iEngage: a digital health education program designed to enhance physical activity in young adolescents

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Abstract

iEngage© is a modular health education and behavioural change program designed to provide adolescents with knowledge and practical skills and to help them moderate to vigorous physical activity (MVPA). Key features of the program include the iEngage© app which integrates learning modules with activity trackers data (Misfit Ray©), evidence-based health information, guidance through goals setting, self-monitoring, assessment of achievements, and experiential learning supported by the activity trackers.

iEngage© was implemented in school context in 10–12 years old adolescents over 5 weeks involving 10 learning and behavioural change modules and continuous monitoring of steps.

Results show that adolescents effectively set goals and self-assessed achievements during the program, progressing toward higher activity levels. Daily steps increased through the program (+ 30% or + 2647 steps/day) as well as the consistency of days totalling at least 11,000 steps/day (from 35% at the beginning to 48% at the end of the program). Average schooldays MVPA was assessed pre- and post- via research grade GENEActiv wrist accelerometers in iEngage and control participants. Contrasting with the control group, MVPA increased after the program (~ + 5 min/day) in short bouts, particularly during lunch time, recess and after school. Girls were found less active than boys and progressed goals and PA achievements less than boys during the program.

The iEngage© program and its digital app, incorporates experiential learning, goals setting, self-monitoring and self-assessment of PA, and effectively helped young adolescents enhance PA and build up MVPA in daily life.

Introduction

Physical activity (PA) is a major component of health and wellbeing across the lifespan and contributes to reducing all-cause mortality. However, current evidence from large population cross-sectional surveys indicates that 81% of children and adolescents globally do not participate in sufficient amounts of PA[1]. Australian guidelines (Australian Government, Department of Health) recommend that children and adolescents perform at least 60 minutes of moderate to vigorous PA (MVPA) each day[2]. Surveys showed that only 20% of 5–17 years-old Australians meet these recommendations, with no improvement over the past 10 years despite a number of public health campaigns and initiatives[3]. Pooled accelerometry data from several countries including Australia provide an even more concerning figure since only ~ 7% of 9–13 years (9% of boys and 2% of girls) meet the recommendations and accumulate an average daily MVPA of 30–35 min, indicating that surveys may over-estimate the amount of MVPA performed [4].

Low participation in PA is concerning because this is a risk factor for the development of overweight and obesity in young people, leading to adverse cardiometabolic profiles[5,6]. A large study including ~ 21,000 children and adolescents found that MVPA was significantly and inversely associated with cardiometabolic outcomes independently of time spent sedentary, demonstrating the importance of

focusing on increasing MVPA[7]. In addition, PA behaviour carries on from childhood to adulthood, with insufficient PA levels during adolescence leading to low PA levels in adulthood [8,9]. These findings indicate that active behaviours must be adopted as early as possible to promote a healthy lifestyle across the whole lifespan.

The overall low level of participation in MVPA is partly driven by perceived lack of support, poor motivation, and low physical competence[10]. This is in line with known important drivers of PA for adolescents which include health knowledge, the ability to organise own PA, and physical competence in diverse forms of PA[11].

Numerous interventions have attempted to enhance participation in PA and MVPA in children and adolescents. Overall, previous studies showed no or small changes in time spent in MVPA in response to interventions, indicating that changing PA behaviour in adolescents is challenging[12]. Evidence shows that school-based PA interventions can increase the proportion of adolescents who engage in MVPA during school hours, however the magnitude of effect is generally small[13]. This is also the case for studies using web-based interventions[14]. With the rise of technology and the availability of accelerometers, it has been recommended to take advantage of objective self-assessment of PA via activity trackers to enhance the adolescents' engagement with the intervention[15]. Technology such as wearable sensors or PA apps provide a wide range of possibilities. However, the overall moderate quality of existing commercial health and fitness apps, the poor app usage as well as the inconsistent use of behavioural change techniques (BCTs) have been identified as barriers to the efficacy of app-based intervention in children and adolescents[16]. In addition, existing apps do not take advantage of the technology to continuously collect PA data during the program or to use these PA data as a mechanism to provide feedback to adolescents during the program[16]. It has been recommended that future PA apps must be specifically designed for the target population, combine BCTs (such as goal setting, self-monitoring and performance feedback), provide health education and behavioural change advice, and incorporate some gamification[16]. The question remaining is to which extent digital health programs integrating activity trackers are effective to increase PA in young adolescents. In this article, we present our approach to designing and implementing iEngage©, an educational and behavioural change program tailored to 10–12 years old adolescents. The program combines experiential learning and BCTs and is delivered via a user-friendly digital app connected to activity trackers. An earlier version of iEngage© was implemented in a school located in one New Caledonia's remote community[17]. This initial study guided the new version of the program.

We hypothesised that iEngage©, combining experiential learning and behavioural change techniques, delivered via a user-friendly digital environment with integrated activity trackers, will be able to engage adolescents in behaviour change towards becoming more active.

