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Validity of the Fitbit Ace and Moki devices for assessing steps during different walking conditions in young adolescents

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1 Original Article

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3 Title: Validity of the Fitbit Ace and Moki devices for assessing steps during different walking
4 conditions in young adolescents

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26 **Abstract**

27 **Purpose:** Using wearable monitoring devices is increasingly ubiquitous, including amongst
28 young people. However, there is limited evidence on the validity of devices which are aimed
29 at children and adolescents. The purpose of this study was to evaluate the validity of Fitbit
30 Ace and Moki monitors in healthy young people.

31
32 **Methods:** This cross-sectional study included 17 young adolescents (ages 11–13 years)
33 ambulating between three different walking conditions (incidental (~6 minutes), controlled
34 and treadmill (each 3 minutes), whilst wearing wrist-worn devices (Fitbit Ace, Moki) on each
35 wrist (left and right, respectively). Data from the devices were compared with observer
36 counts (criterion). Bland-Altman plots and mean absolute percent errors (MAPEs) were
37 computed.

38
39 **Results:** Analyses identified that the Fitbit Ace showed higher levels of bias across
40 conditions compared to the Moki device: (mean difference \pm SD Fitbit Ace, 30.0 \pm 38.0,
41 3.0 \pm 13.0, 13.0 \pm 23.0 steps; Moki, 1.0 \pm 19.0, 4.0 \pm 16.0, 6.0 \pm 14.0 steps, incidental, controlled,
42 and treadmill, respectively). MAPEs ranged from 3.1-9.5% for the Fitbit Ace and 3.0-4.0%
43 for the Moki device.

44
45 **Conclusion:** The Fitbit Ace and Moki devices might not provide acceptable validity under all
46 walking conditions, but the Moki provides more accurate estimates of incidental walking and
47 might therefore be a good choice for free-living research or school-based interventions.

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52 **Introduction**

53 Leading a physically active lifestyle leads to a number of physical and mental health benefits,

54 and prevents a range of non-communicable diseases in both childhood and adulthood (27).

55 Not all children and adolescents however achieve physical activity (PA) guidelines, and

56 physical inactivity of youth and adolescents is a global challenge (1). Interventions to

57 increase PA in children and adolescents are therefore a public health priority.

58

59 Walking is one of the oldest and simplest forms of physical activity (31), and is often referred

60 to as ‘the activity closest to perfection’ (26). Encouraging people to walk is significant to

61 public health because it represents an accessible, affordable, and familiar form of PA (17).

62 There is growing evidence that walking and pedometer based interventions can be effective

63 for children and adolescents to increase PA, especially in the school environment, and thus

64 the encouragement of walking may lead to an increase in PA in children and adolescents (8,

65 9, 19, 20).

66

67 The opportunity to direct PA interventions to walking behaviour has more recently been

68 enhanced via the rapid development and access to consumer-based activity monitors. Whilst

69 some monitors purport to measure a range of behaviours, the most common function is step

70 counting. Often referred to as ‘wearables’ or ‘wearable activity trackers’, these devices can

71 be used by consumers to track personal PA behaviour, and have been used in clinical studies

72 with adults and children (2). Devices, such as the Fitbit Zip for example, are small, long-

73 lasting and convenient for consumers and researchers alike, and the data is typically easy to

74 transfer to a computer for processing (25).

75

76 As people are paying more attention to self-quantification of health parameters and these
77 devices are being adopted for research purposes, both as intervention tools and for the
78 assessment of behaviour, there is an inherent need for confirming the accuracy of
79 commercially available activity trackers (22).

80

81 Among dozens of brands in wearable activity monitors available on the market, Fitbit is
82 among the most commonly purchased options (10, 11). The features of Fitbit activity devices,
83 including their validity and reliability, have been investigated in a number of empirical
84 studies with adults (11, 18). Findings generally suggest that with adults Fitbit devices
85 demonstrate an overall tendency to underestimate steps during controlled testing conditions
86 but may provide accurate step counts (within $\pm 3\%$) approximately 50% of the time (11).

