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1 **Improved physical health in middle-older aged golf caddies following 24-**
2 **weeks of high-volume physical activity**

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25 **ABSTRACT**

26 **Background:** The physical demands of golf caddying, including walking whilst carrying a golf
27 bag, may potentially affect body composition, and markers of metabolic, cardiovascular, and
28 musculoskeletal health. Therefore, this study examined the impact of 24-weeks of caddying on
29 physical health in middle-older aged males.

30 **Methods:** Eleven full-time experienced male caddies (age: 59 ± 8 years; caddying experience:
31 14 ± 12 years) were recruited from a local golf course. The following were assessed at pre-
32 season and after 24-weeks of caddying (March-September 2022): body composition, heart rate,
33 blood pressure, blood lipids, and performance tests (static and dynamic balance, strength, and
34 sub-maximal fitness). Physical activity levels were assessed at pre-season and at the mid-point
35 of the caddying season. Across the caddying season, participants completed a monthly average
36 of 24.0 ± 3.8 rounds.

37 **Results:** Following the caddying season, improvements in static balance ($\Delta = 13.5$ s), dynamic
38 balance ($\Delta = -1.8$ s), and lower-back absolute strength ($\Delta = 112.8$ N) and muscle quality ($\Delta =$
39 2.0 N/kg) were observed (all $p < 0.05$). Additionally, blood lipids, including total cholesterol ($\Delta =$
40 -0.6 mmol·L⁻¹), high-density lipoprotein cholesterol ($\Delta = 0.14$ mmol·L⁻¹), low-density lipoprotein
41 cholesterol ($\Delta = -0.61$ mmol·L⁻¹) (all $p < 0.05$), and body composition, including body mass ($\Delta =$
42 -2.7 kg), fat mass ($\Delta = -1.9$ kg), fat percentage ($\Delta = -1.4\%$), fat-to-muscle ratio ($\Delta = -0.03$), and
43 body mass index ($\Delta = -0.9$ kg·m²) (all $p < 0.05$) improved. Caddying did not offer beneficial
44 changes to cardiovascular variables or cardiorespiratory fitness ($p > 0.05$), while coronary heart
45 disease risk score decreased ($\Delta = -3.3\%$) ($p < 0.05$). In relation to physical activity, light ($\Delta =$

46 145min) and moderate ($\Delta= 71$ min) intensity physical activity, moderate-to-vigorous physical
47 activity ($\Delta= 73$ min), and total physical activity ($\Delta= 218$ min) between pre-season and the mid-
48 point of the caddying season increased, while sedentary time ($\Delta= -172$ min) decreased (all
49 $p<0.05$).

50 Conclusion: Golf caddying can provide several physical health benefits such as improvements
51 in various markers of cardiometabolic health, lower back absolute strength, and static and
52 dynamic balance. The physical health improvements that caddying offers is likely contributed
53 to by increased physical activity volume and intensity through walking on the golf course.
54 Therefore, caddying may represent a feasible model for increasing physical activity volume
55 and intensity and achieve physical health related benefits.

56 **Introduction**

57 Life expectancy in the United Kingdom (UK) has recently stabilised.¹ However, the number of
58 older adults in the population (>60 years) is increasing,² with current estimates within the UK,
59 that beyond this age, individuals can expect to live on average an additional 24 years.³ This
60 presents a challenge to enhance the proportion of life spent in good health, reported to be 79%
61 and 77% from birth in males and females, respectively.⁴ Therefore, strategies are necessary to
62 promote healthy ageing and delay physical declines concomitant with chronological ageing.
63 Physical activity (PA) is a viable possibility and an encouraged behaviour,² which may be
64 realised through activities associated with the sport of golf, such as playing, and caddying.

65 Golf caddies are employed by various golf courses and are broadly responsible for
66 carrying a golfer's clubs and providing advice.⁵ At Carnoustie Golf Links in the United
67 Kingdom, 67.4% of golf rounds completed by non-members in 2022/2023 were with a caddie
68 (15,153 rounds of golf). This demand for golf caddies has increased from 57.4% (10,409

69 rounds) in 2018/2019.⁶ Despite golf caddies' key role within the game, there is limited
70 scientific literature surrounding the physical health-related impact of this role, which has led
71 them to being identified as the 'forgotten worker'.⁷

72 Golf caddies walk on average 15,480 steps per day during caddying at the same golf
73 course whilst carrying a bag weighing approximately 12 kg.⁶ As a result of the physical
74 demands of caddying, the golf caddies' role provides an opportunity to increase an individual's
75 PA in an outdoor environment.^{6,8} Caddying and playing golf share some similarities, in terms
76 of walking and carrying clubs, with an important difference being that the caddie does not take
77 golf shots. A recent systematic review highlighted that golf may be an effective method for
78 improving aspects of physical health, across body composition, and metabolic, cardiovascular
79 and musculoskeletal health domains.⁹ However, the review highlighted a limited number of
80 studies (N=2) related to caddies, whereas most studies (N=21) investigated golfers.⁹ Therefore,
81 it is possible that caddying may also facilitate reductions in risk factors for cardiovascular
82 diseases, metabolic, and musculoskeletal health, which warrants further study.

83 Although limited, previous cross-sectional and longitudinal studies have displayed
84 positive results in relation to the physical health of the golf caddie, from single golf courses
85 within each study.^{8,10} This includes greater Achilles tendon stiffness, and quadricep and grip
86 strength in young-middle aged caddies when compared to age and sex-matched controls.¹⁰
87 Furthermore, young to middle-aged caddies displayed improved bone mineral density and leg
88 press strength following 12 months of caddying.⁸ These findings are likely attributed to the
89 extensive walking and load carrying required of caddies. Although these findings are
90 important, further longitudinal research is required to better understand the long-term physical
91 health effects from golf caddying, especially within a middle-older age category. As outlined,

92 previous research has focused on young-middle aged caddies; however, the caddying
93 population often extends to an older age category (≥ 60 years).^{11,12}

94 Considering the PA that caddying offers, this presents the opportunity to determine the
95 viability of caddies to act as a model for health benefits from high volume low and moderate
96 intensity PA in middle-older aged adults.⁶ This may be realised by establishing the demands
97 and concomitant physical health responses to a season of caddying in middle-older age
98 populations. Therefore, this study aimed to assess the impact that caddying throughout a 24-
99 week period had on markers of body composition, and cardiovascular, metabolic, and
100 musculoskeletal health in middle-older aged caddies. It was hypothesised that regular caddying
101 throughout the course of a 24-week season would improve markers of physical health and
102 function within these domains.

