

Article

A 12-week wearable-based intervention in adolescents: feasibility, adherence, and preliminary outcomes from a quasi-experimental study

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Abstract: Little is known about the impact of wearable devices to promote physical activity (PA) on adolescents' body composition, physical fitness, and psychological status, or whether changes in PA predict changes in these variables. Therefore, the objectives of the present study were: (a) to analyze changes in PA levels, body composition, physical fitness, and psychological status, after a 12-week step goal-based wearable intervention; (b) to examine whether changes in objective PA predicted changes in the other variables; and (c) to explore potential gender differences. A quasi-experimental one-group pre-post design intervention was conducted with 30 adolescents (mean age: 13.89±1.35 years old). The step-based intervention with wearable devices was carried out during extracurricular hours for 12 weeks. PA levels were assessed objectively using accelerometry and subjectively using the PAQ-A questionnaire; body composition following the ISAK protocol; physical fitness through valid and reliable tests performed in an indoor sports hall (cardiorespiratory fitness, upper body strength, lower body power, speed, and abdominal strength); psychological status through questionnaire (life satisfaction and basic psychological needs); and adherence to the intervention was assessed by recording which adolescents dropped out or continued to complete the intervention objectives



each week. Pre–post changes were examined using repeated-measures ANOVA, testing time $\times$ gender interactions, while associations between changes in PA and study outcomes were analyzed using hierarchical linear regression models including gender $\times$ change in PA interaction terms. The results showed that adherence was low, with 26.67% dropping out after the fourth week, and no participants completing the entire program. Pre–post analyses revealed an increase in subjective PA ($p=0.043$), alongside decreases in light PA, moderate-to-vigorous PA (MVPA), and daily steps ($p<0.001$ – 0.008). Competence frustration decreased ($p=0.049$), while curl-up performance improved ($p=0.002$). Regression analyses showed that changes in light PA, MVPA, and daily steps predicted subjective PA ($R^2=0.449$), and that MVPA and daily steps explained changes in competence frustration ($R^2=0.319$). Gender-stratified analyses indicated no significant predictors for males, whereas for females, MVPA and daily steps predicted hip girth ($R^2=0.425$), and MVPA predicted push-up performance ($R^2=0.500$). The findings showed an increase in perceived PA, along with a decrease in objective PA, less competence frustration, and improved curl-up performance. No significant differences were found in body composition variables ($p>0.070$), other psychological variables ($p>0.173$), or other physical fitness variables ($p>0.087$). Changes in objective PA predicted changes in perceived PA and competence frustration for the entire sample, but when analyzed by gender, a significant predictive capacity of changes in objective PA was observed in females. However, lack of adherence to the program and the small sample size of the study are limitations to consider when interpreting the results.

Keywords: Adolescents; Basic psychological needs; Physical activity; Physical condition; Physical performance.

1. Introduction

The use of new technologies, and more specifically wearable devices, is becoming increasingly common for promoting physical activity (PA) among adolescents (Strath & Rowley, 2018). This is because these devices integrate gamified and engaging elements that capture the attention of this population while being easy to use and incorporate into daily life (Koorts et al., 2020). Consequently, wearable devices appear to be effective tools for increasing PA levels and the number of daily steps in adolescents, although caution should be exercised when drawing conclusions, as sample sizes are not particularly large, intervention times vary greatly, and results differ between studies (Creaser et al., 2021; Danković et al., 2023).

In addition to these difficulties, one of the main challenges in using wearable

devices with adolescents is the lack of adherence to PA practice, as only a small percentage of adolescents continue to use these devices during or after the intervention (Koorts et al., 2020; Wang, Cheng, Song, & Shen, 2022). This is partly due to technical issues experienced by adolescents when using wearables, and also to the perception that the novelty effect of incorporating such devices into daily life diminishes after a few weeks, making their long-term use more difficult (Creaser et al., 2021).

Despite these limitations, the results of previous research seem to show that interventions with wearable devices report benefits in different areas. Thus, changes in body composition (Cummings, Crochiere, Lansing, Patel, & Stanger, 2022; Yen & Chiu, 2019), physical fitness (Duck, Hall, Klamm, Temple, & Robinson, 2021; Wilson, Ramsay, & Young, 2017), and adolescents' psychological status (Duck et al., 2021;

Kerner, Burrows, & McGrane, 2019) have been shown. In this regard, the changes in PA and daily step counts achieved through wearables are reflected in improvements in body composition, specifically decreases in body mass index (BMI) and body fat, as well as changes in body weight and waist girth (Cummings et al., 2022; Wang et al., 2022; Yen & Chiu, 2019). However, it should be noted in this regard that these significant changes have been observed mainly in studies conducted with overweight and obese adolescents, as well as with chronic conditions' adolescents. This is important because they tend to show benefits with exercise programs of lower intensity and duration (Cummings et al., 2022; Wang et al., 2022; Yen & Chiu, 2019).

Regarding physical fitness and psychological outcomes, few studies have analyzed changes in these variables, and the findings remain inconclusive. In this respect, previous studies with adolescents have not shown significant increases in cardiorespiratory fitness following the use of wearables (Duck et al., 2021). However, it should be noted that the sample size was small, and the study was conducted in rural areas, which could influence the baseline physical condition of the students (Duck et al., 2021). When analyzing changes in physical condition following this type of intervention in overweight and obese adolescents, improvements have been observed in specific tests, such as push-ups, sit-ups, long jump, and mile run on a treadmill (Wilson et al., 2017), which is similar to what occurred in body composition.

In the psychological domain, some short-term studies (5-10 weeks) have

reported negative results, such as decreased motivation and prosocial behavior and increased demotivation after the intervention period (Duck et al., 2021; Kerner et al., 2019). On the other hand, other studies show that students are motivated and become aware of the importance of daily exercise with these devices. However, it should be noted that, in those studies, the information was collected through focus groups in which it was observed that, despite having this perception, the students showed low adherence and involvement during the intervention (Koorts et al., 2020). Conversely, among adolescents with attention deficit hyperactivity disorder, the use of these devices has been shown to reduce symptoms and improve health status (Schoenfelder, Moreno, Wilner, Whitlock, & Mendoza, 2017).

Therefore, although the impact of wearable device use on adolescents' PA levels has been investigated on numerous occasions (Au et al., 2024; Creaser et al., 2021; Danković et al., 2023), the scientific evidence regarding their benefits on body composition, physical fitness, or psychological status remains limited. Moreover, no previous studies have examined whether the changes observed in adolescents' body composition, physical fitness, or psychological status are truly attributable to changes in PA level, nor whether these effects differ by gender. For this reason, the objectives of the present study were: (a) to determine the changes in PA levels, body composition, physical condition, and psychological state of adolescents after 12 weeks step goal-based wearable intervention; (b) to analyze whether the change in objective PA level predicts

changes in adolescents' body composition, physical fitness, and psychological status; and (c) to examine whether the associations between changes in PA and changes in body composition, physical fitness, and psychological outcomes differ according to gender.

Based on the results of previous studies that have promoted PA among adolescents (Aars et al., 2020; Cummings et al., 2022; Danković et al., 2023; Duck et al., 2021), the research hypotheses were as follows: (H1) there will be an increase in PA, as well as improvements in body composition, physical fitness, and psychological state in adolescents following the intervention; (H2) changes in PA levels will predict the changes observed in body composition, physical fitness, and psychological state in adolescents; and (H3) there will be gender differences in the predictive capacity of PA levels on the other variables.