87

88 There is comparatively less evidence regarding the validity of these devices when worn by
89 children and adolescents. So far there have been studies assessing, for example, the validity
90 of Fitbit Flex (7), Fitbit One (15), Fitbit Zip (25, 28) and Fitbit Charge (30). The research
91 findings have been mixed, generally suggesting that Fitbits may overestimate (15, 25, 30)
92 rather than underestimate (28) step counts. Unlike previously mentioned devices, the recent
93 Fitbit Ace (and now the Fitbit Ace 2 and 3) has been marketed for children and adolescents
94 but, to the best of our knowledge, its validity has not yet been explored.

95

96 Whilst Fitbit has had the market share of wearables (11), other devices are available, as are
97 devices designed specifically for use in school based interventions and surveillance, and
98 those that are arguably more affordable (the Fitbit Ace 3 is currently on the market in the UK
99 for £69.99 (12)). Moki is a new activity-tracking wristband monitor and software
100 application, aimed at providing a safe, simple and fun way for schools to support an active

101 curriculum for their students, and currently priced at £132+VAT for 4 bands and a reader
102 (24). The monitoring device can send users' step data to a computer and generate walking
103 reports and analysis using software installed on a PC. Moki is being used in more than 250
104 Schools and with 7000 pupils in the UK, Europe and Canada (Moki, personal
105 communication, Sept 2020). To the best of our knowledge, there has been no prior empirical
106 research exploring the validity of this consumer-based activity monitor.

107

108 One of the challenges of assessing validity of wearable devices is ensuring ecological validity
109 (5, 6). Assessing validity of devices during controlled treadmill walking is a commonly
110 adopted approach (14, 23) , primarily as the treadmill is able to regulate walking speed.
111 However, treadmill walking overestimates the energy cost of walking over ground in
112 adolescents (21), and is a poor proxy for incidental ambulatory activity (e.g., unstructured
113 play and stair climbing). Device validation in trials that replicate free-living conditions is
114 paramount (5).

115

116 Therefore, the aim of the current study was to assess the validity of the Fitbit Ace and Moki
117 devices in a population of healthy young adolescents under three different walking
118 conditions.

119 **Methods and Procedures**

120 *Study design*

121 This study assessed the validity of Fitbit Ace (Fitbit Inc, San Francisco, CA, USA)
122 and Moki (Moki Technology Ltd, UK) consumer-based PA monitors for young people, under
123 the following three walking conditions: incidental walking, controlled walking, and treadmill
124 walking. All testing was completed in a single high school in the Summer of 2019.

125

126 ***Participants***

127 Participants were recruited from a high school located in Edinburgh, Scotland, using a
128 purposive sampling method. **Participants** were eligible to be included if they were: (a) 11–13
129 years old; (b) no chronic diseases; (c) able to walk without an assistive tool, and (d) able to
130 undertake moderate and vigorous PA. Eighteen students volunteered to take part in the study,
131 of which one participant decided not to complete the data collection process.

132 Approval for the study was granted by the institutional research ethics committee and the
133 local School authority. Participation was dependent upon informed consent being granted by
134 participants and their parents.

135

136 ***Materials***

137 Fitbit Ace (version 1) is an accelerometer, designed for youth ages six and above, that
138 estimates step count, distance travelled, active minutes and sleep time. The weight of the
139 wrist-worn accelerometer is 8gs. Steps are measured via microelectromechanical tri-axial
140 accelerometer and proprietary algorithms. The data from the device are wirelessly uploaded
141 to the software via Bluetooth.

142

143 Moki is an activity-tracking wristband and software application designed with the aim of
144 enabling schools or groups to support an active curriculum for their students or members. It
145 consists of two parts – a band and a reader. The Moki band comprises an accelerometer and
146 battery housed inside a moulded wristband. The contactless (near-field communication)
147 technology contained in the device means that the activity data is transferred to the app by
148 tapping it on the Moki Reader. The Moki Reader (60 x 11 x 110mm) is then connected to a
149 Windows desktop or laptop via a USB cable to allow transfer of data from the Moki bands to
150 the Moki application.

