help establish the usefulness of walking football as a form of exercise
394 prescription for health professionals and exercise referral specialists. Furthermore, more data is required
395 on the benefits of walking football for females, and individuals suffering from clinical conditions, *inter*
396 *alia*, cardiovascular disease, diabetes mellitus, cancers, and chronic obstructive pulmonary disease
397 (COPD).

398 In conclusion, we have shown that walking football is a moderate-to-vigorous intensity activity, that
399 has a similar biomechanical load to 25 minutes of ‘running’ football and requires a relatively high
400 number of changes of direction. The longitudinal health benefits of walking football remain to be
401 elucidated, particularly on bone health, cardiovascular fitness, metabolism, and social and mental
402 wellbeing. Furthermore, the benefits of walking football compared to, and in combination with, other
403 types of training, such as HIIT and resistance training, requires further investigation.

404

405 **5. Acknowledgements**

406 The authors would like to extend their gratitude to all the participants in this study for their commitment
407 to the research, as well as the organisers of the walking football sessions.

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416 **6. Figure Captions**

417 **Figure 1** Mean peak (HR_{peak} ; panel A) and mean heart rate (HR_{mean} ; panel B) values across 11
418 sessions of walking football ($n = 11$). The upper dashed line represents the average
419 theoretical maximum heart rate of the participants, and the lower dashed line represents
420 80% of that value. See weblink for interpretation of violin plots:
421 https://datavizcatalogue.com/methods/violin_plot.html.

422 **Figure 2** Changes in blood lactate concentrations from pre- to post-session across 11 sessions of
423 walking football ($n = 9$).

424 **Figure 3** Individual rating of perceived exertion (RPE) values across 25 walking football
425 sessions ($n = 7$).

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444 **7. References**

445

446 Abt, G., Bray, J., Myers, T., & Benson, A. C. (2019). Walking cadence required to elicit criterion
447 moderate-intensity physical activity is moderated by fitness status. *Journal of Sports Sciences*,
448 37(17), 1989–1995. <https://doi.org/10.1080/02640414.2019.1612505>

449 Arnold, J. T., Bruce-Low, S., & Sammut, L. (2015). The impact of 12 weeks walking football on
450 health and fitness in males over 50 years of age. *BMJ Open Sport & Exercise Medicine*, 1(1),
451 bmjsem-2015-000048. <https://doi.org/10.1136/bmjsem-2015-000048>

452 Atkinson, G., & Nevill, A. M. (1998). Statistical Methods For Assessing Measurement Error
453 (Reliability) in Variables Relevant to Sports Medicine: *Sports Medicine*, 26(4), 217–238.
454 <https://doi.org/10.2165/00007256-199826040-00002>

455 Bangsbo, J., Hansen, P. R., Dvorak, J., & Krstrup, P. (2015). Recreational football for disease
456 prevention and treatment in untrained men: A narrative review examining cardiovascular
457 health, lipid profile, body composition, muscle strength and functional capacity. *British*
458 *Journal of Sports Medicine*, 49(9), 568–576. <https://doi.org/10.1136/bjsports-2015-094781>

459 Beard, J. R., Officer, A., de Carvalho, I. A., Sadana, R., Pot, A. M., Michel, J.-P., ... Chatterji, S.
460 (2016). The World report on ageing and health: A policy framework for healthy ageing. *The*
461 *Lancet*, 387(10033), 2145–2154. [https://doi.org/10.1016/S0140-6736\(15\)00516-4](https://doi.org/10.1016/S0140-6736(15)00516-4)

462 Börsch-Supan, A., Brandt, M., Hunkler, C., Kneip, T., Korbmacher, J., Malter, F., ... Zuber, S.
463 (2013). Data Resource Profile: The Survey of Health, Ageing and Retirement in Europe
464 (SHARE). *International Journal of Epidemiology*, 42(4), 992–1001.
465 <https://doi.org/10.1093/ije/dyt088>

466 Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The Reliability of MinimaxX Accelerometers for
467 Measuring Physical Activity in Australian Football. *International Journal of Sports*
468 *Physiology and Performance*, 6(3), 311–321. <https://doi.org/10.1123/ijsp.6.3.311>

469 Cartee, G. D., Hepple, R. T., Bamman, M. M., & Zierath, J. R. (2016). Exercise Promotes Healthy
470 Aging of Skeletal Muscle. *Cell Metabolism*, 23(6), 1034–1047.
471 <https://doi.org/10.1016/j.cmet.2016.05.007>

472 Casamichana, D., Castellano, J., & Dellal, A. (2013). Influence of different training regimes on
473 physical and physiological demands during small-sided soccer games: continuous vs.
474 Intermittent format. *Journal of Strength and Conditioning Research*, 27(3), 690-697.