We present the original design approach of the iEngage© program and report on its effectiveness for enhancing participation in PA (with a focus on MVPA) in a group of Australian adolescents.

Method

iEngage©: approach and framework

iEngage© is an evidence-based health education and behavioural change program designed to help young adolescents increase MVPA. The program is supported by a digital environment that includes the iEngage© app connected to activity trackers. Using live data from these trackers and digital health education modules, iEngage© aims to drive behavioural change through experiential learning, goal setting and self-assessment of achievements. The program and companion app were co-designed with experts in physical education, exercise science, data science and mobile health industry experts. A few short sessions were organised to gather feedback from adolescents.

Topics such as health, intensity of PA, MVPA, sedentary behaviours (SB), physical fitness, physical effort, exertion, mode of exercise or the impact of PA on body functions are explained through a series of 10 digital modules (Fig. 1A) while activity trackers help connecting concepts with experience. iEngage© is grounded in evidence-based principles and practices in education and physical education and builds on BCTs. We used a refined taxonomy of BCTs, the “Coventry, Aberdeen & London - Refined” (CALO-RE) taxonomy, which is specifically adapted to help people change their PA and health behaviours[18]. The CALO-RE taxonomy comprises 40 items amongst which we identified 16 items relevant to our objectives, the population targeted and the school setting in which we deployed the program, based on current evidence that schools provide a good setting for PA interventions[13]. The 16 items were mapped to each module of the iEngage© program (Fig. 1B, 1C). iEngage© also aligns with the Australian Physical Literacy Framework. Physical literacy is described as the skills, knowledge and behaviours that help us lead active lives[2,3,19,20]. It integrates physical, psychological, social and cognitive domains that can be developed holistically across the lifespan from pre-foundational to mastery level. These domains are embedded in each iEngage© module (Fig. 1C). In addition, through an experiential learning approach, iEngage© supports skill building in recognising and setting internal standards of PA intensities. This is done through understanding how intensity of actual PA relates to perceived exertion. As part of each module, participants practice short bouts (5 to 10 min) of light, moderate and vigorous PA to build practical knowledge and gain experience of diverse PA intensities. Throughout the program, participants learn to assess exercise intensity using perceived rate of exertion and comparing their ratings with the information provided in the app via activity trackers. Each module involves BCTs as well as learning activities such as quizzes, self-assessment of goals’ achievement, individual learning, peer-learning, and goal setting (Fig. 1B, 1D). The general organisation of each module follows a consistent structure to facilitate adolescents’ engagement with the app. Consistency across modules reduces the cognitive effort in understanding the tasks, thus helps with engagement[21].

Goal setting

The process for personalised goal setting and assessment of achievements is designed as follows: in each module, the adolescent must set two types of goals for the next 3 days through two tasks: (1)

choosing the *amount of daily steps and MVPA* they aim for (quantitative goal) and (2) choosing a *mission* from four suggestions (qualitative goal). To facilitate the quantitative goal, the app proposes a finite list of increasing commitments to choose from, with increasing boundaries throughout the program. Step choices from modules 1 to 10 are: 5,000 to 7,000 steps in module 1; 6,000 to 10,000 steps in module 2 and so on. MVPA choices start from module 6 and increase from 20 min to 60-min daily of MVPA as follows: 9000 steps/day and 20 min of MVPA, 10000 steps/day and 30 min of MVPA, 11,000 steps/day and 40 min of MVPA, 12000 steps/day and 60 min of MVPA. The maximum number of steps is based on studies estimating that performing 12,000 steps/day is possible only if adolescents engage in at least 45 minutes of MVPA[22].

The missions encourage adolescents to engage with the program through diverse activities with their parents or siblings, as research shows the importance of family, friends and community in driving behaviour change in adolescents[23]. Examples of missions include sharing with family members their learning from the program, playing a sport game with friends or siblings, spending less time in sedentary activities, participating in more active play during recess at school or identifying small changes in their environment that could help them be more active.

Self-assessment of achievements against goals

In each module but the first one, the adolescent assesses their achievements against their individual goals. This involves: 1) reading the number of steps recorded daily via the activity trackers (Misfit Ray[(C)]) in the iEngage© app; 2) reporting achievements in the app, 3) providing a self-assessment of achievements by answering a quiz and 4) reporting on completion of their mission. It is made clear in module 1 that iEngage© focuses on progressing and achieving individual goals. iEngage© has no component involving ranking the adolescents' achievements and it has no competitive aspect. This is aligned with studies showing that competition and performance-based ranking can lead to adverse outcomes in adolescents[24].