151

152 ***Procedure***

153 ***Pilot.*** To optimise validity of the criterion outcome (observer counts), pilot trials were
154 conducted to familiarise the researchers with the counting procedure. A volunteer was
155 recruited to walk a defined route, during which one researcher followed the volunteer and
156 counted the number of steps taken. The walking (legs and feet only) was also video-recorded
157 (iPhone 8 and a tripod). A second researcher counted the steps from the video recording. The
158 results from the two researchers were compared and the tests were extensively practised until
159 the difference was lower than two steps. Both devices (Fitbit Ace, Moki) were tested to
160 assess time delays between walking activity and steps registering. A 60-second delay was
161 concluded to be necessary to confirm accurate registration of steps taken.

162

163 ***Experimental Conditions.*** Participants attended the testing session in pairs. Each participant
164 completed all three conditions sequentially before the other participant began their trial. The
165 Fitbit Ace was always fitted to participants left wrist, and the Moki to participants right
166 wrist.

167

168 ***Condition 1: Incidental walking.***

169 The participants were first shown the walking route, which included a corridor and two
170 flights of stairs, and took approximately 4 minutes to complete including a short seated
171 period. Once a participant was ready to start the test, the Fitbit Ace was attached to their left
172 wrist and the Moki to their right wrist. The participant was then required to stand still for one
173 minute to collect and record the current number of steps displayed by each band. Next, the
174 participant was asked to follow the walking route. Two researchers followed the participant
175 moving at a normal walking speed and counted their steps, with one researcher holding a

176 stopwatch to record the time. The participant walked down the corridor and up two floors,
177 then sat still for a period of at least 60 seconds before returning. After returning to the start,
178 the participant was asked to stand still for one minute, with their arms naturally dropping to
179 the sides of their body. The researchers then collected the step-count data displayed by the
180 two bands and recorded the counted steps. A mean of the steps counted by the two
181 researchers was considered the criterion.

182

183 ***Condition 2: 3 minute controlled walking***

184 Each participant was led to a square walking path, which was arranged in an empty dance
185 room, with a level floor and no obstacles. The devices were fitted following the same
186 protocol as in Condition 1. On the researcher's signal, the participant was asked to walk
187 around the square course for three minutes. One researcher counted the steps, while the other
188 researcher controlled the camera and tripod to record the walking. The camera was set up to
189 only record the participants' legs and feet from below the knees. At three minutes, the
190 participant was asked to stop walking at once and stand for one minute so the number of steps
191 counted by each band could be recorded. A mean of the steps counted in real time and by the
192 video recording was considered the criterion.

193

194 ***Condition 3: 3 minute treadmill walking.***

195 Following treadmill familiarisation, the participant was asked to straddle the moving
196 treadmill while the devices were prepared as they were in the previous conditions. The
197 participant was then asked to walk on the treadmill at a speed of 1.2 km/h for three minutes.
198 Their steps were also recorded by camera, as above. At three minutes, the participant
199 immediately straddled the treadmill and stood still for one minute, and the step-count data

200 were recorded. As before, a mean of the observer counts and the video recording was
201 considered the criterion.

202

203 ***Data analysis***

204 Analyses were undertaken in Excel (Version 16.37). Descriptive statistics were presented as
205 means \pm standard deviations. The Bland-Altman approach was used to investigate the
206 agreement between measurements (device and criterion; 4, 13). Mean percent errors (MPEs)
207 and mean absolute percent errors (MAPEs) were calculated for each condition in order to
208 enable comparison between the devices and explore overall measurement error. Smaller
209 MAPEs were interpreted as representing better accuracy, with a value of less than 3% as the
210 acceptable level of accuracy (3, 16).