2. Materials and Methods

Design- A quasi-experimental one-group design with repeated pre-post measurements was conducted. Between the pre- and post-test assessments, a 12-week step goal-based wearable intervention was implemented using a wearable device to promote PA during extracurricular hours. Study variables were measured before and after the intervention. A non-probabilistic convenience sample was used, consisting of students from two classes in the same secondary school.

Prior to the start of the study, the design and procedures were approved by the institutional ethics committee of the Catholic University of Murcia (code: CE022102). The

study was conducted in accordance with the principles of the Declaration of Helsinki and followed the guidelines of the Transparent Reporting of Evaluations of Non-randomized Studies (TREND) (Des Jarlais, 2014).

The sample size was calculated based on the standard deviation reported in previous studies that employed wearable devices to increase moderate-to-vigorous physical activity (MVPA) (SD=19.1) (Gaudet, Gallant, & Bélanger, 2017). Accordingly, the minimum required sample size was 27 adolescents, assuming a 95% confidence interval (95% CI) and an estimated error (d) of 6.83 for MVPA.

Participants- A secondary school in the Region of Murcia (Spain) participated in the study. An initial contact was made with the school management to inform them about the purpose and procedures of the research, and upon receiving their approval, the physical education staff were contacted. Subsequently, a meeting was held with the students and parents of the two classes in which the intervention was to be implemented. Participation was entirely voluntary. Students who agreed to take part completed an informed consent form, which included both their signature and that of their parents, authorizing participation in the study, data collection, and the anonymous publication of results. The participants were assured that all data would be treated confidentially and processed exclusively by the research team.

The inclusion criteria for the sample were: (a) being between 12 and 16 years old, and (b) belonging to one of the two classes selected for the study. The exclusion criteria were: (a) not attending the post-test

assessments, and (b) not using the wearable device.

Figure 1 presents the sample flow diagram. A total of 30 adolescents (mean age: 13.89 ± 1.35 years old) ultimately participated in the study. The distribution of males ($n=14$) and females ($n=16$) was similar. Based on the accelerometry values reported before the start of the intervention, adolescents spent 67.43% of the day engaged in sedentary behaviors, 23.50% in light-intensity activities, and 9.07% in moderate-to-vigorous-intensity activities. In fact, based on the PAQ-A values, 21 (70%) were considered inactive and 9 (30%) were considered physically active.

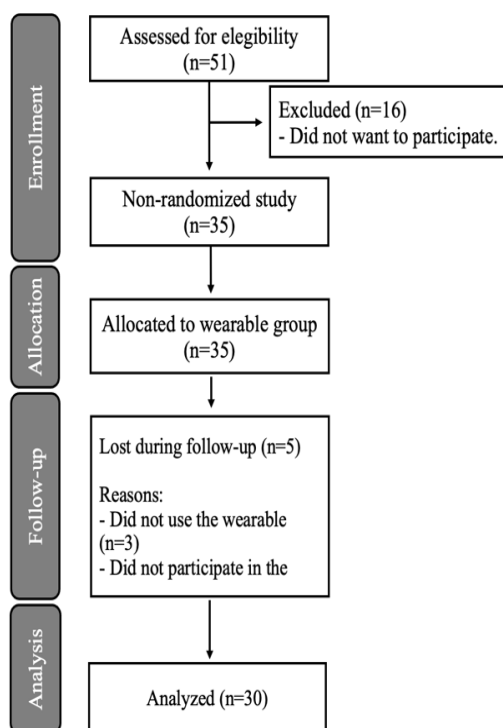


Figure 1. Sample flowchart.

Instruments- Physical activity variables

To assess self-reported PA levels, the Physical Activity Questionnaire for Adolescents (PAQ-A) (Kowalski, Crocker, Columbia, & Donen, 2004; Kowalski,

Crocker, & Kowalski, 1997) was used. This instrument consists of nine items: the first eight are answered using a 5-point Likert scale (1: low PA; 5: high PA), and the ninth item is answered dichotomously (yes/no) to determine whether the participant experienced any difficulty performing PA normally during the previous week. The overall score of the questionnaire is calculated as the arithmetic mean of the first eight items, yielding a value between 1 and 5, with higher scores indicating higher levels of PA. The questionnaire has been validated in Spanish and shows an intraclass correlation coefficient of 0.71 for the final score (Martínez-Gómez et al., 2009).

Objective PA was recorded using wGT3X-BT accelerometers (Actigraph, Pensacola, Florida, USA) worn on the non-dominant wrist of the participants. These accelerometers have been validated for assessing PA in adolescent populations (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014). Initialization, data download, wear-time validation, and scoring were performed using ActiLife 6 software, with a sampling frequency of 30 Hz, following the recommendations of previous studies (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). The accelerometers were worn for seven days prior to the start of the intervention and for seven days following its completion (Kerner et al., 2019). Adolescents were instructed to wear the accelerometer all the time (24 h/day-1) except when engaging in water-based activities such as bathing and swimming. Log sheets were provided for adolescents to record the times when they removed and replaced the accelerometer. This was done because the minimum number

of valid days required for inclusion in the analysis was three weekdays and one weekend day. A day was considered valid if a minimum of 10 hours of use was recorded (Mattocks et al., 2008). Data were downloaded in 15-second epochs (Evenson et al., 2008). Daily step counts were derived from the number of cycles in the accelerometer signal, while time spent in light and MVPA was calculated using the Evenson et al. (2008) cut-points which have been shown to be optimal for assessing PA in secondary school students.

Psychological variables

Life satisfaction was assessed using the Satisfaction with Life Scale (SWLS) (Diener, Emmons, Larsen, & Griffin, 1985). This scale consists of five items rated on a 5-point Likert scale, yielding a total score between 5 and 25 points, with higher scores indicating greater life satisfaction. The scale has been translated and validated in Spanish, showing an adequate internal consistency ($\alpha = 0.84$) for use with adolescents (Atienza, Pons, Balaguer, & García-Merita, 2000).

The Basic Psychological Needs Satisfaction and Frustration Scale (BPNSFS) was used to assess satisfaction and frustration of the basic psychological needs proposed by self-determination theory (autonomy, competence, and relatedness) (Ryan & Deci, 2000a). The scale comprises 24 items divided into six subscales: satisfaction and frustration of autonomy; satisfaction and frustration of competence; and satisfaction and frustration of relatedness. The items are rated on a 5-point Likert scale (1 = completely false; 5 = completely true), with higher scores indicating higher levels of satisfaction or frustration. The scale has been demonstrated to have adequate validity and reliability in

both its original version (Chen et al., 2015) and its Spanish translation (Del Valle, Matos, Díaz, Pérez, & Vergara, 2018).

Anthropometric and body composition variables

Body composition was assessed following the protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Esparza-Ros & Vaquero-Cristóbal, 2023). The measurements included a basic measurement (body mass), three skinfolds (triceps, thigh, and calf), and five girths (arm relaxed, waist, hips, thigh, and calf). All measurements were performed by ISAK-certified level 3 and 4 anthropometrists with prior experience in measuring more than 1,000 adolescents each.

The instruments used were a Tanita BC418-MA segmental scale with a 100 g precision for body mass; a Harpenden skinfold caliper with a 0.2 mm precision for skinfolds; and a Lufkin W606PM anthropometric tape with a 0.1 cm precision for girths. All instruments were calibrated prior to measurement.

Each variable was measured twice, with a third measurement taken if the difference between the first two exceeded 5% for skinfolds or 1% for other measurements. When two measurements were obtained, the mean was used as the final value; when three measurements were necessary, the median was used (Esparza-Ros & Vaquero-Cristóbal, 2023).