103 **Methods**

104 **Participants**

105 Eleven males (aged: 59 ± 8 years (range: 42–70 years); height: 176.5 ± 3.7 cm; body mass 86.5
106 ± 11.9 kg) who were employed full-time as golf caddies at Carnoustie Golf Links volunteered
107 to participate (caddying experience: 14 ± 12 years (range: 3–41 years)). On average participants
108 were overweight (body mass index (BMI): 27.7 ± 3.0 kg m²), grade 1 hypertensive¹³ (systolic
109 blood pressure (SBP): 147 ± 22 mmHg; diastolic blood pressure (DBP): 93 ± 16 mmHg) and
110 had slightly elevated total cholesterol (TC) (5.63 ± 1.02 mmol L⁻¹). The inclusion criteria for
111 this study were aged ≥ 40 years,^{12,14,15} free from any musculoskeletal injuries at the time of
112 testing, and completing caddying duties whilst walking the golf course. Two participants
113 reported regular use of cardioactive medication (e.g., anti-hypertensives and Aspirin), with the
114 same dosages at pre- and post-season. All participants completed a written consent form and a

115 physical readiness questionnaire prior to participating. Ethical approval was granted from
116 Abertay University, School of Applied Sciences.

117 **Protocol**

118 See Figure 1 for a schematic overview of the protocol. Prior to the 24-week caddying season
119 (March 2022), physical activity data was recorded via accelerometry and then again mid-
120 season (July 2022), while physical health data were collected pre-season and post-season
121 (March-September 2022).

122 **Course and Weather Details**

123 Throughout the 24-week caddying season (April-September 2022), all caddying duties were
124 completed on the 18-hole Championship Course at Carnoustie Golf Links, Angus, Scotland,
125 United Kingdom (yardage: 6139; men's par: 70, women's par: 74; men's slope rating: 130,
126 women's slope rating: 140; men's course rating: 71.5, women's course rating: 77.3 (data based
127 on green tee position))¹⁶; total ascent (elevation gain): 40m; minimum elevation: 2m, maximum
128 elevation: 10m. Elevation values were calculated using Google Earth Pro. Par is defined as the
129 score a scratch golfer (defined as a handicap 0 golfer) is expected to score on a given golf
130 course. The course rating and slope rating is the evaluation of the playing difficulty of the
131 course for the scratch golfer and the bogey golfer (defined as a handicap 18 golfer) under
132 normal playing conditions.¹⁷ Additionally, Carnoustie weather data were collected using Visual
133 Crossing,¹⁸ and calculated to represent daylight hours between sunrise to sunset to the nearest
134 hour for each individual day. This included average temperature, humidity, wind speed and
135 ultraviolet index and the sum of precipitation. These daily values were then average from 4th
136 April 2022 to 22nd September 2022.

137 **Accelerometry**

138 Firstly, participants were provided with an accelerometer (ActiGraph wGT3X-BT, Pensacola,
139 FL, USA) to wear for 7 consecutive days, 2 weeks prior to the caddying season commencing.
140 All accelerometry data were collected between mid-late March 2022. The accelerometer unit
141 was attached to an elastic belt and worn on the participant's right hip. Participants were
142 instructed to wear the accelerometer at all times, except during bathing activities (e.g.,
143 showering) and sleeping.¹⁹ Throughout the 7-days of accelerometer data collection,
144 participants were asked to maintain their habitual activity patterns. Participants were also asked
145 to complete an activity log detailing the times the monitor was removed and replaced each day.
146 Accelerometer data were then collected via the same process at the mid-point of the caddying
147 season (July 2022).

148 ActiLife software (Version 6.13.4, ActiGraph) was used to analyse accelerometer data.
149 All data were downloaded at 60 second epochs. Raw accelerometry data were presented in
150 counts per minute ($\text{counts}\cdot\text{min}^{-1}$). Non-wear time (90 consecutive minutes of zero $\text{counts}\cdot\text{min}^{-1}$)
151 ¹⁾²⁰ was excluded from all analyses. PA intensities were determined using the cut points: light-
152 intensity ($\leq 2689 \text{ counts}\cdot\text{min}^{-1}$), moderate-intensity ($\leq 6166 \text{ counts}\cdot\text{min}^{-1}$), and vigorous-
153 intensity ($> 6167 \text{ counts}\cdot\text{min}^{-1}$).²¹ To determine time spent in moderate-to-vigorous PA
154 (MVPA), the time engaged in moderate and vigorous PA were summed. Total PA time was
155 calculated by summing the time spent engaged in light, moderate and vigorous PA. Sedentary
156 behaviour was defined using the cut point $\leq 200 \text{ counts}\cdot\text{min}^{-1}$.²² Participant's data were only
157 included for analyses if the following criteria were met: ≥ 10 hours of wear time per day, for a
158 minimum of four days, including one weekend day.²³ Additionally, participants completed a
159 monthly questionnaire to determine how many rounds they caddied each month (April -
160 September). To determine the average number of steps per round during the mid-season, the

161 steps per round for each individual was determined and then an overall average calculated from
162 87 rounds.

163 **Passive Physical Health**

164 Participants were asked to attend a physical testing session prior to and following the 24-week
165 period of caddying. Participants were asked to avoid alcohol and caffeine for at least 12 hours,
166 vigorous exercise for 24 hours, exercise on the day of the testing, and to be fasted for >6
167 hours.²⁴ All tests were performed in the same order, which is outlined below, and were
168 conducted during the same part of the day (i.e., morning or afternoon).²⁵ Firstly, passive
169 physical health measures were recorded, followed by active physical function and performance
170 tests.

171 ***Body Composition***

172 Body composition was assessed using bioelectrical impedance scales (manufacturer stated
173 error $\pm 2\%$) (Tanita, Tokyo, Japan). Participants were asked to void their bladder prior to
174 standing on the scales. The scales automatically calculated: body mass, fat percentage, fat mass,
175 fat free mass (FFM), muscle mass, total body water (TBW), TBW percentage, bone mass, basal
176 metabolic rate (BMR), metabolic age, BMI, and degree of obesity. Fat-to-muscle ratio was
177 calculated as fat mass divided by muscle mass.²⁶ Height was measured using a wall stadiometer
178 (Secca, UK) with socks and shoes removed.

179 ***Blood Pressure and Heart Rate***

180 Following a 10-minute supine rest in a quiet environment, heart rate and blood pressure were
181 recorded 2 to 3 times, separated by 2-3 minutes, and then averaged. Heart rate was measured
182 using a three-lead electrocardiogram (ECG), inherent to an ultrasound machine (Vivid iq, GE
183 Healthcare, London). SBP and DBP were recorded using an automated sphygmomanometer
184 placed around the right-sided upper arm (Omron, 705IT, Hoofddorp, Netherlands). Mean

185 arterial pressure (MAP) was calculated as: $(SBP + 2 * DBP)/3$ and rate pressure product (RPP)
186 as: heart rate x SBP.²⁷

187 *Abdominal and Quadricep Thicknesses*

188 Ultrasound image acquisition was performed by the same sonographer for all measurements
189 (AB), with gain, depth, focus points, and frame rate altered to obtain the clearest images
190 possible with clear inter-muscular delineation. All ultrasound measures were performed using
191 a two-dimensional B-mode ultrasound using a 12 MHz linear array transducer (12L-RS, GE
192 Healthcare, London) and an ultrasound machine (Vivid iq, GE Healthcare, London). Minimal
193 pressure was applied to the ultrasound probe to avoid manual compression of subcutaneous fat
194 and muscular tissue. Images were analysed by AC, who was blinded to data collection and
195 study time point. Images were measured using a calliper-tool on an offline software (EchoPac,
196 version 204), and the average of three images was calculated.