Learning activities

Knowledge acquisition involves either quiet individual self-paced learning activities such as reading, watching videos, and answering quizzes, or peer-learning through open questions that adolescents discuss with their friends in the classroom or outdoor while walking in the playground. Each module includes some physical exercises, with sessions lasting 5- to 15-min. Physical activity is proposed as an experiential learning activity and skill acquisition, not as an exercise training session. The maximal amount of additional PA due to the program's activities during a module is 15 minutes[17]. The school did not propose additional physical education session during the program. iEngage© embeds gamification features as a strategy to enhance engagement and motivation: achieving goals, answering correctly to quizzes, or participation in the physical exercises, all provide opportunities to win points that unlock a badge. Each badge discloses a letter that will make a word by the end of the module and a full sentence (the iEngage© moto) by the end of the program. While this strategy aims at promoting engagement with each module through the recognition of achievements across knowledge and behaviours, it is also used

to develop a narrative across the program. Indeed, each completed module progresses the adolescent in their iEngage© journey which is mapped as an expedition around an imaginary island. A map showing their progress is presented at the end of each module (Fig. 2F).

iEngage App: design and mode of delivery

A key feature of the iEngage program lies in the digital integration via the iEngage© app and activity trackers worn throughout the program, providing 5 weeks of continuous PA data. The app interface is specifically designed to promote positive and inclusive user experience for 9–12 years old adolescents and develops a narrative on PA and health through a creative and colourful design. It brings into play five animal mascots, each dedicated to a specific activity (knowledge sharing, tips and skills learning, quiz, tracker synchronisation, goal setting and choosing missions, experiential activity). They signal the start of a specific activity, thus helping the transition between activities (Fig. 2B to 2H). An animated video embedded in the first module explains the program https://www.youtube.com/watch?v=AXpObnV72uI. The iEngage© kit is made of a digital tablet, a booklet where adolescents record information manually in writing during each module and add summary stickers, a Misfit Ray© activity tracker and earphones (Fig. 2A).

iEngage© program implementation: Study design

The research protocol and consent procedures were approved by The University of Sydney Human Research Ethics Committee (2017/272) and by the NSW Department of Education State Education Research Applications Process (2017151).

The study was conducted in 2017 and 2018 with a sample of one control class (26 students) and 2 intervention classes (57 students) in different schools located in the Sydney inner city area. Written consent was obtained from the principals, class teachers, parents and students. All participants were consenting students attending a Year 5/6 class and were able to withdraw from the study at any time. The 2017 and 2018 studies were conducted over the same month (November) of each year and the data were combined for analysis. The program was delivered over 5 consecutive weeks. The research team attended the school to supervise the delivery of the program in the morning, usually between 9AM and 11AM. The control class received no program over the 5 weeks.

The participants' MVPA was objectively measured prior the program and after completion of the last iEngage© module using a research grade accelerometer validated in young adolescents (GENEActiv)[25]. The GENEActiv accelerometer was worn on non-dominant wrist for three complete school days and nights. Data was collected at 60 Hz, downloaded using the GENEActiv software (Version 3.2) as 1-sec Epoch and analysed using 3-sec bouts[26]. The participants also completed a self-report questionnaire on their physical activity over the previous 7 days (C-PAQ)[27], providing a subjective measure of their physical activity. Baseline measurements including anthropometry (age, height, weight, waist circumference) and physical fitness tests (20m multistage shuttle test, flexibility, hand grip, vertical jump, agility) were

performed two weeks prior to starting the program in accordance with existing standards as previously described[28].

For the iEngage© classes participants wore a Misfit Ray© activity tracker continuously for the 5-week duration of the program on the non-dominant wrist. Misfit Ray© is a commercial tracker well tolerated by children and adolescents. Daily step counts were provided to the participant via the iEngage app during each module. In addition, raw data, averaged over 1 min periods were downloaded at the end of the program to allow analysis of daily steps consistency rate as previously described [17].

Goals, self-assessment, answers to quizzes, data from the activity tracker, and free text were all recorded in the iEngage app. The data from each module provided information on students' engagement with the program through goal setting and self-assessment of achievements. Self-reported data are reported as the percentage of participants achieving either personal goals, or the 11,000-step/day target.

Statistical analysis

Twenty six participants were included in the control group and seventy-one participants in the iEngage© group (36 from school A and 35 from school B), however the analysis was conducted with 57 participants. Fourteen participants were excluded from the analysis because they missed 3 or more modules due to absences, injury, or attendance to special study programs. No student asked to stop the program. Anthropometric, fitness and PA data from the activity tracker (daily steps collected at each module for 5 weeks) as well as GENEActiv data (collected and averaged over 3 school days before and after the iEngage program) are presented as mean +/- standard deviation (SD). Goals and achievements are presented as a percentage of students choosing or achieving a particular goal or PA level. To assess goal achievement for the whole cohort, data was aggregated over the 3 days preceding each module (57 participants x 3 days, Fig. 4). Missing data from the activity tracker dataset was imputed using regression analysis. Differences between groups and gender with regards to anthropometry and physical fitness were analysed using a two-way ANOVA (group x gender). Goals and achievements data were analysed using a Pearson Chi-square statistical test for goodness-of-fit. A one-way ANOVA (gender) with repeated measures was used to test goals progression during the program. Pre- post- MVPA was analysed in 23 control and 41 iEngage© participants GENEActiv datasets. A two-way ANOVA with repeated measures (gender x group) was used to test the impact of iEngage on PA as assessed by GENEActiv sensor before and after the iEngage program. The statistical analysis was conducted using IBM SPSS Statistics 24 Software (New York, USA). Statistical significance was set at alpha level = 0.05.