The intra- and inter-observer technical error of measurements (TEM) were calculated. The intra-observer TEM was 0.02% for basic measurements, 1.19% for skinfolds, and 0.05% for girths, whereas the inter-observer TEM was 0.04% for basic measurements, 1.99% for skinfolds, and

0.09% for girths. The experience and familiarity of the anthropometrists with the measurements taken directly influenced the high accuracy of the measurements and the small TEM.

Final values were used to calculate muscle mass (Poortmans, Boisseau, Moraine, Moreno-Reyes, & Goldman, 2005), fat mass (Slaughter et al., 1988), the $\Sigma 3$ skinfolds (triceps, thigh and calf), corrected girths for the arm [arm relaxed girth – (π * triceps skinfold)], thigh [middle thigh girth – (π * thigh skinfold)] and calf [calf girth – (π * calf skinfold)].

Physical fitness variables

Cardiorespiratory fitness was assessed using the 20-m shuttle run test. This is a maximal incremental test in which adolescents ran back and forth over a 20-meter distance as many times as possible in sync with an audio signal. Participants were eliminated if they failed to reach the target line before the signal on two consecutive occasions or reached exhaustion. The maximum volume of oxygen (VO_2 max) was estimated based on the last stage completed using Leger et al.'s formula (1998).

Upper-body strength was evaluated using the handgrip strength test and the push-up test. For the handgrip test, participants applied maximal force on a Takei TTK5401 manual dynamometer (Takei Scientific Instruments, Tokyo, Japan) with the elbow fully extended, which has been shown to be the optimal position for maximal force production (España-Romero et al., 2010). The push-up test consisted of performing as many repetitions as possible in one minute, starting from a prone position with elbows flexed at 90° on both sides of the body and toes in contact with the ground.

Participants performed full elbow extensions while keeping the back and legs straight throughout the movement. For a repetition to be valid, the participant had to touch the floor with their chest and keep their back completely straight. Repetitions in which the knees were supported, or the floor was not touched and only the arms were bent, were not counted. A researcher was responsible for counting the number of valid repetitions during one minute for each participant (Castro-Piñero, Artero, et al., 2010).

Lower-body power was assessed using the countermovement jump (CMJ) and the standing broad jump (SBJ). The CMJ was performed on a force platform with a 200 Hz sampling frequency (MuscleLab, Stathelle, Norway). Participants started in an upright position with hands on the waist, then performed a 90° knee flexion followed by maximal-speed extension to reach maximum jump height, keeping their hands on the waist and their back straight throughout the action (Barker, Harry, & Mercer, 2018). For the SBJ, participants jumped for a maximum horizontal distance from a starting line with feet shoulder-width apart. Before jumping, participants had to swing their arms to gain momentum, but they were not allowed to move behind the line. The distance was measured from the starting line to the nearest landing point (Castro-Piñero, Ortega, et al., 2010; Tabacchi et al., 2019).

Speed was measured using a 20-m sprint test. Single-beam photocells (Polifemo Light, Microgate, Italy) were positioned at hip height to avoid premature beam interruption by the arms (Altmann et al., 2017; Cronin & Templeton, 2008). The participants started from a standing position

behind the photocells and chose when to initiate the sprint.

Abdominal strength and endurance were assessed using the curl-up test. Participants lay supine with arms crossed over the chest, knees flexed at 90°, and feet on the floor. They performed trunk flexions until the upper back lost contact with the ground, repeating the movement as many times as possible in one minute (Garcia-Pastor, Salinero, Sanz-Frias, Pertusa, & Del Coso, 2016).

Procedure- Pre-test measurements were conducted during the week prior to the start of the intervention, using physical education class hours. First, the adolescents completed the PA and psychological questionnaires in a quiet classroom to ensure accurate responses. The researchers did not assist in completing the questionnaires and only clarified any doubts regarding the content of the items. Following this, body composition measurements were conducted in the sports hall changing rooms, ensuring the privacy of the participants. Once these measurements were completed, the physical fitness tests were conducted in the indoor sports hall, preventing any environmental conditions from affecting the assessments. Prior to warm-up, the participants were familiarized with each fitness test. Two trials of each test were performed, with the exception of the 20-meter shuttle run test, with the best result used as the final score. A two-minute rest was provided between repetitions of the same test (handgrip, CMJ, 20-m sprint, curl-up, push-up, SBJ), as well as a five-minute rest between different tests, following recommendations from the National Strength and Conditioning Association (NSCA) to avoid negative

interference in performance (Coburn & Malek, 2014). The handgrip, push-up, CMJ, SBJ, 20-m sprint, and curl-up tests were performed in random order for each participant. The 20-m shuttle run test was performed last and only once, as it is a maximum incremental test that could affect performance in the other evaluations and whose repetition would condition the results due to the fatigue generated. Post-test measurements were conducted after the twelve-week step goal-based wearable intervention, following the same protocol as the pre-test assessments, and at the same time of day to avoid fluctuations caused by this confounding variable.

To enhance the validity and reliability of data collection, measurements were conducted by researchers with prior experience in assessing adolescents. Additionally, to minimize inter-observer error, each researcher administered the same test during both the pre- and post-test assessments.

Wearable Intervention- The intervention initially included 35 adolescents who used the Xiaomi Smart Band (Xiaomi, Beijing, China) for a period of twelve weeks. A total of 30 adolescents completed the study, participating in the pre-post measurements. Participants had no prior experience with wearable devices and had not participated in previous interventions similar to the one in this study. Participants were instructed to continue their regular physical and sports activities as usual and to attend their physical education classes normally.

The Xiaomi Smart Band was selected because it has been used in previous studies aimed at promoting PA in adolescents and

had been found to be user-friendly for this population (Mayorga-Vega, Casado-Robles, López-Fernández, & Vicianá, 2022). Furthermore, it demonstrated a good criterion validity and showed a moderate to high accuracy in step counting when compared to ActiGraph accelerometers (Alvarenga et al., 2025; Casado-Robles, Mayorga-Vega, Guijarro-Romero, & Vicianá, 2023).

Throughout the 12 weeks of the step goal-based wearable intervention, the extracurricular use of wearable devices was promoted in physical education classes. The adolescents wore the wearable device every day during those twelve weeks, but only those sessions that were specifically recorded on the device were counted as training sessions. The adolescents were asked to use the device to record at least three training sessions each week. The rest of the activities and daily steps completed were recorded on the wearable device but were not considered when determining whether the intervention objectives had been met (steps set for each session depending on the week of intervention).

The participants were instructed to complete a minimum of 5,000 steps per session during the first week, as values below this threshold are associated with a sedentary lifestyle (Lubans et al., 2015; Tudor-Locke & Bassett, 2004), and between 12,000 and 13,000 steps per session in the last week. This is because 1,000 steps is approximately equivalent to 10 min of brisk walking, which is sufficient to achieve a total activity time to consider the young person active or highly active and improve cardiorespiratory fitness and health (Epstein et al., 2001; Tudor-Locke & Bassett, 2004). This final step goal was

achieved by progressively increasing the weekly step target by 600 steps, following the methodology from previous studies (Mateo-Orcajada, Abenza-Cano, Albaladejo-Saura, & Vaquero-Cristóbal, 2023).

A researcher was responsible for analyzing adherence to the intervention by recording which adolescents dropped out or continued to complete the intervention objectives each week. Participants who completed the entire intervention received a bonus on their final physical education grade, but no adolescent achieved this final goal. Adolescents who did not meet the weekly minimum step goal were not excluded from the study, nor were those who did not complete the full intervention. However, based on previous scientific evidence showing that four-week interventions are sufficient to achieve changes using technological devices (Galy, Yacef & Caillaud, 2019; Schoenfelder et al., 2017), the sample was divided into “non-completers” (who dropped out before the first four weeks) and “completers” (who completed more than five weeks of intervention).