475 Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The Use of Wearable Microsensors to
476 Quantify Sport-Specific Movements. *Sports Medicine*, 45(7), 1065–1081.
477 <https://doi.org/10.1007/s40279-015-0332-9>

478 Chung, P.-K., Zhao, Y., Liu, J.-D., & Quach, B. (2015). A Brief Note on the Validity and Reliability
479 of the Rating of Perceived Exertion Scale in Monitoring Exercise Intensity among Chinese

480 Older Adults in Hong Kong. *Perceptual and Motor Skills*, 121(3), 805–809.
481 <https://doi.org/10.2466/29.PMS.121c24x8>

482 Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., ... Zamboni, M.
483 (2010). Sarcopenia: European consensus on definition and diagnosis: Report of the European
484 Working Group on Sarcopenia in Older People. *Age and Ageing*, 39(4), 412–423.
485 <https://doi.org/10.1093/ageing/afq034>

486 Curran, K., Drust, B., Murphy, R., Pringle, A., & Richardson, D. (2016). The challenge and impact of
487 engaging hard-to-reach populations in regular physical activity and health behaviours: An
488 examination of an English Premier League ‘Football in the Community’ men’s health
489 programme. *Public Health*, 135, 14–22. <https://doi.org/10.1016/j.puhe.2016.02.008>

490 Ferrucci, L., & Fabbri, E. (2018). Inflammaging: Chronic inflammation in ageing, cardiovascular
491 disease, and frailty. *Nature Reviews Cardiology*, 15(9), 505–522.
492 <https://doi.org/10.1038/s41569-018-0064-2>

493 Fox, K. R., Stathi, A., McKenna, J., & Davis, M. G. (2007). Physical activity and mental well-being
494 in older people participating in the Better Ageing Project. *European Journal of Applied
495 Physiology*, 100(5), 591–602. <https://doi.org/10.1007/s00421-007-0392-0>

496 Gába, A., Cuberek, R., Svoboda, Z., Chmelík, F., Pelclová, J., Lehnert, M., & Frömel, K. (2016). The
497 effect of brisk walking on postural stability, bone mineral density, body weight and
498 composition in women over 50 years with a sedentary occupation: A randomized controlled
499 trial. *BMC Women’s Health*, 16(1), 63. <https://doi.org/10.1186/s12905-016-0343-1>

500 Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., ... Swain,
501 D. P. (2011). Quantity and Quality of Exercise for Developing and Maintaining
502 Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults:
503 Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise*, 43(7), 1334–
504 1359. <https://doi.org/10.1249/MSS.0b013e318213fefb>

505 Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., ... for
506 the Health ABC Study. (2006). The Loss of Skeletal Muscle Strength, Mass, and Quality in
507 Older Adults: The Health, Aging and Body Composition Study. *The Journals of Gerontology
508 Series A: Biological Sciences and Medical Sciences*, 61(10), 1059–1064.
509 <https://doi.org/10.1093/gerona/61.10.1059>

510 Hagman, M., Helge, E. W., Hornstrup, T., Frstrup, B., Nielsen, J. J., Jørgensen, N. R., ... Krstrup,
511 P. (2018). Bone mineral density in lifelong trained male football players compared with
512 young and elderly untrained men. *Journal of Sport and Health Science*, 7(2), 159–168.
513 <https://doi.org/10.1016/j.jshs.2017.09.009>

514 Hamer, M., Muniz Terrera, G., & Demakakos, P. (2018). Physical activity and trajectories in
515 cognitive function: English Longitudinal Study of Ageing. *Journal of Epidemiology and
516 Community Health*, 72(6), 477–483. <https://doi.org/10.1136/jech-2017-210228>

517 Hanson, S., & Jones, A. (2015). Is there evidence that walking groups have health benefits? A
518 systematic review and meta-analysis. *British Journal of Sports Medicine*, 49(11), 710–715.
519 <https://doi.org/10.1136/bjsports-2014-094157>

520 Hart, N. H., Nimphius, S., Rantalainen, T., Ireland, A., Siafarikas, A., & Newton, R. U. (2017).
521 Mechanical basis of bone strength: Influence of bone material, bone structure and muscle
522 action. *Journal of Musculoskeletal and Neuronal Interactions*, 17(3), 114-139.