Results

Descriptive and baseline data

There was no statistical difference between control and experimental groups at baseline for anthropometric data, physical activity or physical fitness (Table 1). Most participants (77%) achieved aerobic fitness meeting the Health Fitness Zone criteria[29]. Self-reported PA (PA Questionnaire) showed

higher PA levels in boys and no difference between groups. Objective PA assessment via GENEActiv accelerometers showed that average daily MVPA for all participants at baseline was 50 ± 21.3 min/day with only 32% of participants achieving 60-min /day of MVPA. Overall, boys spent more time in MVPA at baseline (62.8 ± 23.2 min/day) than girls (43.3 ± 17.7 min/day) ($F(1, 5862) = 14.7$, $P < 0.001$).

Analysis of participants physical activity goals and self-assessment of achievements

On average, participants progressively and significantly increased their daily steps goals from 6,153 ± 774 steps/day in M2 to 9,153 ± 1317 in M6 and finally 10,461 ± 760 in M10 (Wilks' Lambda $F(8,17) = 91.1$, $P < 0.001$, Fig. 3A). We found that 9% of participants set their goals at 9,000 steps/day in M3 while 48% did so in M8 showing progression in PA goals (Fig. 3B). While participants could select 12,000 steps/day from module 8, 17% of participants set this goal in M8 compared to 27% in M10, with a marked difference between girls (7%) and boys (48%) (Fig. 3B). Across the program, boys set goals higher than girls by about 800 steps, aiming for ~ 11,200 steps at the end of the iEngage© program ($F(1, 24) = 4.46$, $P < 0.05$, Fig. 3A, 3B).

Within each module, students entered the daily steps recorded by the activity tracker for each of the previous three days. Results showed that students met or surpassed goals in the 3 days preceding modules M2, M3, M4, M6, M9 and M10 while they missed out on achieving goals in M5 and M8 (Fig. 4A). The proportion of days that the cohort achieved goals varied from 40–80% depending on the module as participants adjusted to step goals of increasing difficulty. Daily step goals were quite achievable at the beginning of the program and participants met or surpassed goals on most days (all: 72%, G: 70%, B: 79% of days following M2 and M3, Fig. 4B). At the end of the program, while goals were much more challenging, participants met or surpassed their daily steps goals (i.e., their average daily steps met their goals) on 55% of the days (M9 and M10, Fig. 4B). When asked to self-assess their achievements, participants said they had achieved or surpassed their daily step goals on 60% of the days in M2 and M3, and at least 50% of the days at the end of the program (M9, M10), showing a good interpretation of the step data they recorded in the app. Overall during the iEngage© program participants said they either achieved or almost achieved their goals on 77% of days (with no difference between boys and girls G:76%, B: 77%; Fig. 5A), while 10% across the program declared that they were "not quite there" and missed out. Overall, 79.5% of participants reported that they completed their mission (G:81%, B:78%, ranging from 62–89% across all modules, Fig. 5B).

We assessed participants' satisfaction with the program with a simple question at the end of each module ("did you have fun in completing the module") using a Likert scale (1 to 5). The average score for the whole program was 4.3 ± 0.99.

Analysis of participants objective measures of physical activity using activity trackers data

Objective continuous assessment of steps via Misfit Ray© activity trackers during the program showed that both female and male participants increased their daily steps over time (Table 2, ANOVA with repeated measures all: F = 12.2, P = 0.001). Comparing the first 4 with the last 4 days of program showed that daily steps increased by 2,647 steps/d (30% increase, all: 8,625 ± 1,263 versus 11,272 ± 1,471 steps/day, G: 8,545 ± 1,704 versus 10,155 ± 719 steps/day, B: 8,703 ± 895 versus 12,387 ± 1,070 steps/day; Table 2). During the program, daily steps dropped during weekends and raised again during school days with highest achievements seen after M5 and then M7 and M8 (Fig. 6A). Consistency analysis showed that the proportion of days consistently displaying daily steps above 11,000 steps increased from 35% at the beginning to 48% at the end of the program, and up to 58% of days in male participants. Consistency was lower in girls compared to boys across the program with a more pronounced difference toward the end (Fig. 6B). This difference between boys and girls is well aligned with the data reported in the platform by participants (Fig. 4C). Objective data collected via GENEActiv accelerometers pre- and post- program or control indicated a significant increase in MVPA after iEngage© and a significant difference between the iEngage and control groups (Table 2, 49.6 ± 19.1 pre- versus 54.3 ± 26.5 post- min/day in iEngage© group; 54.9 ± 26.2 pre- versus 49.8 ± 19.8 post min/day in the control group, time*group, Willks' Lambda, F(1,63) = 5.41, P = 0.023). Boys tended to increase MVPA more than girls (Table 1, time*group*gender, Willks' Lambda, F(1,62) = 3.30, P = 0.073. Analysis of physical activity patterns over the full school day showed that opportunities to spend more time in MVPA in response to the iEngage© program were found during school time (recess and lunch breaks) and after school, about one hour after school until 7PM (Fig. 6C). After school, both light and MVPA increased while time spent in sedentary time decreased.