Data analysis- Data normality was assessed using the Shapiro-Wilk test, as well as analyses of skewness and kurtosis. Since the sample followed a normal distribution, parametric tests were used for the analysis. The mean (M) and standard deviation (SD) were reported as descriptive statistics. Baseline differences between non-completers and completers, and between males and females, were analyzed. The Student's t-test for independent samples, as well as the chi-square test (X^2), were used for numerical and categorical variables, respectively. Changes in study variables between pre- and post-

intervention were examined using repeated-measures ANOVA, with time (pre vs. post) as the within-subject factor. Gender was included as a between-subject factor, and the time $\times$ gender interaction term was tested to examine whether pre–post changes differed by gender. Partial eta squared (η^2) was used to calculate effect sizes, defined as small ($\eta^2 \geq 0.01$), medium ($\eta^2 \geq 0.06$), and large ($\eta^2 \geq 0.14$) (Hopkins, Marshall, Batterham, & Hanin, 2009). Hierarchical linear regression analyses were conducted to examine the association between changes in PA (light, MVPA, and daily step count) and changes in the dependent variables (body composition, physical fitness, and psychological variables). For each model, the dependent variable was the pre–post change in the corresponding outcome. Changes in PA were entered as predictors, gender was included as a binary variable, and gender $\times$ change in PA interaction terms were added to test whether these associations differed by gender. Regression coefficients were reported as standardized values (β), along with their *t*-values and statistical significance (*p*). Adjusted R^2 was reported as a measure of the variance explained by each model. Statistical significance was set at $p < 0.05$. All analyses were performed using the SPSS statistical package (v.27.0; SPSS Inc., IL).

3. Results

At baseline, there were differences between males and females. Notably, males showed higher levels of PA ($p=0.009$), greater competence ($p=0.036$) and autonomy ($p<0.001$) satisfaction, greater corrected arm ($p=0.013$), thigh ($p=0.044$) and calf girths ($p<0.001$), greater muscle mass ($p<0.001$), and greater performance in right ($p=0.002$) and

left handgrip ($p<0.001$), CMJ ($p=0.016$), 20-m sprint ($p=0.004$), curl-up ($p=0.042$), push-up ($p=0.041$), and SBJ ($p=0.004$).

The baseline characteristics of the total sample at the start of the study, as well as the differences in baseline characteristics between the sample divided into non-completers and completers' adolescents are shown in Table 1. No differences were found between the two groups in any of the study variables analyzed.

Of the 35 participants initially included in the study, 30 (85.71%) completed it, participating in the pre- and post-test measurements. The 30 participants ultimately analyzed completed an average of 20.81 km and 36,509 steps during training sessions with wearable devices throughout the intervention. The maximum distance covered was 133.93 km and 226,365 steps. It should be noted that 26.67% of participants dropped out of the wearable device intervention between the first and fourth week. No participant completed the final goal of the intervention in its entirety (36 sessions). The highest recorded adherence was 72.22% of the program duration (26 sessions). Table 2 shows the weekly progress and the number of participants who achieved each week's objectives. It should be noted that, in weeks 10 and 11, the adolescents who continued to use the wearable did not complete the proposed weekly goal, but they did not abandon it either and recorded their workouts on the wearable.

Table 3 shows the pre–post differences in the study variables. Significant differences were found in subjective PA, which increased after the intervention ($p=0.043$), as well as in light PA ($p<0.001$), MVPA ($p=0.008$), and daily steps ($p<0.001$),

which showed a significant decrease after the intervention. Regarding psychological variables, a significant decrease was observed in competence frustration ($p=0.049$). For physical fitness variables, improvements were found in the curl-up test ($p=0.002$). No significant differences were found in any of the body composition variables analyzed ($p=0.070-0.742$). The inclusion of the covariate gender had a significant effect only on relatedness frustration ($p=0.011$).

The linear regression analysis performed to examine how changes in light PA, MVPA, and daily steps influenced the study's dependent variables is presented in Table 4. Notably, changes in light PA, MVPA, and daily steps predicted changes in subjective PA level ($R^2: 0.449$). Furthermore, changes in MVPA and daily steps explained changes in competence frustration ($R^2: 0.319$).

Table 4 also presents the gender $\times$ change in PA interaction terms using linear regression models. In this regard, the change in MVPA and daily steps affected hip girth differently depending on gender ($R^2: 0.251$); while the change in MVPA affected push-ups differently depending on gender ($R^2: 0.393$).

Supplementary Table 1 and 2 show the linear regression analyses for males and females, respectively. In this regard, changes in light PA, MVPA, and daily steps did not significantly predict changes in any dependent variable for males ($p=0.105-0.986$) (Supplementary Table 1). And for females, changes in MVPA and daily steps predicted changes in hip girth ($R^2: 0.425$) ($p=0.009-0.023$), and changes in MVPA predicted changes in push-up performance ($R^2: 0.500$) ($p=0.029$) (Supplementary Table 2).

Table 1. Analysis of baseline characteristics of adolescents based on their level of participation in the intervention

Variable	Total sample (n=30)	Completers (n=22)	Non-completers (n=8)	<i>p</i>	Cohen's <i>d</i> or X^2
Age	13.89 $\pm$ 1.35	13.69 $\pm$ 1.29	14.35 $\pm$ 1.46	0.232	0.34
Gender					
Male	14	11	3	0.628	0.24
Female	16	11	5		
Grade					
1st	21	15	6	0.471	2.53
4th	9	7	2		
Study variables					
Subjective PA	2.41 $\pm$ 0.73	2.43 $\pm$ 0.77	2.36 $\pm$ 0.67	0.782	0.74
Light PA	39.47 $\pm$ 9.08	40.26 $\pm$ 8.71	38.85 $\pm$ 9.93	0.486	0.19
MVPA	15.24 $\pm$ 4.09	14.83 $\pm$ 3.92	15.71 $\pm$ 4.38	0.503	0.17
Daily steps	10792.71 $\pm$ 2554.65	10525.29 $\pm$ 2348.36	10967.56 $\pm$ 2730.27	0.941	0.05
Life satisfaction	3.76 $\pm$ 0.81	3.76 $\pm$ 0.81	3.75 $\pm$ 0.86	0.989	0.02
Competence satisfaction	4.32 $\pm$ 1.24	4.36 $\pm$ 1.15	4.22 $\pm$ 1.49	0.789	0.15
Autonomy satisfaction	4.04 $\pm$ 0.89	4.03 $\pm$ 0.83	4.06 $\pm$ 1.07	0.934	0.03
Relatedness satisfaction	4.07 $\pm$ 1.08	4.13 $\pm$ 0.91	3.93 $\pm$ 1.44	0.641	0.08