197 *Abdominal Subcutaneous Thickness*

198 The transducer was positioned perpendicular to the skin in a transverse plane.²⁸ Participants
199 lay supine with the transducers positioned 1 cm above the navel,²⁸ in line with the xiphoid
200 process and approximately at the intersection to the waist circumference.²⁹ Subcutaneous fat
201 was measured as the distance between the cutaneous boundary beneath the skin layer, and the
202 linea alba as the superficial fascia of the rectus abdominis.^{28,29}

203 *Quadricep Muscle Thickness and Subcutaneous Fat*

204 Remaining in the supine position, muscle thickness was assessed at the half distance between
205 the greater trochanter and lateral femoral condyle to represent the mid-thigh of the femur.³⁰
206 The transducer was positioned perpendicular to the skin surface³⁰ in the transverse plane to
207 maximise echogenicity for cross-sectional image acquisition. After initial placement, the probe
208 was retracted until a thin layer of ultrasound conducting gel was visible and the rectus femoris

209 appeared at its largest and least compressed.³⁰ Analysis of maximum thicknesses of the rectus
210 femoris and vastus intermedius were determined separately, excluding the intramuscular fascia,
211 and then summed to calculate the total muscle thickness. Rectus femoris thickness was
212 determined as the widest point between the superficial fascia of the perimysium and deep fascia
213 proximal to the vastus intermedius.³¹ Second, vastus intermedius thickness was determined as
214 the proximal fascia border to the anterior border of the femoral cortex.³⁰ Subcutaneous fat was
215 recorded as the distance between the skin and superficial aspects of the fascia on the inferior
216 border.³² Relative muscle thickness was calculated as absolute thickness divided by body
217 mass.³²

218 ***Blood Lipids***

219 Blood samples were collected using a disposable lancet (Accu-Chek, Roche Diagnostics Ltd.,
220 Sussex, UK), then 35 μ L of whole blood was inserted into a capillary tube (Cholestech LDX
221 Capillary Tube; Hayward, CA, USA). Blood samples were then dispensed into a lipid profile
222 Cholestech LDX cassette before being placed in a Cholestech LDX Analyser (Cholestech
223 Corp., Hayward, CA, USA) to provide measures of TC, high-density lipoprotein cholesterol
224 (HDL), triglycerides (TRG), low-density lipoprotein cholesterol (LDL), non-LDL, LDL/HDL,
225 glucose, and coronary heart disease (CHD) risk. CHD risk was measured using the
226 Framingham algorithms, where the points were totalled to determine each participant's
227 Framingham total score.³³

228 **Active Physical Function and Performance**

229 **Warm-up**

230 Participants completed a 5-minute warm-up on a cycle ergometer (Monark Ergomedic 894E,
231 Varberg, Sweden) at a pedal frequency of 60-70 rpm with 0.5 kilopond (kp) resistance.

232 Following the warm-up, participants were familiarised with each performance test prior to data
233 collection commencing.

234 *Dynamic Balance*

235 Participants performed the Berg Balance Scale (BBS) test, designed to measure balance in
236 older adults.³⁴ This test consists of a 14-item scale, measured from 0 to 4 scored subjectively
237 by the rater.³⁵ Total scores of 0–20 demonstrate balance impairment, 21–40 represent suitable
238 balance, and 41–56 show good balance.^{34,35} The items comprise of mobility tasks, including:
239 transfers, standing unsupported, sit-to-stand, tandem position, turning 360°, and single-leg
240 position.³⁵ Participants then completed a timed up-and-go (TUG) test to measure dynamic
241 balance. The time taken for participants to stand from sitting in a chair, walk 3m and then return
242 to the seated position was recorded.³⁶

243 *Static Balance*

244 Participants then performed the one leg stance (OLS) test, which is commonly used to measure
245 static balance capabilities.³⁷ Each participant performed the test on their dominant leg, with
246 their hands on their hips, their eyes open, and their non-dominant leg at the level of the shin.³⁷
247 The total time that participants remained in this position was recorded. The trial ended if the
248 participant removed their hands from their hips, or the standing foot shifted or touched the non-
249 dominant leg.³⁸ Each participant performed three trials, with 60-sec rest between trials, and the
250 average over the three trials was calculated.³⁹

251 *Strength*

252 Peak isometric knee extension force was measured using a handheld dynamometer (HHD)
253 (MicroFET2, Hogan Health, UT, USA).^{40,41} A “make test” method was used to measure leg
254 strength due to its greater reliability when compared to the “break test”.⁴² In order to begin the
255 “make test”, participants were seated in an upright position with their knees at a 90° angle and

256 hips secured to a chair with a seat belt.⁴¹ The examiner's elbow was flexed at 90° and fixed
257 against a wall, whilst the HHD was placed against the participant's lower leg, proximal to the
258 talocrural joint. Peak force was measured for 5-sec on three separate trials, with 60-sec rest
259 between trials,⁴⁰ and the average over the three trials was calculated.¹⁰

260 Peak isometric lower back strength was measured using a back and leg dynamometer
261 (Takei, Analogue dynamometer, Japan).⁴³ Participants stood in an upright position on the base
262 of the dynamometer with their arms straight and the lumbar spine flexed at 30° lumbar
263 flexion.^{44,45} Similar to the knee extension force, peak force was measured for 5-sec on three
264 separate trials, with 60-sec rest between trials,^{40,46} and the average over the three trials was
265 calculated. The leg and lower back strength tests were expressed as absolute strength (N) and
266 muscle quality (N/muscle mass in kg).