523 Heil, D. P., Newton, R. U., & Salle, D. D. A. (2018). Characterizing the Metabolic Intensity and
524 Cardiovascular Demands of Walking Football in Southeast Asian Women. *International*
525 *Journal of Physical Education, Fitness and Sports*, 7(3), 12–23.
526 <https://doi.org/10.26524/ijpefs1832>

527 Hunt, K., Gray, C. M., Maclean, A., Smillie, S., Bunn, C., & Wyke, S. (2014). Do weight
528 management programmes delivered at professional football clubs attract and engage high risk
529 men? A mixed-methods study. *BMC Public Health*, 14(1), 50. [https://doi.org/10.1186/1471-](https://doi.org/10.1186/1471-2458-14-50)
530 [2458-14-50](https://doi.org/10.1186/1471-2458-14-50)

531 Izadi, M. R., Ghardashi Afousi, A., Asvadi Fard, M., & Babae Bigi, M. A. (2018). High-intensity
532 interval training lowers blood pressure and improves apelin and NOx plasma levels in older
533 treated hypertensive individuals. *Journal of Physiology and Biochemistry*, 74(1), 47–55.
534 <https://doi.org/10.1007/s13105-017-0602-0>

535 Karstoft, K., Clark, M. A., Jakobsen, I., Müller, I. A., Pedersen, B. K., Solomon, T. P. J., & Ried-
536 Larsen, M. (2017). The effects of 2 weeks of interval vs continuous walking training on
537 glycaemic control and whole-body oxidative stress in individuals with type 2 diabetes: A
538 controlled, randomised, crossover trial. *Diabetologia*, 60(3), 508–517.
539 <https://doi.org/10.1007/s00125-016-4170-6>

540 Kraus, W. E., Janz, K. F., Powell, K. E., Campbell, W. W., Jakicic, J. M., Troiano, R. P., ... Piercy,
541 K. L. (2019). Daily Step Counts for Measuring Physical Activity Exposure and Its Relation to
542 Health: *Medicine & Science in Sports & Exercise*, 51(6), 1206–1212.
543 <https://doi.org/10.1249/MSS.0000000000001932>

544 Lamont, E., Harris, J., McDonald, G., Kerin, T., & Dickens, G. L. (2017). Qualitative investigation of
545 the role of collaborative football and walking football groups in mental health recovery.
546 *Mental Health and Physical Activity*, 12, 116–123.
547 <https://doi.org/10.1016/j.mhpa.2017.03.003>

548 Lancaster, G. I., & Febbraio, M. A. (2014). The immunomodulating role of exercise in metabolic
549 disease. *Trends in Immunology*, 35(6), 262–269. <https://doi.org/10.1016/j.it.2014.02.008>

550 Leblanc, A. D., Schneider, V. S., Evans, H. J., Engelbretson, D. A., & Krebs, J. M. (2009). Bone
551 mineral loss and recovery after 17 weeks of bed rest. *Journal of Bone and Mineral Research*,
552 5(8), 843–850. <https://doi.org/10.1002/jbmr.5650050807>