Competence frustration	2.80±1.08	2.85±1.06	2.69±1.18	0.727	0.10
Autonomy frustration	3.09±1.25	3.11±1.34	3.06±1.10	0.912	0.27
Relatedness frustration	2.64±1.30	2.58±1.41	2.78±1.07	0.705	0.32
Body mass	56.33±14.70	53.27±11.76	63.15±18.75	0.094	0.20
Waist girth	70.72±9.87	69.54±9.55	73.34±10.66	0.347	0.09
Hip girth	89.51±10.74	87.61±10.28	93.72±11.14	0.161	0.25
Corrected arm girth	21.02±3.42	20.22±2.82	22.79±4.11	0.060	0.33
Corrected thigh girth	40.43±4.72	39.36±3.21	42.80±6.66	0.068	0.26
Corrected calf girth	28.87±2.91	28.38±2.67	29.96±3.26	0.181	0.16
Fat mass	25.94±10.29	25.64±10.88	26.59±9.40	0.823	0.36
Muscle mass	18.18±5.54	16.92±3.83	20.96±7.74	0.068	0.30
Sum of 3 skinfolds	59.29±25.65	59.26±27.57	59.34±22.96	0.994	0.12
VO ₂ max	36.14±5.37	37.52±4.98	33.07±5.17	0.056	0.45
Handgrip right hand	24.49±8.41	23.76±7.95	28.19±10.70	0.223	0.16
Handgrip left hand	23.24±7.71	22.66±7.10	26.32±10.10	0.270	0.20
CMJ	23.79±6.89	23.63±6.48	24.18±7.73	0.845	0.09
20-m sprint	4.14±0.42	4.14±0.45	4.09±0.34	0.793	0.05
Curl-up	21.52±11.30	22.86±10.93	18.56±12.20	0.343	0.12
Push-up	4.07±8.89	3.70±9.10	4.89±8.88	0.746	0.07
Standing broad jump	1.37±0.25	1.40±0.26	1.35±0.23	0.626	0.09

PA: physical activity; MVPA: moderate-to vigorous physical activity; Sum: summation; VO₂ max: maximum oxygen consumption; CMJ: countermovement jump.

Table 2. Weekly progress in steps and distance (km) covered by participants, as well as degree of completion of intervention objectives

Week	Steps per session (objective)	Steps per week (objective)	Km per week (objective)	Adolescents who dropped out	Number of adolescents who completed the weekly sessions
1	5000	15000	9.58	0	30
2	5684	17051	10.90	3	27
3	6367	19102	12.21	4	23
4	7051	21153	13.52	1	22
5	7735	23204	14.83	0	20
6	8418	25255	16.14	3	15
7	9102	27305	17.45	6	9
8	9785	29356	18.76	5	5
9	10469	31407	20.07	4	3
10	11153	33458	21.38	1	0
11	11836	35509	22.69	1	0
12	12520	37560	24.00	2	0

Table 3. Analysis of differences between pre- and post-test study variables.

Variable	Intervention					Pre-post x gender		
	Pre	Post	Mean Diff	95% CI	<i>p</i>	Effect size	<i>p</i>	Effect size
Subjective PA (score)	2.41±0.73	2.64±0.76	-0.23	-0.50; -0.04	0.043	0.197	0.686	0.006
Light PA (min)	39.47±9.08	32.08±12.85	7.39	2.56; 9.30	<0.001	0.456	0.640	0.008
MVPA (min)	15.24±4.09	12.95±5.43	2.29	1.47; 4.49	0.008	0.224	0.604	0.010
Daily steps (n)	10792.71±2554.65	8883.37±3465.80	1909	1464.71; 2546.74	<0.001	0.347	0.653	0.008
Life satisfaction	3.76±0.81	3.60±0.94	0.16	-1.21; 2.79	0.424	0.023	0.633	0.009
Competence satisfaction	4.32±1.24	4.31±1.22	0.01	-1.83; 1.97	0.941	0.000	0.667	0.007
Autonomy satisfaction	4.04±0.89	4.24±0.95	-0.20	-2.98; 0.56	0.173	0.065	0.506	0.017
Relatedness satisfaction	4.07±1.08	4.29±0.96	-0.22	-3.51; 0.89	0.233	0.050	0.543	0.014
Competence frustration	2.80±1.08	2.47±1.19	0.34	0.01; 0.67	0.049	0.131	0.443	0.022
Autonomy frustration	3.09±1.25	3.09±1.52	0.01	-0.44; 0.46	0.969	0.000	0.244	0.050
Relatedness frustration	2.64±1.30	2.59±1.48	0.05	-0.32; 0.42	0.775	0.003	0.011	0.215
Body mass	56.33±14.70	57.09±14.27	-0.76	-1.59; 0.07	0.070	0.113	0.338	0.034
Waist girth	70.72±9.87	69.93±9.68	0.79	-1.24; 2.82	0.433	0.022	0.697	0.006
Hip girth	89.51±10.74	91.11±8.98	-1.60	-3.75; 0.55	0.139	0.076	0.404	0.026
Corrected arm girth	21.02±3.42	21.34±3.20	-0.32	-0.87; 0.22	0.232	0.051	0.938	0.001
Corrected thigh girth	40.43±4.72	40.28±4.72	0.15	-0.75; 1.04	0.742	0.004	0.284	0.042
Corrected calf girth	28.87±2.91	29.30±3.33	-0.43	-1.07; 0.21	0.184	0.062	0.909	0.000
Fat mass	25.94±10.29	24.66±9.77	1.28	-0.95; 3.51	0.250	0.047	0.916	0.000
Muscle mass	18.18±5.54	18.46±5.59	-0.28	-0.85; 0.29	0.322	0.035	0.393	0.027
Sum of 3 skinfolds	59.29±25.65	57.39±26.14	1.90	-3.55; 7.35	0.482	0.018	0.645	0.008
VO ₂ max	36.14±5.37	36.09±5.25	0.05	-1.46; 1.57	0.942	0.000	0.767	0.003
Handgrip right hand	24.49±8.41	24.43±6.84	0.06	-1.05; 1.18	0.906	0.001	0.327	0.037
Handgrip left hand	23.24±7.71	22.66±6.43	0.58	-0.45; 1.60	0.257	0.047	0.311	0.039
CMJ	23.79±6.89	24.05±7.32	-0.26	-1.49; 0.97	0.669	0.007	0.331	0.038
20-m sprint	4.14±0.42	4.11±0.41	0.03	-0.12; 0.22	0.087	0.020	0.681	0.007
Curl-up	21.52±11.30	26.79±9.55	-5.28	-8.37; -2.18	0.002	0.304	0.463	0.020
Push-up	4.07±8.89	3.76±7.13	0.31	-1.18; 1.81	0.674	0.006	0.734	0.004
Standing broad jump	1.37±0.25	1.34±0.21	0.03	-0.04; 0.10	0.402	0.027	0.775	0.003

Table 4. Linear regression of changes in light, moderate-vigorous physical activity, and number of steps on dependent variables.