267 *Sub-Maximal Cardiorespiratory Fitness Test*

268 The Ekblom-Bak submaximal test was used to predict maximal oxygen uptake ($\dot{V}O_{2\max}$),⁴⁷ as
269 an estimate of cardiorespiratory fitness (CRF). This test is a valid estimation of $\dot{V}O_{2\max}$ for the
270 current study's participant age range (42–70 years).⁴⁷ Prior to the test, participants were fitted
271 with a heart rate monitor (Polar H10, Kempele, Finland) and introduced to the Borg scale of
272 perceived exertion.^{47,48} The test procedure included 4-minutes of cycling on a cycle ergometer
273 at a standardised low work rate of 0.5 kp at 60 rpm, followed by 4-minutes of cycling at a
274 higher work rate chosen by the participant, based on their rating of perceived exertion. Average
275 heart rate during the final minute of the high and low work rates were recorded.⁴⁷ The 2016
276 prediction equation was used to estimate $\dot{V}O_{2\max}$.⁴⁷

277 **Statistical Analysis**

278 Statistical analyses were performed using Statistical Package for the Social Sciences (IBM
279 SPSS) (version: 28). Data were measured for normality using the Shapiro-Wilk test. For all

280 parametric data, Paired Samples T-Tests were used to compare data pre and post caddying
281 season. Non-parametric data were analysed using Wilcoxon Signed-Rank Tests. Hedges' g
282 effect sizes were calculated and then interpreted using the following Cohen's thresholds: trivial
283 (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0-4.0) and extremely
284 large (>4.0).^{49,50} All data are presented as mean \pm standard deviation (SD), p-value and effect
285 sizes.

286 To determine relationships between the total number of caddying rounds throughout
287 the 24-week caddying season and all other variables, Pearson's Correlation Coefficients were
288 conducted for all parametric data, whereas Spearman's Rank Correlations were conducted for
289 non-parametric data. Correlation coefficients of 0–0.3 were categorised as negligible, 0.3–0.5
290 low, 0.5–0.7 moderate, 0.7–0.9 high, and 0.9–1 very high.⁵¹ In all instances, $p < 0.05$ was
291 considered to be statistically significant.

292 **Results**

293 Descriptive statistics for PA levels, body composition, blood pressure, heart rate, blood lipids,
294 and performance tests are presented in Tables 1–4. Total golf rounds completed by the caddies
295 throughout the duration of the study (April–September) are presented in Figure 2. Throughout
296 the caddying period, caddies completed an average of 24.0 ± 3.8 rounds per month and an
297 overall average of 147 ± 36 rounds. Throughout the 24-week caddying period (April–
298 September) the weather conditions were as follows: temperature: 14.21 ± 3.63 °C; humidity:
299 $72.99 \pm 10.64\%$; precipitation: 0.84 ± 2.25 mm; wind speed: 18.08 ± 6.87 km/h; and ultraviolet
300 index: 2.44 ± 0.95 . No injuries were reported that prevented caddies from completing the 24-
301 week study (See Figure 2 for a full data set of complete rounds from all participants (n=11)
302 each month)).

303 **Accelerometry**

304 When comparing PA levels prior to the caddying season commencing and the mid-point of the
305 season, significant increases were observed for light- and moderate-intensity PA, MVPA, total
306 PA, and steps ($p < 0.05$). Sedentary time significantly reduced ($p < 0.05$), whereas no significant
307 difference was observed for vigorous-intensity PA ($p > 0.05$) (Table 1). The golf caddies walked
308 on average $11,101 \pm 2,442$ steps per round.

309 **Passive Physical Health**

310 Following the caddying season, significant improvements were observed for various body
311 composition measures including body mass, fat percentage, fat mass, FFM, muscle mass, fat-
312 to-muscle ratio, TBW, TBW %, BMR, BMI and degree of obesity ($p < 0.05$). No significant
313 differences were observed for bone mass and metabolic age ($p > 0.05$). A significant reduction
314 in absolute muscle thickness ($p < 0.05$) of the quadriceps was observed following the caddying
315 season. No significant differences were observed for muscle thickness relative to body mass,
316 and thigh and abdominal subcutaneous fat thickness ($p > 0.05$) (Table 2).

317 Significant improvements were observed in TC, HDL, LDL, non-LDL, LDL/HDL, and
318 CHD risk ($p < 0.05$). No significant differences were observed for TRG and glucose ($p > 0.05$)
319 (Table 3). In addition, no significant differences were observed for resting heart rate, SBP,
320 DBP, MAP and RPP ($p > 0.05$) (Table 3).

321 **Active Physical Function and Performance**

322 TUG, OLS, absolute lower back strength, and relative lower back muscle quality
323 significantly improved following the caddying season ($p < 0.05$). No significant differences
324 were observed for all other active physical function and performance measures ($p > 0.05$) (Table
325 3-4).

326 **Associations between Caddying Rounds and Physical Health, Function and Performance**

327 Total caddying rounds throughout the 24-week caddying season were significantly associated
 328 with body mass ($r = -0.64$, $p = 0.03$), BMR (kj) ($r = -0.66$, $p = 0.03$), BMR (kcal) ($r = -0.66$,
 329 $p = 0.03$), metabolic age ($r = -0.70$, $p = 0.02$), BMI ($r = -0.63$, $p = 0.04$), degree of obesity ($r = -0.63$,
 330 $p = 0.04$), absolute muscle thickness ($r = -0.60$, $p = 0.049$), HDL ($r = 0.80$, $p = 0.01$) and LDL/HDL
 331 ($r = -0.83$, $p = 0.42$). No significant associations ($p > 0.05$) were observed between caddying
 332 rounds and all other variables.

333

334 **Table 1.** Device-measured daily physical activity (PA), sedentary time, and step count of
 335 participants prior to the caddying season commencing (pre-season) and at the mid-season of
 336 the caddying season.

	Pre-Season	Mid-Season	p-value	Effect size
Sedentary (min)	437 ± 54	265 ± 22	<0.001	3.20
Light-intensity PA (min)	298 ± 53	443 ± 34	<0.001	2.59
Moderate-intensity PA (min)	96 ± 43	167 ± 29	0.001	1.79
Vigorous-intensity PA (min)	1 ± 1	3 ± 3	0.09	0.66
MVPA (min)	97 ± 44	170 ± 31	<0.001	1.84
Total PA (min)	395 ± 46	613 ± 45	<0.001	3.44
Steps (n)	12703 ± 3703	23707 ± 3148	<0.001	2.40

337 Data presented as mean ± SD (n=8). Bold values indicate statistical significance. Significance
 338 granted at $p < 0.05$. PA- physical activity; MVPA- moderate-to-vigorous physical activity.

339

340

341

342

343

344 **Table 2.** Body composition of the study participants.