- 553 Loadman, A. (2017). 'He's Running, Ref!' An ethnographic study of walking football. *Soccer &*
554 *Society*, 20(4), 675–692. <https://doi.org/10.1080/14660970.2017.1396451>
- 555 Malone, J. J., Lovell, R., Varley, M. C., & Coutts, A. J. (2017). Unpacking the Black Box:
556 Applications and Considerations for Using GPS Devices in Sport. *International Journal of*
557 *Sports Physiology and Performance*, 12(s2), S2-18-S2-26. [https://doi.org/10.1123/ijsp.2016-](https://doi.org/10.1123/ijsp.2016-0236)
558 0236
- 559 Mansfield, A., Wong, J. S., Bryce, J., Knorr, S., & Patterson, K. K. (2015). Does Perturbation-Based
560 Balance Training Prevent Falls? Systematic Review and Meta-Analysis of Preliminary
561 Randomized Controlled Trials. *Physical Therapy*, 95(5), 700–709.
562 <https://doi.org/10.2522/ptj.20140090>
- 563 Masuki, S., Mori, M., Tabara, Y., Sakurai, A., Hashimoto, S., Morikawa, M., ... Nose, H. (2015). The
564 factors affecting adherence to a long-term interval walking training program in middle-aged
565 and older people. *Journal of Applied Physiology*, 118(5), 595–603.
566 <https://doi.org/10.1152/jappphysiol.00819.2014>
- 567 McEwan, G., Buchan, D., Cowan, D., Arthur, R., Sanderson, M., & Macrae, E. (2019). Recruiting
568 Older Men to Walking Football: A Pilot Feasibility Study. *EXPLORE*, 15(3), 206–214.
569 <https://doi.org/10.1016/j.explore.2018.12.001>
- 570 McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2018). The
571 Relationships Between Internal and External Measures of Training Load and Intensity in
572 Team Sports: A Meta-Analysis. *Sports Medicine*, 48(3), 641–658.
573 <https://doi.org/10.1007/s40279-017-0830-z>
- 574 Murphy, M. H., Nevill, A. M., Murtagh, E. M., & Holder, R. L. (2007). The effect of walking on
575 fitness, fatness and resting blood pressure: A meta-analysis of randomised, controlled trials.
576 *Preventive Medicine*, 44(5), 377–385. <https://doi.org/10.1016/j.ypmed.2006.12.008>
- 577 Murphy, M., Nevill, A., Neville, C., Biddle, S., & Hardman, A. (2002). Accumulating brisk walking
578 for fitness, cardiovascular risk, and psychological health: *Medicine & Science in Sports &*
579 *Exercise*, 34(9), 1468–1474. <https://doi.org/10.1097/00005768-200209000-00011>
- 580 Nemoto, K., Gen-no, H., Masuki, S., Okazaki, K., & Nose, H. (2007). Effects of High-Intensity
581 Interval Walking Training on Physical Fitness and Blood Pressure in Middle-Aged and Older
582 People. *Mayo Clinic Proceedings*, 82(7), 803–811. <https://doi.org/10.4065/82.7.803>
- 583 Nicolella, D. P., Torres-Ronda, L., Saylor, K. J., & Schelling, X. (2018). Validity and reliability of an
584 accelerometer-based player tracking device. *PLOS ONE*, 13(2), e0191823.
585 <https://doi.org/10.1371/journal.pone.0191823>
- 586 Okubo, Y., Schoene, D., & Lord, S. R. (2017). Step training improves reaction time, gait and balance
587 and reduces falls in older people: A systematic review and meta-analysis. *British Journal of*
588 *Sports Medicine*, 51(7), 586–593. <https://doi.org/10.1136/bjsports-2015-095452>

589 Page, R. M., Marrin, K., Brogden, C. M., & Greig, M. (2015). Biomechanical and Physiological
590 Response to a Contemporary Soccer Match-Play Simulation: *Journal of Strength and*
591 *Conditioning Research*, 29(10), 2860–2866. <https://doi.org/10.1519/JSC.0000000000000949>

592 Palombaro, K. M. (2005). Effects of Walking-only Interventions on Bone Mineral Density at Various
593 Skeletal Sites: A Meta-analysis. *Journal of Geriatric Physical Therapy*, 28(3), 102-107.

594 Pringle, A., Zwolinsky, S., McKenna, J., Daly-Smith, A., Robertson, S., & White, A. (2013).
595 Delivering men’s health interventions in English Premier League football clubs: Key design
596 characteristics. *Public Health*, 127(8), 716–726. <https://doi.org/10.1016/j.puhe.2013.04.011>

597 Randers, M. B., Nielsen, J. J., Bangsbo, J., & Krstrup, P. (2014). Physiological response and activity
598 profile in recreational small-sided football: No effect of the number of players: Organizing
599 effective recreational football. *Scandinavian Journal of Medicine & Science in Sports*, 24,
600 130–137. <https://doi.org/10.1111/sms.12232>

601 Randers, M. B., Nybo, L., Petersen, J., Nielsen, J. J., Christiansen, L., Bendiksen, M., ... Krstrup, P.
602 (2010). Activity profile and physiological response to football training for untrained males
603 and females, elderly and youngsters: Influence of the number of players: Physical demands of
604 recreational football. *Scandinavian Journal of Medicine & Science in Sports*, 20, 14–23.
605 <https://doi.org/10.1111/j.1600-0838.2010.01069.x>

606 Randers, Morten B., Ørntoft, C., Hagman, M., Nielsen, J. J., & Krstrup, P. (2018). Movement pattern
607 and physiological response in recreational small-sided football – effect of number of players
608 with a fixed pitch size. *Journal of Sports Sciences*, 36(13), 1549–1556.
609 <https://doi.org/10.1080/02640414.2017.1402552>

610 Reddy, P., Dias, I., Holland, C., Campbell, N., Nagar, I., Connolly, L., ... Hubball, H. (2017).
611 Walking football as sustainable exercise for older adults – A pilot investigation. *European*
612 *Journal of Sport Science*, 17(5), 638–645. <https://doi.org/10.1080/17461391.2017.1298671>

613 Reljic, D., Lampe, D., Wolf, F., Zopf, Y., Herrmann, H. J., & Fischer, J. (2019). Prevalence and
614 predictors of dropout from high-intensity interval training in sedentary individuals: A meta-
615 analysis. *Scandinavian Journal of Medicine & Science in Sports*, sms.13452.
616 <https://doi.org/10.1111/sms.13452>