211

212 **Results**

213 The final sample included 17 young adolescents (59% girls; 12.97 ± 0.28 years of age). Table
214 1 presents the descriptive statistics (mean \pm SD), levels of agreement and MAPE for each
215 device and walking condition.

216

217 The MAPE values in Table 1 demonstrate the error rates for Fitbit Ace and Moki devices
218 across the three walking conditions. Neither device under or overcounted participant's steps
219 by more than 10%. The Fitbit device consistently undercounted across conditions. The
220 greatest difference between criterion and the Fitbit Ace and Moki devices was in the
221 incidental walking condition (9.5% and 4.0%, respectively), both of which were greater than
222 the 3% level of acceptable accuracy. The Fitbit Ace controlled condition and the Moki
223 treadmill condition were both 3.1 and 3.0% respectively.

224

225

[Table 1 here – see page 19]

226

227 Bland-Altman plots comparing the criterion with Fitbit Ace and Moki are provided in Figure

228 1. Analyses demonstrated the incidental and treadmill walking conditions of the Fitbit Ace

229 showed the greatest bias (30.0 ± 38 and 13.0 ± 23.0 , respectively). The Fitbit Ace had the

230 widest 95% limits of agreement (-104.1, 44.1, incidental walking).

231

232

[Insert Figure 1 here]

Discussion

233 The aim of the current study was to assess the validity of the Fitbit Ace and Moki devices in

234 young people. This is the first study to examine the validity of these specific consumer-based

235 activity devices in this population and under different walking conditions (incidental,

236 controlled and treadmill walking). Our results indicate that both devices may provide a valid

237 measure of step counts in young adolescents aged 11-13 years in some conditions. Findings

238 also suggest there may be a tendency for the FitBit Ace to undercount during specific PA

239 conditions. In particular this may be the case with incidental walking conditions and treadmill

240 walking (see Table 1 & Figure 1).

241

242 Our findings indicated that the Fitbit Ace had greater bias and wider limits of agreement

243 compared to Moki, whilst the majority of all data fell within the 95% limits of agreement,

244 which is consistent with previous studies in children (28). As this is the first study to evaluate

245 the validity of the Moki device it is not yet possible to compare current findings with

246 previous studies. It is interesting to note, however, that the Moki device may provide a more

247 valid estimate of step count under certain types of PA (i.e., incidental and treadmill walking)

248 compared to the Fitbit Ace. In the main, the Moki device appears to undercount less than the

249 Fitbit Ace, and have very limited bias, although MAPE was marginally above 3% for both

250 incidental and controlled walking. In practical terms, if a young adolescent took 12,000 steps
251 in a day (29) the error may be in the region of 1140 steps for the Fitbit, rather than 480 steps
252 for the Moki. Thus the Moki device may be a preferable choice for intervention and research
253 studies, as well as school use. Difference in functionality and cost may also contribute to the
254 choice of device. For example, at present the Moki does not provide immediate step count
255 feedback on the device in the way that the Fitbit does, but needs to be used with the
256 classroom reader to provide step counts. The Moki is however considerably cheaper per unit.

257

258

259 We found that the Fitbit Ace consistently undercounted steps across conditions. This trend of
260 undercounting is consistent with Sharp et al. (28), who evaluated the validity of the Fitbit Zip
261 in a sample of preschool children during a 3-min walking task. Further, this is consistent with
262 the evidence from Fitbit studies with adults (11). In contrast, most previous studies with
263 children have shown Fitbit devices may overestimate step counts in this age group (15, 25,
264 30), regardless of whether they are hip (25) or wrist worn (30). Mooses et al. (25) reported
265 the Fitbit Zip (worn by 147 children for 5 school days, aged 9-10 years) had a tendency to
266 overestimate step counts throughout the day, particularly during physical education class.