Measurements	Pre-Season	Post-Season	p-value	Effect size
Height (cm)	176.5 ± 3.7	176.5 ± 3.8	0.828	0.07
Body Mass (kg)	86.5 ± 11.9	83.8 ± 11.9	<0.001	1.45
Body Mass Index (kg·m ²)	27.7 ± 3.0	26.8 ± 3.2	<0.001	1.74
Fat Percentage (%)	27.0 ± 5.7	25.6 ± 6.0	0.009	0.94
Fat Mass (kg)	23.9 ± 8.3	22.0 ± 8.2	0.005	1.03
Fat Free Mass (kg)	62.6 ± 4.6	61.9 ± 5.0	0.006	1.02
Muscle Mass (kg)	59.5 ± 4.4	58.8 ± 4.7	0.005	1.03
Fat-to-Muscle Ratio	0.40 ± 0.12	0.37 ± 0.12	0.011	0.90
Total Body Water (kg)	43.4 ± 3.8	42.6 ± 4.0	<0.001	1.78
Total Body Water (%)	50.5 ± 3.1	51.2 ± 3.2	0.02	0.77
Bone Mass (kg)	3.1 ± 0.2	3.1 ± 0.2	0.19	0.41
Basal Metabolic Rate (kj)	7651 ± 653	7529 ± 691	<0.001	1.42
Basal Metabolic Rate (kcal)	1829 ± 156	1799 ± 165	<0.001	1.42
Metabolic Age (years)	59 ± 11	56 ± 12	0.08	0.57
Degree of Obesity (%)	25.9 ± 13.8	21.9 ± 14.3	<0.001	1.74
Muscle Thickness (cm)	3.8 ± 0.5	3.4 ± 0.6	0.037	0.70
Muscle Thickness (cm/kg)	0.04 ± 0.01	0.04 ± 0.01	0.092	0.54
Thigh Subcutaneous Fat Thickness (cm)	0.7 ± 0.2	0.7 ± 0.2	0.313	0.31
Abdominal Subcutaneous Fat Thickness (cm) (n=8)	3.0 ± 0.4	2.8 ± 0.4	0.206	0.47

345 Data presented as mean ± SD (n=11). Bold values indicate statistical significance. Significance
346 granted at p<0.05.

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353 **Table 3.** Blood lipids, blood pressure, heart rate and sub-maximal cardiorespiratory fitness of
 354 the study participants.

Measurements	Pre-Season	Post-Season	p-value	Effect size
TC (mmol·L ⁻¹)	5.63 ± 1.02	5.03 ± 0.77	0.02	0.82
HDL (mmol·L ⁻¹)	1.11 ± 0.23	1.25 ± 0.33	0.03	0.77
TRG (mmol·L ⁻¹)	1.56 ± 1.11	1.12 ± 0.69	0.21 ^a	0.36
LDL (mmol·L ⁻¹) (n=8)	3.97 ± 0.96	3.36 ± 0.66	0.02^a	0.98
Non-HDL (mmol·L ⁻¹) (n=6)	4.51 ± 1.05	3.55 ± 0.68	0.02	1.37
LDL/HDL (n=8)	3.80 ± 0.79	2.86 ± 0.85	0.004	1.42
Glucose (mmol·L ⁻¹)	5.42 ± 2.10	5.48 ± 1.20	0.58 ^a	0.52
CHD Risk (%)	14.0 ± 6.1	10.7 ± 5.1	0.03^a	0.85
Systolic blood pressure (mmHg)	147 ± 22	144 ± 20	0.38	0.28
Diastolic blood pressure (mmHg)	93 ± 16	89 ± 15	0.10	0.57
Mean arterial pressure (mmHg)	111 ± 18	107 ± 16	0.18	0.44
Resting heart rate (beats·min ⁻¹)	64 ± 12	58 ± 6	0.17	0.46
Rate pressure product (beats·min ⁻¹ mmHg)	9321 ± 2176	8413 ± 1600	0.15	0.48
Absolute $\dot{V}O_{2max}$ (L·min ⁻¹)	3.4 ± 0.3	3.5 ± 0.4	0.41	0.21
Relative $\dot{V}O_{2max}$ (mL·kg ⁻¹ ·min ⁻¹)	40.2 ± 4.2	42.1 ± 4.9	0.07	0.61

355 Data presented as mean ± SD (n=10). Bold values indicate statistical significance. Significance
 356 granted at p<0.05. ^a Non-normally distributed analysis. TC- total cholesterol; HDL- high-
 357 density lipoprotein cholesterol; TRG- triglycerides; LDL- low-density lipoprotein cholesterol;
 358 CHD- coronary heart disease; $\dot{V}O_{2max}$ - maximal oxygen uptake.

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366 **Table 4.** Physical function and performance measures of the study participants.

Measurements	Pre-Season	Post-Season	p-value	Effect size
TUG (s)	10.7 ± 1.0	8.9 ± 0.9	< 0.001	1.74
BBS	53 ± 2	54 ± 2	0.07 ^a	0.60
One Leg Stance (s)	27.5 ± 24.3	41.0 ± 16.0	0.03 ^a	0.77
Absolute Leg Strength (N)	266.1 ± 60.6	270.2 ± 39.6	0.67	0.13
Relative Leg Muscle Quality (N/kg)	4.5 ± 0.9	4.6 ± 0.7	0.43	0.25
Absolute Lower Back Strength (N)	945.0 ± 204.9	1057.8 ± 210.1	< 0.01	2.03
Relative Lower Back Muscle Quality (N/kg)	15.9 ± 2.8	17.9 ± 2.6	< 0.01	2.58

367 Data presented as mean ± SD (n=11). Bold values indicate statistical significance.

368 Significance granted at p<0.05. ^a Non-normally distributed analysis. TUG- timed up-and-go

369 test; BBS- Berg Balance Scale Test

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Health benefits of physical activity via caddying