Discussion

iEngage©, a health education and behaviour change program integrating a digital app and activity tracker, guided adolescents' engagement and progression toward higher PA goals and achievements. Adolescents almost doubled steps goals during the program however girls progressed their PA goals slower than boys. They self-reported achieving goals and completing mission over the program at rates above 75% with no difference between boys and girls.

The 5-week program led to increased daily PA (+ 30% or + 2647 steps/day) in both boys and girls, and consistency in achieving 11,000 daily steps increased from 35–48% during the program, boys achieving higher consistency (58%). Accelerometry data collected pre and post the implementation of the iEngage© program indicate that adolescents increased MVPA in daily life through short bouts of activity during recess, lunch and after school.

iEngage, goal settings and achievements

This study is the first to report on the implementation and outcomes of a fully integrated mobile health program in primary school context, using both data self-reported by participants and continuous monitoring of PA during the program. iEngage© was based on BCTs, the Australian physical literacy framework and WHO recommendations for in adolescents[18,20,30]. In addition, it encouraged connections

with friends, siblings and parents through the accomplishment of missions, aiming to endorse the program beyond the school context, as recommended in the literature[12,13].

While multicomponent school interventions address key determinants of PA, they are also complex, often resulting in poor implementation fidelity and low effectiveness[31]. Digital technologies provide the combined opportunity to enhance fidelity for program deployment, to record and evaluate process and to track engagement during the program[31]. iEngage© takes the full advantage of digital technology through continuous recording of PA behaviour for 5 weeks and capturing all students' interaction with the platform.

Recent systematic reviews and meta-analysis found interventions using diverse degree of mobile health technologies targeting the promotion of healthy behaviours in schools, however none used mobile health[14,32]. None of the identified primary studies integrated activity trackers in an educational program and none were set to provide continuous recording and self-monitoring of PA during the intervention. While commercial PA apps exist and may provide an option, a study showed that only a few are suitable for children and adolescents[16]. In addition, these apps have a limited use of BCTs, provide poor information quality and do not take advantage of scientific evidence[16]. In addition, mobile apps alone or activity trackers alone do not seem to achieve change of health-related behaviour[24,33]. Furthermore, studies showed that if students are not appropriately supported when provided with commercial activity trackers and apps, they may feel guilt and internal pressure particularly if a feeling of competition is developed or encouraged[24]. More recently new evidence-based digital apps designed for adolescents integrated functionalities including self-monitoring of health behaviours but did not integrate activity trackers, experiential learning and self-assessment[34]. By contrast, iEngage© successfully promoted user engagement via several techniques and features including health and PA education, digital literacy uplift, self-paced goal settings, regular self-assessment of PA achievements against goals, an inclusive design, and missions that aimed to connect the program with the family as previously recommended[18]. These features and activities were supported through activity tracker data embedded in a structured framework using consistent wordings and graphics, allowing all participants to keep up with the process and to focus on learning and progressing their PA levels. iEngage© promoted achievement of own goals rather than competing for highest PA levels. We found a good concordance between self-reported steps achievements and objective steps/day levels during the intervention, as well as sustained positive feedback indicating a high level of engagement with the program and the app[16]. This is important since self-efficacy, autonomy in goals-setting and self-assessment as well as intrinsic motivation, which are core to iEngage©, predict the development of PA in young adolescents[35]. It is known that PA behaviour varies between school days and weekend days particularly in less active adolescents[36]. Continuous recording and analysis of daily steps over the duration of the program shows that daily PA behaviour did not change linearly and that continuous monitoring during intervention is key to understand patterns. Our study shows that the impact of the program on PA behaviour was stronger during school days compared to weekends, with sharp drop in daily steps over each weekend captured in the study. The effectiveness

of a module delivered on Fridays was probably dampened by the change in environment and opportunities during the following weekend days. This suggests that future programs will need to include modules specifically targeting weekends with objectives and goals better adapted to family activities while aiming for maintaining a minimal acceptable level of PA.

Impact of iEngage on MVPA

MVPA can only be assessed through research grade accelerometers which do not provide information to the user on their PA. This was done before and after the program in the iEngage group and before and after a 5-week period in the control group over the same weeks of the school term. At baseline, daily MVPA in all participants was on average ~ 50 min /day with higher MVPA engagement in boys (~ 63 min) compared to girls (~ 43 min), and only 32% of the cohort achieving 60-min/day MVPA on average[30]. Our data compare well with previous studies using activity trackers in similar age groups: average daily MVPA has been reported to be around 50 min, with more MVPA time in boys compared to girls in Australia[37,38] or in the UK where the school system is comparable[36].