Dependent variable	Predictor	Change in PA				Gender x change in PA			
		β	t	p	R ²	β	t	p	R ²
Δ Subjective PA level	Δ Light PA	-0.85	-2.98	0.006	0.449	-0.45	-2.10	0.460	0.256
	Δ MVPA	-0.91	-2.35	0.041		-0.06	-0.07	0.945	
	Δ Daily steps	1.43	2.05	0.049		0.84	1.05	0.304	
Δ Life satisfaction	Δ Light PA	-0.13	-0.35	0.730	0.084	-0.05	-0.17	0.863	0.002
	Δ MVPA	-0.01	-0.02	0.987		-0.11	-0.11	0.917	
	Δ Daily steps	0.40	0.40	0.657		0.12	0.12	0.909	
Δ Competence satisfaction	Δ Light PA	0.21	0.55	0.586	0.019	0.16	0.58	0.564	0.021
	Δ MVPA	-0.11	-0.14	0.889		-0.33	-0.33	0.747	
	Δ Daily steps	-0.14	-0.15	0.885		0.14	0.14	0.888	
Δ Autonomy satisfaction	Δ Light PA	-0.20	-0.53	0.599	0.030	-0.01	-0.02	0.984	0.020
	Δ MVPA	-0.04	-0.04	0.965		0.58	0.59	0.564	
	Δ Daily steps	0.07	0.07	0.941		-0.49	-0.49	0.627	
Δ Relatedness satisfaction	Δ Light PA	0.12	0.32	0.752	0.009	-0.14	-0.54	0.592	0.111
	Δ MVPA	-0.15	-0.18	0.858		1.43	1.51	0.145	
	Δ Daily steps	0.09	0.09	0.926		-1.15	-1.22	0.234	
Δ Competence frustration	Δ Light PA	-0.45	-1.40	0.175	0.319	-0.33	-1.35	0.190	0.187
	Δ MVPA	-1.86	-2.75	0.011		-0.85	-0.93	0.361	
	Δ Daily steps	1.87	2.41	0.023		0.75	0.83	0.413	
Δ Autonomy frustration	Δ Light PA	-0.05	-0.14	0.887	0.076	-0.04	-0.17	0.868	0.060
	Δ MVPA	-1.11	-1.41	0.171		-1.17	-1.20	0.241	
	Δ Daily steps	1.15	1.28	0.213		1.14	1.18	0.249	
Δ Relatedness frustration	Δ Light PA	0.07	0.20	0.841	0.107	-0.01	-0.02	0.986	0.102
	Δ MVPA	-0.15	-0.20	0.846		-0.54	-0.56	0.581	

	Δ Daily steps	-0.24	-0.27	0.791		0.23	0.24	0.813	
Δ Body mass	Δ Light PA	-0.27	-0.72	0.480	0.045	-0.12	-0.46	0.650	0.096
	Δ MVPA	0.23	0.29	0.772		-1.27	-1.32	0.198	
	Δ Daily steps	0.14	0.15	0.882		1.45	1.53	0.140	
Δ Waist girth	Δ Light PA	-0.35	-0.99	0.331	0.152	-0.03	-0.11	0.914	0.002
	Δ MVPA	-1.49	-1.99	0.058		-0.04	-0.04	0.968	
	Δ Daily steps	1.67	1.93	0.065		0.03	0.03	0.979	
Δ Hip girth	Δ Light PA	0.23	0.66	0.513	0.182	0.00	0.01	0.992	0.251
	Δ MVPA	1.59	2.15	0.051		-0.52	-0.52	0.032	
	Δ Daily steps	-1.57	-1.85	0.076		0.52	0.52	0.047	
Δ Corrected arm girth	Δ Light PA	0.04	0.10	0.919	0.085	-0.05	-0.18	0.857	0.059
	Δ MVPA	1.04	1.33	0.197		-0.84	-0.85	0.401	
	Δ Daily steps	-1.18	-1.31	0.201		0.68	0.71	0.487	
Δ Corrected thigh girth	Δ Light PA	-0.10	-0.26	0.799	0.038	-0.19	-0.73	0.472	0.056
	Δ MVPA	0.41	0.51	0.612		0.76	0.77	0.446	
	Δ Daily steps	-0.47	-0.51	0.618		-0.48	-0.50	0.623	
Δ Corrected calf girth	Δ Light PA	0.02	0.05	0.962	0.145	0.02	0.06	0.955	0.003
	Δ MVPA	1.53	2.02	0.054		-0.22	-0.22	0.832	
	Δ Daily steps	-1.51	-1.73	0.096		0.17	0.17	0.868	
Δ Fat mass	Δ Light PA	-0.21	-0.55	0.585	0.076	-0.02	-0.06	0.956	0.005
	Δ MVPA	-1.04	-1.32	0.199		-0.06	-0.06	0.955	
	Δ Daily steps	1.27	1.41	0.172		0.13	0.13	0.897	
Δ Muscle mass	Δ Light PA	-0.07	-0.19	0.854	0.067	-0.13	-0.49	0.626	0.011
	Δ MVPA	0.70	0.89	0.381		-0.07	-0.07	0.948	
	Δ Daily steps	-0.80	-0.88	0.385		0.13	0.13	0.901	
Δ Sum of 3 skinfolds	Δ Light PA	-0.14	-0.36	0.720	0.033	0.07	0.25	0.807	0.008
	Δ MVPA	-0.62	-0.77	0.447		-0.40	-0.39	0.697	

	Δ Daily steps	0.81	0.87	0.390		0.34	0.34	0.739	
Δ VO ₂ max	Δ Light PA	-0.54	-1.47	0.155	0.097	-0.34	-1.49	0.148	0.267
	Δ MVPA	0.16	0.21	0.837		1.81	2.10	0.056	
	Δ Daily steps	0.40	0.45	0.659		-1.24	-1.45	0.160	
Δ Handgrip right hand	Δ Light PA	-0.47	-1.26	0.220	0.078	-0.34	-1.34	0.192	0.100
	Δ MVPA	-0.73	-0.92	0.364		-0.67	-0.70	0.490	
	Δ Daily steps	1.05	1.16	0.256		0.81	0.85	0.402	
Δ Handgrip left hand	Δ Light PA	-0.59	-1.61	0.120	0.104	-0.40	-1.57	0.129	0.118
	Δ MVPA	-0.63	-0.82	0.421		-0.63	-0.66	0.514	
	Δ Daily steps	1.06	1.19	0.244		0.83	0.88	0.387	
Δ CMJ	Δ Light PA	-0.64	-1.77	0.089	0.115	-0.57	-2.38	0.085	0.205
	Δ MVPA	-0.40	-0.52	0.610		-0.03	-0.03	0.978	
	Δ Daily steps	0.99	1.12	0.272		0.54	0.61	0.549	
Δ 20-m sprint	Δ Light PA	-0.82	-2.41	0.054	0.231	-0.59	-2.70	0.072	0.341
	Δ MVPA	-0.12	-0.16	0.873		0.45	0.55	0.585	
	Δ Daily steps	1.03	1.25	0.224		0.33	0.40	0.690	
Δ Curl-up	Δ Light PA	-0.48	-1.30	0.207	0.077	-0.14	-0.56	0.584	0.095
	Δ MVPA	0.21	0.27	0.788		0.99	1.03	0.312	
	Δ Daily steps	0.26	0.29	0.774		-0.65	-0.69	0.499	
Δ Push-up	Δ Light PA	-0.33	-0.89	0.385	0.074	-0.19	-0.75	0.460	0.393
	Δ MVPA	-0.94	-1.20	0.243		-0.95	-0.99	0.031	
	Δ Daily steps	1.26	1.40	0.175		1.23	1.29	0.209	
Δ Standing broad jump	Δ Light PA	-0.71	-2.02	0.055	0.166	-0.47	-2.04	0.052	0.257
	Δ MVPA	-0.59	-0.79	0.440		-0.33	-0.38	0.707	
	Δ Daily steps	1.33	1.55	0.133		0.98	1.14	0.266	

Δ : change (post-pre); PA: physical activity; MVPA: moderate-to vigorous physical activity; Sum: summation; VO₂ max: maximum oxygen consumption; CMJ: countermovement jump.

4. Discussion

Summary of the Main Findings- This study aimed to examine the effects of a 12-week step goal-based wearable intervention on PA, body composition, physical fitness, and psychological well-being in adolescents, as well as to explore the associations between changes in PA and these outcomes. Overall, the results showed mixed and modest changes across the assessed variables, with improvements observed in selected physical fitness and psychological outcomes, while objectively measured PA decreased and body composition remained unchanged. Importantly, these findings must be interpreted in light of a critical limitation affecting all analyses: adherence to the intervention was extremely low. No participant completed the full 12-week program, and more than one quarter of the sample discontinued participation within the first four weeks, substantially limiting the exposure to the intervention and likely shaping the observed outcomes.