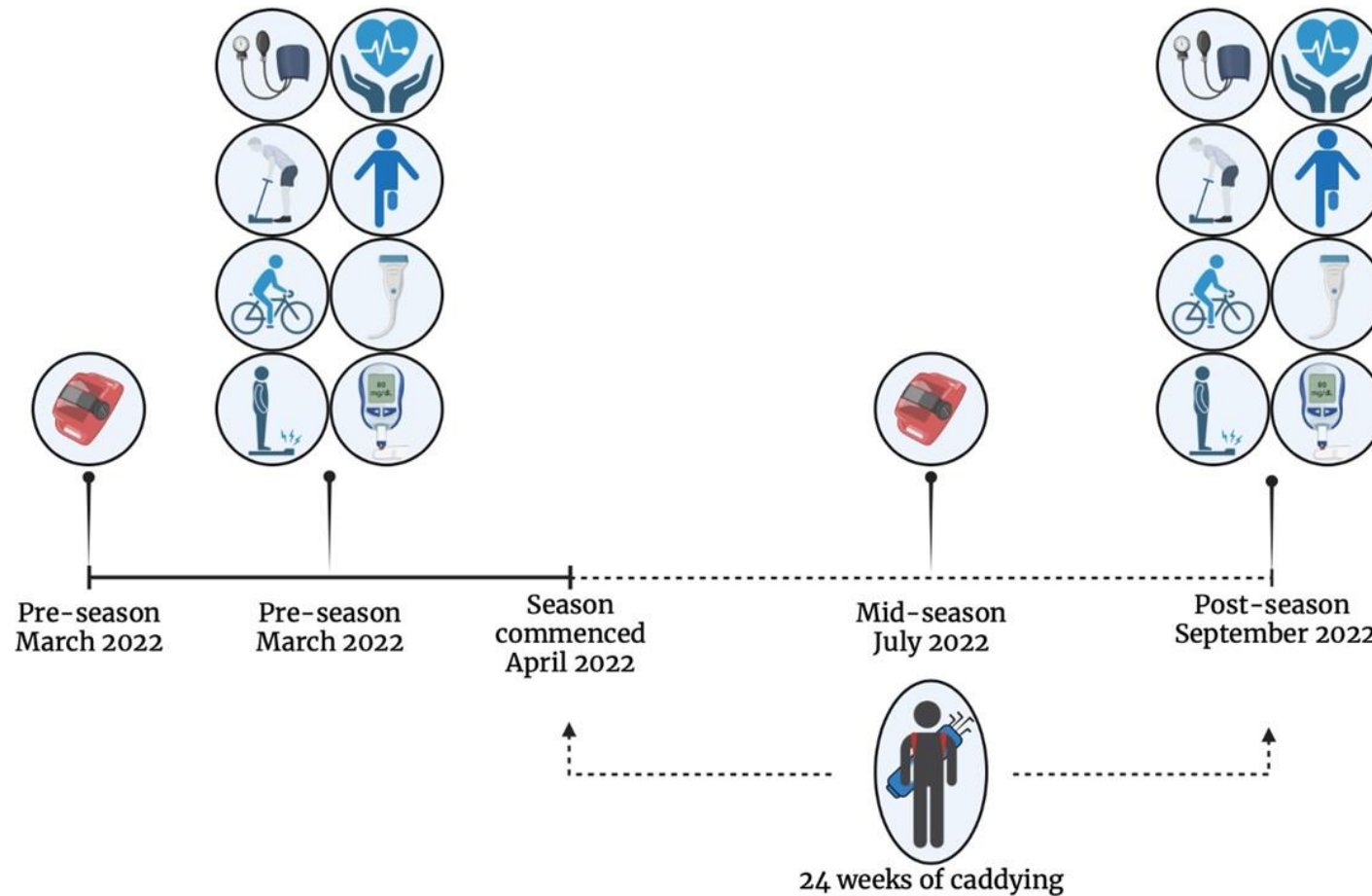


Figure 1. Schematic overview of the study protocol. Accelerometry data were collected before (March) the 24-week caddying season (April-September) commenced and then again mid-season (July). Outcome variables related to domains of body composition, cardiovascular, metabolic, and musculoskeletal health were collected pre- (March) and post-season (September).

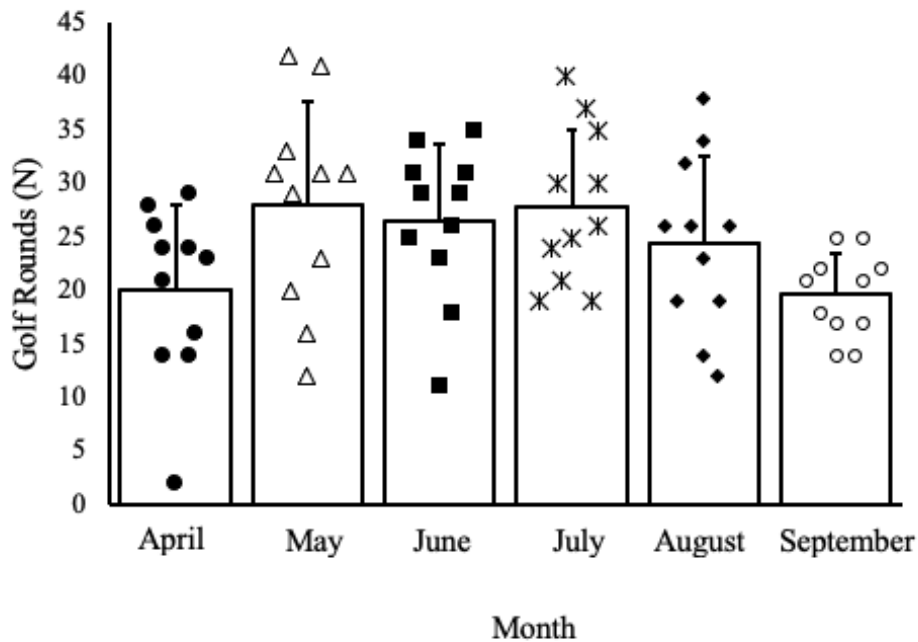


Figure 2: Number of golf rounds completed by the caddies throughout the duration of the study (April – September 2022) from 18-hole rounds. Data presented as mean \pm SD with individual data overlaid (n=11).

Discussion

The aim of the study was to assess the impact of 24-weeks of golf caddying on markers of physical health in middle-older age caddies. The principal findings were that: (1) statistically significant improvements in multiple markers of cardiovascular and musculoskeletal health including: body mass, BMI, fat mass, TC, CHD risk score, balance, and absolute lower back strength and muscle quality were observed following the caddying season; 2) no statistically significant changes were observed in absolute leg strength and muscle quality, heart rate, blood pressure, or cardiorespiratory fitness following the caddying period.

The influence of caddying on cardiometabolic markers

In our study, following the caddying season global improvements were noted for markers of body composition, such as body mass, fat mass, fat percentage, fat-to-muscle ratio, BMI, and degree of obesity. BMI findings agree with a 20-week golf training study,⁵² yet disagree with a 12-month observational study in caddies.⁸ We studied caddies during the summer period of 6-months, while 12-months may have included periods of fluctuating frequencies in caddying. Previous studies have shown seasonal variation in PA in golfers,⁵³ therefore, during the winter months when PA is typically lower, it is not clear whether the improvements in body composition extend to the off-season for caddies. Moreover, in our study, the caddies performed on average more rounds (24.0 ± 3.8) and steps (23707 ± 3148) per month over the 24-weeks compared to Goto et al.⁸ (18.2 ± 2.9 rounds, and 17970 ± 3434 steps, respectively), which may explain the differing study findings. Additionally, the total number of rounds within a condensed 6-month period was inversely associated with body mass, BMI, and degree of obesity in our study. This may suggest caddying, and by extension, PA volume is important for facilitating reductions in body mass. The overall reduction in fat mass exceeded the loss of whole-body muscle mass, reflecting improved (i.e., decreased) fat-to-muscle ratio. Previous research shows fat-to-muscle ratio is significantly associated with metabolic syndrome, hypertension, prediabetes, and type 2 diabetes,⁵⁴ with a lower fat-to-muscle ratio decreasing the risk of metabolic syndrome.²⁶ Together, these observations suggest that in a group of older males who are already active, additional benefits can be achieved by augmenting PA volumes. However, more research is needed to establish the effects on other measures that are associated with the metabolic syndrome, such as insulin resistance. Furthermore, our findings imply that caddying may improve body composition and aid muscular performance and balance. Therefore, collectively these benefits could reduce the likelihood of ‘sarcopenic obesity’, which has been associated with worsening physical function⁵⁵ in an ageing cohort of men.