When analysing post- versus pre-intervention PA, previous systematic reviews and meta-analysis found no or little effect of school-based interventions, with no significant differences between those using or not web-based technology[14,31]. Our study shows small changes, however, comparable to those obtained after much longer multicomponent school programs[31], indicating that our approach and a shorter program was effective. Analysis of hourly MVPA patterns indicated that 48% of the daily MVPA was achieved before the start of class, during lunch break, at recess and just after school (respectively contributing 15%, 10%, 11% and 11% of daily MVPA). On average school hours are more active and less sedentary than the rest of the day. Our results also showed that adolescents increased MVPA during lunch time and recess (+ 40% MVPA, + 4 min) despite the relatively short duration of these periods, indicating that school time provides opportunities[30] for MVPA. Overall, our results demonstrate that, after completing iEngage, adolescents were able to effectively identify opportunities for MVPA and that they built up MVPA levels in daily life via short bouts of activities. This may be a direct impact of the program during adolescents were encouraged to identify and take the opportunity of times of the day to be more active, particularly with friends and siblings.

One study[37] found that MVPA was the most important activity behaviour for body composition in 11-12-years old and that conversion of sedentary time or light PA time was effective to prevent fat gain pointing to the importance of focusing on MVPA, rather than light PA or sedentary time, for intervention in children and adolescents. The authors found that participants doing on average 23-min MVPA daily, the re-allocation of 30 min daily to MVPA from sedentary time was key to influence body composition. Our results, as well as those from others indicate that interventions with higher initial MVPA lead to an increase in MVPA in the range of 5 to 10 minutes. Shifting toward more MVPA, even in small amounts after school may have significant health impact since it has been shown that sedentary after school time was often associated with recreational screen time and consumption of unhealthy foods[39]. Importantly, avoiding a decrease in MVPA must also be an important target[37]. Our results indicate that participants in

the control group decreased their MVPA during the same 5-week period (and same period of the calendar year), reinforcing the outcome of the iEngage© program.

Gender

Adolescent boys and girls differed from each other with regards to both PA levels and the way they responded to the program. While all students developed competences in setting goals, girls tended to be less ambitious with setting daily step goals during the whole program, progressing goals slightly slower than boys on average. This indicates that, although they were exposed to the same program, the pace at which girls were willing to progress was slower than for the boys. This attitude toward goals setting cannot be explained by physical capacity since girls in the program had similar or slightly better performance across all baseline fitness tests. However, we cannot exclude the impact of perceived fitness or to social norms on goal setting[40]. While girls set goals at lower step levels during the program, they still struggled to achieve their goals after module 8 when the program encouraged participants to progress above 10,000 steps. Our results still show a significant progression of daily steps in girls, but a longer program may be better suited to the way girls wish to engage with PA programs. Other studies have pointed to the fact that there may be less opportunities for girls to further engage in PA afterschool[41], but differences between boys and girls with regards to intrinsic motivation or self-efficacy may play a role[35].

While both girls and boys increased daily PA, boys were more successful than girls in increasing MVPA following iEngage. The greater enhancement of PA in boys compared to girls aligns with previous studies on school-based PA interventions including either single (PA) or combined (PA and nutrition) components[42] and with multicomponent school-based web-based health interventions[14]. More specifically, a comprehensive intervention tailored to 13-year-old adolescent girls, including sport, lunch time PA and seminars conducted over 12 months failed to increase PA assessed via accelerometry[43]. While it cannot be excluded that PA changed during the program, it was not possible to show any significant modification after the program[43]. A meta-analysis of interventions conducted in any setting in girls aged 12–18 years reported small size effects, large heterogeneity and concluded that behaviour change in girl adolescents will likely be challenging but that school intervention may be more effective[41].

Limitations

One limitation of this study is the relatively small cohort however our results were consistent across the two schools. In each school, all year 5 and 6 students were included indicating that a whole class can participate in the program. iEngage© is a short program with 10 modules delivered over 5 weeks. While this allows for strong focus and facilitates sustained motivation, a slower pace may be envisaged to enable progression and maintenance at slower rates, which may be more suitable for female adolescents. This study specifically focused on PA changes during the program and immediately after, however allowing the adolescents to keep the Misfit Ray© activity tracker and to synchronise weekly with the app once the program is completed could encourage sustaining the behaviour over longer periods.

Conclusions And Further Directions

Delivered through a tailored digital environment, iEngage© combines health education, experiential learning, interaction with peers and behavioural change theory. It enables individual goal setting, self-monitoring and self-assessment. In addition, iEngage© provides researchers with a powerful tool to study how adolescents respond to information, activities and goals setting through continuous recording embedded in the app. In the future, iEngage© could be considered to help adolescents maintain or increase PA in situations such as pandemic-induced lockdown and remote school activities but also in paediatric populations in which PA behaviour is important.

Declarations

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Data availability

Data will be made available upon request.

Mixed competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: CD and SL have no competing interests. CC, OG, KY and GC received a research grant from Australia Diabetes Research Trust to conduct the research. GC is employed at bepatient (an Alira Health company) a digital health company that provided technical support for the integration of the program into the bepatient digital platform.