Main differences found in the study variables after the 12-week step goal-based wearable intervention.

The first objective of the present study was to determine changes in PA levels, body composition, physical fitness, and psychological state of adolescents after a 12-week step goal-based wearable intervention. Attending to the PA, the results showed an increase in subjective PA levels, but a decrease in daily step count and in objectively measured PA, in both light and MVPA. These findings are consistent with previous research, which indicated that following interventions aimed at promoting

PA in adolescents, subjective perceptions of PA often increased, but this improvement was not always confirmed by objective measurements (Ruotsalainen, Kyngäs, Tammelin, & Kääriäinen, 2015). Indeed, recent studies have shown that school-based interventions produce small and non-significant effects on both total PA and MVPA (Borde, Smith, Sutherland, Nathan, & Lubans, 2017; Duck et al., 2021), and reductions in MVPA have even been observed following the use of wearable devices (Kerner et al., 2019). One possible explanation for these results is that these interventions, despite initially motivating adolescents through the use of wearable devices (Creaser et al., 2021; Koorts et al., 2020), fail to generate high adherence that would allow participants to complete the entire program (Koorts et al., 2020; Wang et al., 2022). This means that, although perceived PA is higher when using these types of devices (Maher et al., 2017), the reality is that they do not generate sufficient behavioral change to report objective benefits in PA. Taking this into account, since no adolescent completed the final objective proposed for the intervention in this study, it is likely that it was not sufficient to induce significant changes in objectively measured PA. However, given that a high percentage of the sample of adolescents were sedentary and inactive at the beginning of the intervention, the changes brought about by the use of wearable devices could be perceived by participants as sufficient to change their perception of their PA level.

Regarding psychological variables, no significant differences were found in life satisfaction, satisfaction or frustration with autonomy, or relatedness. The only variable

that showed significant differences was competence frustration, which decreased after the intervention, although competence satisfaction did not show significant changes. These findings differ from those of previous research, which showed that mobile apps based PA interventions have beneficial effects on adolescents' psychological well-being by enhancing competence, autonomy, relatedness, or intrinsic motivation (Cowley et al., 2024; Mateo-Orcajada, Vaquero-Cristóbal, & Abenza-Cano, 2024); but they are similar to previous studies that have used wearables such as Fitbit and have shown declines in autonomous motivation and increases in both amotivation and controlled motivation, even if these were not significant (Kerner et al., 2019). The absence of changes in autonomy and relatedness could be due to the design of the intervention. Each adolescent had to record their workouts on their wearable device, with only those involving walking or running being valid, and no other alternative activities were offered to help them achieve their goal. Furthermore, no cooperative challenges or interactions were created to help motivate the adolescents, despite this being a highly relevant aspect indicated in previous research (Marker & Staiano, 2015), and one that should be considered in future intervention designs involving wearables. However, the decrease in competence frustration is a key finding of the present research and could be due to the fact that many adolescents tend to give up sports during this stage (Kjønniksen, Torsheim, & Wold, 2008), with lack of perceived competence being one of the main reasons for withdrawal (Crane & Temple, 2015). In sports contexts, competitiveness and the

pursuit of victory prevail, which often leads those with higher levels of competence and performance to continue practicing. This is why adolescents with lower levels of competence and competitiveness are more likely to drop out prematurely (Rinta-Antila, Gavin, Ooms, & Kokko, 2022). In contrast, technology-based interventions, such as the use of wearables, provide opportunities for adolescents to engage in PA without the need to compete against peers, fostering a greater sense of competence as they achieve the proposed goals. Analyzing the characteristics of the sample in this study, given that most of the adolescents were sedentary and inactive, it seems logical to think that completing some of the PA objectives proposed during the intervention could reduce the frustration of competition that these young people might experience, as they may have thought that they were not capable of performing effectively in this field. Furthermore, the fact that a large part of the sample consisted of first-year compulsory secondary education students could be relevant to the results obtained. As previous research have shown, adolescents have different profiles of satisfaction and frustration of basic psychological needs, with the change of educational stage being a key moment in which these profiles are defined (Ratelle et al., 2023).

In terms of physical fitness outcomes, the results showed no significant differences in any of the tests (VO₂ max, handgrip, CMJ, 20-m sprint, push-up, or SBJ), except for the curl-up, where an improvement in performance was observed after the intervention. The improvement in curl-up performance is consistent with previous studies that promoted PA in

adolescents through mobile applications over a ten-week period (Gómez-Cuesta, Mateo-Orcajada, Meroño, Abenza-Cano, & Vaquero-Cristóbal, 2024; Mateo-Orcajada, Vaquero-Cristóbal, Mota, & Abenza-Cano, 2024). However, unlike the present study, in the aforementioned studies, the adolescents did complete the entire intervention, so the changes found in curl-up performance in those studies could be due to the fact that walking contributes to improving muscle strength and trunk stabilization capacity (Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006). This is because walking involves lateral and vertical displacements of the trunk, requiring muscle activation to maintain stabilization (Ceccato, de Sèze, Azevedo, & Cazalets, 2009; Waters & Morris, 1972). Therefore, since the adolescents did not meet the target set for the intervention, it is difficult to consider this as the main reason for the changes found in curl-up. In this regard, it is possible that, as this is an abdominal endurance test, where power and strength are not so decisive, and as the adolescents were untrained and mostly sedentary, the effect of familiarization with the test during the second measurements was more decisive in the changes observed (Coledam & De Oliveira, 2020).

Another surprising result, given that it is a variable directly involved in the intervention, was the absence of improvements in VO_2 max at the end of the intervention. This coincides with previous research conducted on adolescents with wearable devices, in which no improvement in VO_2 max was observed, probably due to the decrease in MVPA during the intervention (Au *et al.*, 2024; Ridgers *et al.*, 2021), since a minimum intensity is required

to achieve improvements in this variable (Landgraaf *et al.*, 2021).

As for body composition, no significant differences were found in the analyzed variables. Previous research has reported reductions in BMI, fat mass, or waist girth after completing interventions that promote PA through wearable devices (Cummings *et al.*, 2022; Wang *et al.*, 2022). However, it is important to note that the evidence in this regard remains inconclusive, and most of the benefits tend to occur in adolescents with overweight or obesity (Cummings *et al.*, 2022; Wang *et al.*, 2022). One possible explanation for the lack of changes after using wearable devices is that a minimum of 60 minutes of PA, 3 days a week, for 8 weeks is recommended to generate significant changes in the body composition of this population, with the intensity and volume of the activity being decisive factors (Zhou, Li & Jiang, 2024). The fact that none of the adolescents completed the prescribed volume and that intensity was not monitored makes it difficult to determine whether the training protocol designed with wearables for this study could be useful, and further research is needed to address this issue.

Based on the results obtained, the first research hypothesis, can be rejected. Although improvements were observed in some psychological and physical fitness variables, it cannot be established that these were due to the effect of the intervention, since adherence was one of the major limitations encountered and, in fact, a decrease in objectively measured PA was observed.