Favourable improvements in blood lipid profile were found, including reduced TC and LDL, and increased HDL. Acute physiological responses following low intensity, high-volume golf have demonstrated improved lipid profiles compared to lower volume Nordic walking and walking.⁵⁶ These findings support observations in this study, and may provide some explanation for our chronic adaptations. These findings also agree with improved HDL following golf training of varying durations (1-20 weeks),^{52,57} yet we extend these previous findings by showing improved lipid profiles are also possible in caddies, after 24-weeks. Moreover, improved HDL would have contributed to the reduction in 10-year CHD Framingham risk score, since HDL is inversely associated with CHD.⁵⁸ Such changes are of clinical importance since 25% of all mortalities in the UK are caused by heart and circulatory disease.⁵⁹ Indeed, we observed a reduction of 3.3 percent points in CHD risk score, which reflects an improvement given the association between CHD and mortality.⁵⁹ Although these improvements are positive, the Framingham risk score may over-estimate CHD⁶⁰ and risk fluctuates throughout the year, therefore, this must be considered when interpreting our findings.⁶¹ While our caddies walked the course, it is not known whether the golf bags were carried predominantly with a single or double strap. Golf bag carrying method has been shown to alter the acute metabolic cost of walking with a 12.5 kg bag in golfers,⁶² with greater demand from single strap load carriage. This may be important for determining the repetitive acute physiological responses and thus, chronic cardiometabolic adaptations over a sustained period of caddying and warrants further study.

The influence of caddying on balance and musculoskeletal properties

Improvements were observed in the TUG and OLS tasks, which together suggests that caddying imparts a positive influence on dynamic and static balance. Although no changes were observed in the BBS test, a ceiling effect may have been present with the caddie group

being categorised within the good balance category at pre-season [41-56],^{34,35} and considered an independent group who are able to walk without an aid [≥ 49 -56].⁶³ The positive findings regarding dynamic and static balance may be due to increased total volume of PA, including the amount of moderate-intensity PA, as well as continuous walking on uneven ground on the golf course, with an asymmetric load. Similarly, previous research demonstrated positive changes in dynamic balance following PA training programmes, which included walking,^{64,65} and golf training.⁶⁶ Specifically, Du Bois et al.⁶⁶ reported a 13.3% improvement in the TUG test following a 12-week golf training programme, which included progressive golf play. These findings corroborate the 16.8% improvement reported within the current study, following 24 weeks of caddying. Furthermore, at pre-season, the TUG test score (10.7 seconds) was comparable to the sarcopenia predictor cut-off point of 10.85 seconds,⁶⁷ which improved to 8.9 seconds after the caddying season. Since the TUG test represents a measure of physical function,⁶⁸ an improvement of 1.8 seconds is indicative of superior functional ability in our group of middle-older age men following caddying. These findings are of practical importance since older adults suffer the most falls that lead to mortality,⁶⁹ and the TUG test is an important predictor of falls in seniors.⁷⁰ The improvements in dynamic and static balance, may provide support for encouragement to participate in activities to improve balance, which could contribute towards achieving UK PA guidelines for improved physical function.⁷¹ However, our experienced caddies were physically capable of the high volume PA, whilst carrying golf bags, and more research is needed to determine whether smaller dosages of activity in those with compromised balance and physical capacities elicit similar adaptations. These results regarding balance are of significant clinical relevance since falls are the second leading cause of unintentional mortality,⁶⁹ and are suggested to contribute to rapid deteriorations in overall health, requiring frequent care.⁷² The financial burden of fragility fractures is estimated to be

an annual £4.4 billion in the UK National Health Service (NHS).⁷³ It is likely that these improvements in balance are reflective of the muscular strengthening and balance enhancing PA that caddying provides, which we recently reported during isolated rounds,⁶ alongside the improved absolute back strength and muscle quality observed in the current study.

Augmented back strength following 24-weeks of caddying may be a result of the continual lifting and carrying of golf bags during repetitive rounds, which we observed to weigh on average 12 kg.⁶ This is of particular importance since back muscle strength and quality of life are positively associated in older adults,⁷⁴ and with the former a contributor to the Geriatric Locomotive Function scale, a measure of locomotive syndrome.⁷⁵ While absolute lower back strength improved following the caddying season, absolute leg strength remained unchanged, which contrasts the improvements noted by Goto et al.⁸ after 12-months of caddying. Methodological differences in strength tests used may be explanatory, with Goto et al.⁸ utilising a leg press test, which requires substantial gluteal muscle activation.⁷⁶ Moreover, we noted improved lower back muscle quality, albeit calculated based on whole body muscle mass. Indeed, muscle quality is an indicator of muscle function in the elderly⁷⁷ and may be used as a supplementary tool for the assessment of functional decline in association with sarcopenia.⁷⁸ Within the current study, absolute muscle thickness reduced, which contrasts with cross-sectional work reporting larger muscle thickness in elderly female golfers compared to non-golfers.³² However, it must be noted that Herrick et al.³² recruited golfers who were significantly younger than non-golfers, which may have contributed to their greater muscle thickness. Without a control group in this study, it is difficult to draw a direct comparison, however, since we employed a longitudinal design, it is important to interpret the changes in muscle thickness within the context of reduced body mass after caddying. Relative muscle thickness did not significantly change from pre-season to post-season. This suggest caddying

was neither advantageous nor deleterious for leg muscle thickness relative to body mass, however, further investigation is needed with an age-matched control group and longitudinal observation.

The influence of caddying on cardiovascular parameters and cardiorespiratory fitness

Caddying did not offer beneficial statistically significant changes to cardiovascular (heart rate and blood pressure) variables or cardiorespiratory fitness. Our observations contrast the reduced SBP and DBP following one-week of golf,⁷⁹ however, these participants were on vacation as opposed to our caddies, where it is their occupation. Moreover, Parkkari et al.⁵² found through a longer golf training study (20-weeks) that those with the highest blood pressure reduced DBP by 3 mmHg. Since our group of older men represented a hypertensive cohort,^{80,81} it is unexpected that blood pressure did not reduce, as others have also shown hypertensives yield the greatest exercise-induced reductions in SBP.⁵² We noted increased time in MVPA, but not vigorous-intensity PA which may be of importance to the lack of changes, since others have shown reduced SBP following 6-weeks of high-intensity interval training in ageing men.⁸² Likewise, Molmen et al.⁸³ observed 12% reductions in SBP following 12-weeks of aerobic interval training in older men with similar baseline blood pressure (145 ± 17 mmHg) to our group (147 ± 22 mmHg), therefore, exercise intensity may be an important factor. External factors beyond PA intensity could also have contributed to a maintenance of blood pressure, such as diet, sleep quality, and alcohol intake,^{84,85} which are known to influence blood pressure but were not assessed in this study.