617 Roy, B. A. (2015). Monitoring Your Exercise Intensity. *ACSM's Health & Fitness Journal*, 19(4), 3-4.

618 Santos, L., Elliott-Sale, K. J., & Sale, C. (2017). Exercise and bone health across the lifespan.
619 *Biogerontology*, 18(6), 931–946. <https://doi.org/10.1007/s10522-017-9732-6>

620 Sawers, A., & Bhatt, T. (2018). Neuromuscular determinants of slip-induced falls and recoveries in
621 older adults. *Journal of Neurophysiology*, 120(4), 1534–1546.
622 <https://doi.org/10.1152/jn.00286.2018>

623 Shigematsu, R., Ueno, L. M., Nakagaichi, M., Nho, H., & Tanaka, K. (2004). Rate of Perceived
624 Exertion as a Tool to Monitor Cycling Exercise Intensity in Older Adults. *Journal of Aging*
625 *and Physical Activity*, 12(1), 3–9. <https://doi.org/10.1123/japa.12.1.3>

626 Søgaard, D., Lund, M. T., Scheuer, C. M., Dehlbaek, M. S., Dideriksen, S. G., Abildskov, C. V., ...
627 Helge, J. W. (2018). High-intensity interval training improves insulin sensitivity in older
628 individuals. *Acta Physiologica*, 222(4), e13009. <https://doi.org/10.1111/apha.13009>

629 Sparling, P. B., Howard, B. J., Dunstan, D. W., & Owen, N. (2015). Recommendations for physical
630 activity in older adults. *BMJ*, 350(jan20 6), h100–h100. <https://doi.org/10.1136/bmj.h100>

631 Stevens, J. A., Corso, P. S., Finkelstein, E. A., & Miller, T. R. (2006). The costs of fatal and non-fatal
632 falls among older adults. *Injury Prevention*, 12(5), 290–295.
633 <https://doi.org/10.1136/ip.2005.011015>

634 Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited.
635 *Journal of the American College of Cardiology*, 37(1), 153–156.
636 [https://doi.org/10.1016/S0735-1097\(00\)01054-8](https://doi.org/10.1016/S0735-1097(00)01054-8)

637 Tudor-Locke, C., Han, H., Aguiar, E. J., Barreira, T. V., Schuna Jr, J. M., Kang, M., & Rowe, D. A.
638 (2018). How fast is fast enough? Walking cadence (steps/min) as a practical estimate of
639 intensity in adults: a narrative review. *British Journal of Sports Medicine*, 52(12), 776–788.
640 <https://doi.org/10.1136/bjsports-2017-097628>

641 Turner, C. H., & Robling, A. G. (2003). Designing Exercise Regimens to Increase Bone Strength:
642 *Exercise and Sport Sciences Reviews*, 31(1), 45–50. [https://doi.org/10.1097/00003677-](https://doi.org/10.1097/00003677-200301000-00009)
643 [200301000-00009](https://doi.org/10.1097/00003677-200301000-00009)

644 Weerdesteyn, V., Rijken, H., Geurts, A. C. H., Smits-Engelsman, B. C. M., Mulder, T., & Duysens, J.
645 (2006). A Five-Week Exercise Program Can Reduce Falls and Improve Obstacle Avoidance
646 in the Elderly. *Gerontology*, 52(3), 131–141. <https://doi.org/10.1159/000091822>

647 White, A. D., & Macfarlane, N. G. (2015). Analysis of international competition and training in men's
648 field hockey by global positioning system and inertial sensor technology. *Journal of Strength*
649 *and Conditioning Research*, 29(1), 137-143.

650 Wyckelsma, V. L., Levinger, I., McKenna, M. J., Formosa, L. E., Ryan, M. T., Petersen, A. C., ...
651 Murphy, R. M. (2017). Preservation of skeletal muscle mitochondrial content in older adults:
652 Relationship between mitochondria, fibre type and high-intensity exercise training: High-
653 intensity training in elderly humans. *The Journal of Physiology*, 595(11), 3345–3359.
654 <https://doi.org/10.1113/JP273950>

655 Wyke, S., Bunn, C., Andersen, E., Silva, M. N., van Nassau, F., McSkimming, P., ... van der Ploeg,
656 H. P. (2019). The effect of a programme to improve men's sedentary time and physical
657 activity: The European Fans in Training (EuroFIT) randomised controlled trial. *PLOS*
658 *Medicine*, 16(2), e1002736. <https://doi.org/10.1371/journal.pmed.1002736>

659