267

268 To our knowledge, this is the first study with children or adolescents to validate the devices
269 under different walking states designed to simulate the walking patterns that this population
270 may display in everyday life. For example, the incidental walking condition simulated daily
271 living activities such as how children and adolescents walk around school, while the
272 controlled and treadmill conditions aimed to reflect daily exercise as well as laboratory
273 conditions. Whilst device validation trials during free-living are also needed with children
274 and adolescents (5), this type of protocol may make it challenging to delineate how a device

275 might perform during specific types of walking activity. For example, current findings
276 suggest the device may perform differently under the different conditions, and neither device
277 achieved 3% MAPE during incidental walking. To help address the associated challenges of
278 measuring ecological validity, further research with these walking conditions and in free-
279 living conditions is needed for these devices that have been purposely designed for young
280 people.

281

282 It is unclear why the Fitbit Ace under incidental walking condition showed the greatest bias,
283 error and limits of agreement in the current study. Extraneous factors such that effected arm
284 movement during normal ambulation may have impacted the step-count registered. In
285 contrast, the Moki device appears to have been less effected in this condition compared to the
286 Fitbit. Future replication studies are warranted to better understand the present results.

287

288 This study had a number of limitations. The study included a small sample of participants
289 (n=17) from one urban school thus replication is needed to generalise the findings to other
290 samples. The Fitbit Ace was always fitted to participants left wrist, and the Moki to
291 participants right wrist, with no adjustments for hand dominance despite this being an option
292 in the Fitbit setup. Whilst it is unlikely that during normal ambulation this will have effected
293 validity, future studies should counterbalance the placement of the devices on each wrist to
294 minimize potential confounders associated with dominant versus non-dominant wrists.

295 Finally, the current study examined the validity of the Fitbit Ace, which has now been
296 superceded by more recent models. The extent to which the validity of the first generation
297 Fitbit Ace represents the validity of subsequent models is not known.

298

299 **Conclusion**

300 Using wearable monitoring devices is increasingly ubiquitous but there is mixed evidence on
301 the validity of these devices and limited evidence for those designed specifically for young
302 people. This is the first study to validate the use of the Fitbit Ace and Moki devices in young
303 adolescents aged 11-13 years. The Fitbit Ace and Moki devices might not provide acceptable
304 validity under all walking conditions, but the Moki provides more accurate estimates of
305 incidental walking and might therefore be a good choice for free-living research or school-
306 based interventions.

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413

414

415 **Table 1. Mean difference, levels of agreement, and absolute percentage errors of Fitbit Ace & Moki-estimated step counts relative to**
 416 **observed criterion counts in three different walking conditions.**

417

Device	Condition	Mean SC Criterion (SD)	Mean SC Device (SD)	Difference (SD)	Lower LoA	Upper LoA	MAPE % (SE)	MPE % (SE)
Fitbit Ace	Incidental	342 (51)	312 (64)	-30 (38)	-104.1	44.1	9.5 (2.7)	-9.0 (2.8)
	Controlled	337 (28)	334 (22)	-3 (13)	-27.9	21.3	3.1 (0.6)	-0.8 (0.95)
	Treadmill	324 (23)	312 (31)	-13 (23)	-57.3	32.3	5.3 (1.4)	-3.8 (1.7)
Moki	Incidental	342 (51)	342 (52)	-1 (19)	-37.3	36.2	4.0 (1.0)	-0.1 (1.4)
	Controlled	337 (28)	341 (21)	4 (16)	-27.2	35.9	3.9 (0.8)	1.6 (1.2)
	Treadmill	324 (23)	330 (26)	6 (14)	-20.6	33.4	3.0 (0.8)	2.0 (1.0)

418 *Note: SC - step counts, SD - standard deviation, MAPE – mean absolute percentage error, MPE – mean percentage error, LoA – limits of*
 419 *agreement. SE -standard error of the mean.*

420

421

422

423

424 Figure legend –

425

426 **Figure 1.** Bland-Altman plots representing the comparisons between the criterion observer count and Fitbit Ace or Moki device across (A)

427 Incidental walking, (B) Controlled walking, and (C) Treadmill walking conditions. Solid lines indicate the mean difference between observer

428 count and device, and dashed lines indicate limits of agreement (± 1.96 SD).