Cardiorespiratory fitness ($\dot{V}O_{2\max}$) did not change after caddying, which aligns with other longitudinal work in golfers.⁵² It is likely that the exercise stimulus was not sufficient to induce central or peripheral adaptations, therefore maintaining absolute $\dot{V}O_{2\max}$. Maintained $\dot{V}O_{2\max}$ could be due to CRF (3.4 ± 0.3 L.min⁻¹) in our middle-older aged caddies (59 ± 8

years) pre-season being directly comparable to age-related normative values reported in the HUNT study (50-59 years, 3.7 L.min⁻¹; 60-69 years, 3.3 L.min⁻¹).⁸⁶ Therefore, a stronger exercise stimulus may be required during caddying to further improve CRF to surpass the age-predicted estimates. Moreover, we observed a trend towards greater relative $\dot{V}O_{2max}$, therefore, a larger cohort may produce statistically significant results. Still, this change likely reflects reduced body mass as opposed to improved absolute CRF. Nevertheless, these findings do indicate that physical health improvements are possible without the necessity for altered CRF through low and moderate intensity, high volume PA.

Practical Implications

Using an interdisciplinary approach, the findings from this study can be applied to the golf caddying community and generalised to the ageing population. The number of individuals >60 years of age is continually increasing,⁸⁷ which presents a key challenge to implement non-pharmacological strategies to promote healthy ageing, and well-being in older age through the maintenance and augmentation of functional ability.² Our cohort of men represent a middle-older age group (59 ± 8 years),^{12,14,15} and we report the benefits that caddying may offer as a model for increasing PA through walking, while achieving the UK PA aerobic activity guidelines⁷¹ through caddying. While caddying may involve some technical requirements, such as offering advice and determining yardage, the role also involves non-technical/sport specific knowledge such as carrying golf bags,^{5,88} which has been reported to be approximately 12 kg.^{6,7} Therefore, caddying represents an activity capable of eliciting a high volume of PA through occupational walking,⁶ which general populations may participate in. It is feasible to suggest that opportunities to increase high volume PA through caddying may grow in future years due to the continuing rise in golf participation following the COVID-19 pandemic.⁸⁹ Nevertheless, golf bag carriage style can influence the biomechanical demands of the lower extremity,⁹⁰

which must be considered before undertaking the role of a golf caddie. While we did not investigate caddie-related injuries beyond those that prevented participants from caddying, previous cross-sectional research has demonstrated that golf caddies reported higher prevalence of musculoskeletal pain compared to non-caddies;¹¹ Therefore, inactive individuals wishing to enhance their PA through a model of high volume exercise, which may include increased walking volumes and/or carrying a heavy load, should take caution to prevent injury occurrence. Nevertheless, walking has been shown through meta-analyses to provide a wide range of positive health outcomes.⁹¹ Through findings that high volume activity, including the carrying of weight, provides physical health benefits, this knowledge may be extrapolated to those beyond golfing communities. We observed improvements in experienced caddies with relatively high PA, and normative aerobic capacity before the 24-weeks. This is promising for those who are already active to still gain physical health improvements, but also for sedentary individuals, since the largest cardiovascular benefits are seen in those with the lowest initial activity.⁹²

Limitations and Future Directions

The current study provides valuable insights in the physical health of golf caddying; however, some limitations warrant consideration. Whilst positive findings were reported in relation to body composition, it should be noted that these measures were estimated using Tanita bioelectrical impedance analysis. In terms of body composition measurements, techniques such as dual-energy X-ray absorptiometry (DXA) and magnetic resonance imaging (MRI) have greater accuracy.⁹³ Previous research has, however, demonstrated that using Tanita bioelectrical impedance analysis is valid when measuring variables such as body fat %.⁹⁴ Additionally, Tanita provides good absolute (no significant difference in mean scores) and

relative ($r^2 = 0.44$, $p < 0.001$) agreement with DXA scans for body mass % when testing overweight and obese men.⁹⁵ Moreover, we indirectly estimated $\dot{V}O_{2\max}$, which may have reduced the sensitivity for detecting change, however, this approach was taken due to the constraints of field-based testing. Furthermore, static balance was assessed using the total standing duration during the OLS task. To detect sensitive changes in balance, centre of pressure measures via a force platform may be more advantageous.⁹⁶

We used an observational study design without a control group to explore the impact that a 24-week season of golf caddying had on the physical health in a small sample of experienced male golf caddies (14 ± 12 years of caddying (range: 3–41 years)). Although we only included 11 participants, post hoc power calculations suggested an achieved power of 64% (TC) and 100% (TUG and BMI) for key variables of interest. Nevertheless, future work is also needed in larger samples and in varying populations such as, females and different age groups. To determine whether any lack of change was potentially due to a high pre-season PA, and by extension physical health qualities in the caddies, future studies may wish to include a matched control group. While we studied trained caddies, future research would benefit from a randomised controlled trial to determine the influence of the physical demands of caddying in those without previous exposure to caddying. Additionally, the current study assessed golf caddying during the standard golf season in the UK; however, golf seasons may differ between courses both within the UK and other countries. Additionally, research is needed to replicate this study using different golf course profiles, which may elicit higher PA demands and intensities through caddying in middle-older age.⁹⁷ In turn, caddies working on the professional tour who caddie at different courses throughout the season may be affected differently than those regularly working at the same golf course, in terms of PA volumes, intensities and potentially the resultant impact on PA health markers.

Conclusion

Golf caddying provided several physical health benefits in middle-older age caddies following a 24-week season. Improvements were noted in balance, body composition, lower back strength and muscle quality, and blood lipid profile, while cardiorespiratory fitness, leg strength and muscle quality, muscle thickness, and blood pressure were maintained. The physical health improvements occurred concomitantly with elevated levels of PA volume and intensity, which may suggest that caddying provides a useful high-volume model for concomitant PA and health related improvements. Still, future studies with larger samples of caddies and a matched control group are needed to establish causal inferences.

Declarations

Competing Interests: Graeme G. Sorbie, Ashley K. Williams, Sophie E. Carter, Amy K. Campbell, Jonathan Glen, David Lavalley, Nicholas Sculthorpe, Alexander J. Beaumont declare that they have no competing interests. Andrew Murray is a consultant to The R&A (a global governing body for golf).

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Authors' contributions: GS, AW, JG, AB were involved in the data collection process. SC analysed the accelerometry data. AC analysed the muscle thickness data. GS and AB analysed all other data and interpreted the data. GS and AB were major contributors in writing the manuscript. All authors read and approved the final manuscript.

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