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Tables

Table1. Participants' age, physical measures and physical fitness (G: girls, B: boys).

Group (G/B/All)	gender	Age (y)	Weight (kg)	Height (cm)	Waist $ (cm)	% fat	BMI (kg/m^2)	waist to height $	VO2max (ml/kg/min)	Running Speed (km/h)	Agility (s)	Vertical Jump (cm)	Flexibility $ (cm)	Hand Grip $ (kg)
CONTROL														
G	16	**10.4**	**37.4**	**144.5**	**66.6**	**21.8**	**17.8**	**0.46**	**46.4**	**10.2**	**14.6**	**25.9**	**23.0**	**14.3**
		0.5	7.9	6.9	7.1	5.1	2.5	0.03	5.4	1.0	1.1	5.6	8.1	4.3
B	10	**10.4**	**45.2**	**147.5**	**77.6**	**24.4**	**20.7**	**0.53**	**45.5**	**9.9**	**14.3**	**26.7**	**10.1**	**13.8**
		0.5	12.5	5.2	11.9	8.3	5.3	0.08	4.0	0.9	1.9	6.2	9.3	5.1
ALL	26	**10.4**	**40.4**	**145.6**	**70.8**	**22.8**	**18.9**	**0.49**	**46.1**	**10.1**	**14.5**	**26.2**	**18.0**	**14.1**
		0.5	10.4	6.4	10.6	6.5	4.0	0.06	4.8	1.0	1.3	5.7	10.6	4.5
iEngage intervention														
G	29	**11.2**	**44.2**	**150.7**	**69.2**	**23.6**	**19.3**	**0.46**	**45.7**	**10.3**	**13.9**	**27.6**	**25.8**	**21.2**
		0.6	11.4	7.7	9.7	6.9	3.5	0.05	4.7	0.9	0.9	6.2	8.4	4.7
B	28	**10.7**	**42.7**	**147.8**	**71.2**	**20.5**	**19.2**	**0.48**	**44.2**	**9.8**	**14.1**	**27.3**	**15.3**	**17.3**
		0.7	11.8	7.6	10.5	8.4	3.7	0.06	5.3	1.0	1.7	8.7	6.1	4.7
ALL	57	**10.9 ***	**43.5**	**149.3**	**70.5**	**22.1**	**19.2**	**0.47**	**45.0**	**10.1**	**14.0**	**27.4**	**20.6**	**19.3**
		0.7	11.5	7.7	10.0	7.8	3.7	0.06	5.0	1.0	1.4	7.5	9.0	5.1

*: P<0.05 Control compared to iEngage group

$: P<0.05 female compared to male participants

Table 2. Physical activity assessed via physical activity questionnaire (PAQ), daily steps via wrist step tracker Misfit and moderate to vigorous physical activity (MVPA) assessed using GENEactiv wrist accelerometer. Statistical analysis showed an increase in physical activity across all methods of measure.

Group (G/B/All)		PAQ score PRE	PAQ score POST	Daily steps First 4 days	Daily steps Last 4 days	Geneactiv MVPA PRE (min /day)	Geneactiv MVPA POST (min /day)
				CONTROL			
G	m	2.49	2.59			43.3	42.3
	SD	0.87	0.49			17	10
B	m	2.75	2.2			74.1[&]	61[&]
	SD	1.07	0.92			28	26.9
ALL	m	2.59	2.44			54.9	49.8
	SD	0.94	0.92			26.2	19.8
				iENGAGE			
G	m	2.54	2.74	8545	10155 **	43.7	46.6
	SD	0.92	0.49	1704	918	17.6	21.6
B	m	3.02	3.08	8703	12387 **	57.2[&]	64.1[&]
	SD	0.87	0.66	994	1077	18.7	29.1
ALL	m	2.77	2.91 *[#]	8625	11272 **	49.6	54.3[#]
	SD	0.92	0.6	1263	1471	19.1	26.5

PAQ was completed by participants before and after the program. Step data from Misfit Ray© activity tracker was averaged over the first 4 days and the 4 last days of the program. Daily MVPA was calculated over 3 school days before and after the program.

*: P<0.05 Pre compared to post in each group; [#] P<0.05 Interaction effect group x time; **: P<0.01 steps achieved at the end compared to the beginning of the program in each group; [&]: P<0.01 gender effect in each group.

Figures

Figure 1

iEngage© structure. Description of the content of each module and the progression through the various stages of behaviour change. Individual goal setting (daily steps goals and missions) started in module 2 (A). Panel B: Mapping of each module content with behavioural change techniques (B). Panel C: mapping with the Australian physical literacy framework. Each square represents an activity which is colour coded to show mapping with the framework. Panel D: mapping of all activities within each module across the program. Each activity is coded as per the legend.