The second objective of the study was to analyze whether changes in objective PA levels predict changes in adolescents'

body composition, physical fitness, and psychological status. The results showed that changes in light PA, MVPA, and daily steps predicted changes in subjective PA levels. This finding reinforces the idea that although the direction of change in perceived and objectively measured PA does not always coincide after the intervention, the adolescents' perception of their PA is related to their actual movement experience throughout the day. A possible explanation is that subjective assessments of PA, generally collected through questionnaires, are influenced by psychological, motivational, and environmental factors, leading adolescents to overestimate their actual PA (Corder et al., 2010; Garcia et al., 2016). This suggests that future research should include both objective and subjective assessments of this construct, as this approach would provide more detailed insights not only into PA and movement, but also into the potential influence of other factors on the observed outcomes. This is not straightforward, as objective measurement of PA, as in the present study, requires valid and reliable accelerometers, which may limit sample sizes in longitudinal studies. However, this measure is highly representative and provides accurate data on the actual movement and PA of adolescents.

Furthermore, changes in MVPA and daily steps were found to predict changes in competence frustration. This finding is highly relevant, as it highlights the impact that PA can have on adolescents' psychological state. According to the self-determination theory (Ryan & Deci, 2000b), competence is influenced by the perception of efficacy and success in PA. Thus, achieving goals and experiencing success during PA is

necessary to enhance perceived competence. While this can be challenging in certain sports due to the many factors affecting performance (Salcinovic, Drew, Dijkstra, Waddington, & Serpell, 2022), it may be easier to accomplish in a wearable-based intervention where competitiveness is not promoted, allowing each participant to progress at their own pace. However, these results could also be interpreted differently, as changes in competence frustration might be perceived negatively. Motor performance in adolescents is closely related to their perceived competence (Robinson et al., 2015). Therefore, as the weekly step goals increased throughout the intervention, students with lower PA capacities may have failed to meet the targets, experiencing frustration in their perceived competence. This could also partly explain the high dropout rate observed in the intervention, as competence frustration has been shown to be an indirect predictor of disengagement in educational activities (Earl, Taylor, Meijen, & Passfield, 2017). Future research is needed to confirm these findings and to determine whether weekly step goals in PA interventions are appropriate and beneficial for adolescents, or whether they may negatively impact their psychological well-being.

The results partially reject the second research hypothesis. This is because changes in objectively measured PA only predicted changes in perceived PA and competence frustration in adolescents.

The third objective of the study was to examine whether the associations between changes in PA and changes in body composition, physical fitness, and psychological outcomes differ according to gender. The results showed that gender

moderated pre-post differences in relatedness frustration. This finding is consistent with previous research, which indicated that after participating in organized physical activities, the satisfaction of basic psychological needs differed between males and females, with males reporting higher scores (Fraguela-Vale, Varela-Garrote, Carretero-García, & Peralbo-Rubio, 2020). Furthermore, it is noteworthy that the linear regression analyses showed that changes in PA among males did not predict changes in body composition, physical fitness, or psychological variables, whereas in females, changes in MVPA and daily steps predicted changes in hip girth and push-up performance. A possible explanation for these findings is that adolescent males tend to engage in higher levels of PA than females (Brazo-Sayavera, Aubert, Barnes, González, & Tremblay, 2021; Ricardo *et al.*, 2022), they exhibit lower adiposity (Čech, Vadašová, Sedláček, Ružbarský, & Lacková, 2023) and have better physical fitness (Tingelstad *et al.*, 2025), so the changes in PA achieved through the step goal-based wearable intervention may not have been sufficient to produce measurable changes in the study variables. In contrast, adolescent females, who generally have a lower physical fitness (Tingelstad *et al.*, 2025), and higher adiposity during puberty, particularly in the hip region (Taylor, Grant, Williams, & Goulding, 2010), may have experienced sufficient changes in PA from the step goal-based wearable intervention to generate significant changes in these variables. Moreover, previous research has shown that adolescent females respond positively in body composition and strength-related variables during PA interventions,

likely because they have a greater potential for improvement (Biddle, Braithwaite, & Pearson, 2014; Pearson, Braithwaite, & Biddle, 2015). In light of the results found in this study, which shows baseline differences between males and females, with females having lower values in muscle development, as well as in the satisfaction of basic psychological needs and physical performance, the greatest potential for improvement in females could be a possible explanation.

Based on the results obtained, the third research hypothesis, can be accepted. This is because changes in PA did not predict changes in other variables among males, whereas in females, a significant predictive capacity was observed in body composition and physical fitness. However, these findings should be interpreted with caution and confirmed in future research.

This study is not without limitations. Firstly, a quasi-experimental design was chosen instead of a randomized controlled trial (RCT) due to a material limitation in terms of the accelerometers available to carry out the research. With only 35 accelerometers available, it was decided to conduct a single experimental group, rather than an experimental group and a control group, in which the samples would have been too small, especially given that the dropout rate in these interventions is close to 30% (Egilsson, Bjarnason & Njardvik, 2021). Secondly, low adherence to the intervention, as well as not having completed it in its entirety, makes it necessary to be cautious about the conclusions drawn from this 12-week intervention with wearable devices in adolescents. Thirdly, the final sample size was small, and although it addresses a novel

topic such as the predictive capacity of changes in objective PA levels on other variables following a wearable-based intervention, the results should be interpreted with caution due to the low statistical power of the analyses. Fourthly, because of the limited sample size, the gender-based analyses, as well as the analysis between completers and non-completers relied on reduced subsamples, which hinders the extrapolation of the findings. Fifthly, although aspects of training load such as volume were considered, another key factor, intensity, was not considered. And sixthly, the fact that most of the sample was inactive and sedentary at the start of the study could influence adherence levels and the effect achieved with the intervention.

5. Practical Applications

Despite the limitations of the present study, particularly the extremely low adherence to the intervention, the findings provide preliminary insights into the potential role of wearable-based interventions in adolescents. Importantly, the lack of meaningful changes in most outcomes should not be interpreted as evidence that a 12-week intervention is insufficient per se, as no participant completed the full program and exposure to the intervention was highly variable. Rather, the results highlight the critical importance of adherence as a prerequisite for achieving measurable benefits in PA, physical fitness, body composition, and psychological outcomes.

From a practical perspective, these findings underscore the need for future wearable-based interventions to prioritize strategies aimed at enhancing engagement and sustained participation, such as

individualized goal setting, adaptive progression, and the inclusion of social or cooperative components. In addition, the discrepancy observed between increases in perceived PA and decreases in objectively measured PA reinforces the importance of combining subjective and objective assessments when evaluating intervention effectiveness, as self-reported measures alone may overestimate behavioral change.

Finally, the gender-related differences observed in the regression analyses should be interpreted with caution due to the limited sample size and incomplete intervention exposure. Nonetheless, they suggest that certain subgroups, particularly female adolescents, may experience measurable benefits even with modest changes in PA. These preliminary findings warrant further investigation in adequately powered studies with sufficient intervention adherence to determine whether wearable-based interventions can be tailored to maximize benefits across different adolescent populations.

6. Conclusions

The present study provides preliminary evidence on the effects of a wearable-based intervention in adolescents. Following the intervention period, increases in perceived PA were observed alongside decreases in objectively measured PA, while no changes were detected in body composition. Modest improvements were found in selected outcomes, including reduced competence frustration and improved curl-up performance, and gender-related differences were observed for relatedness frustration.

Exploratory regression analyses suggested that changes in objectively measured PA were associated with changes in perceived PA and competence frustration. When analyses were stratified by gender, no significant associations were observed among males, whereas in females, changes in MVPA and daily step count were associated with changes in hip girth and push-up performance.

These findings should be interpreted with caution due to the small sample size, the quasi-experimental design, and, most importantly, the low adherence to the intervention, which limited exposure to the program. Consequently, the results cannot be used to draw definitive conclusions about the effectiveness of wearable-based interventions but rather highlight the need for future studies with improved adherence, adequate statistical power, and well-controlled intervention exposure.

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