Figure 2

iEngage© design. Design of the iEngage© app interface and overview of the user experience. The iEngage© kit including a tablet, a Misfit Ray activity tracker, earphones and a booklet (A). The digital environment supporting the diverse activities (B to H) included a welcome screen displaying learning objectives (B), health education, quiz and badges reward (C), synchronisation with trackers (D), self-assessment and goals setting (E) that included visuals of daily steps and time spent in MVPA,

experiential learning (F), goals setting and mission (G) and the iEngage© journey mapping showing progress toward the iEngage© secret message (H).

Figure 3

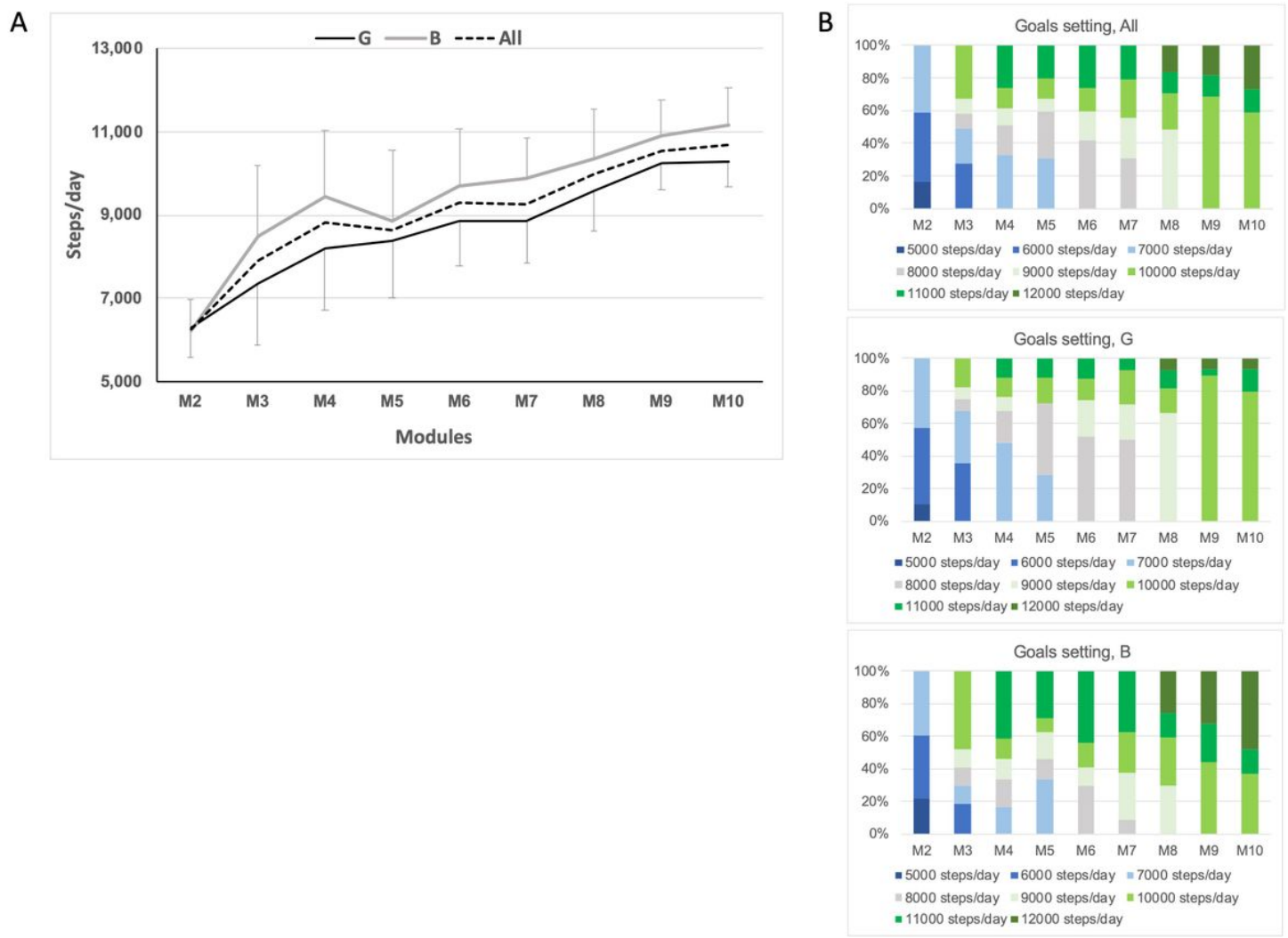

Figure 3

Goals setting. Panel A: average daily steps goals set by adolescents over the course of the program for each module. Goals increased from module 2 to module 10 (Wilks' Lambda $F(8,17) = 91.1$, $P<0.001$). There was a significant gender effect ($F(1, 24) = 4.46$, $P<0.05$) with boys aiming for higher daily steps goals. Panel B: proportion of adolescents choosing a given step goal for each module. Note: From M6, goals also included a minimum amount of MVPA (10,000 steps and at least 15 min MVPA, 11,000 steps and at least 15 min MVPA, 12,000 steps and at least 30 min MVPA).

Figure 4

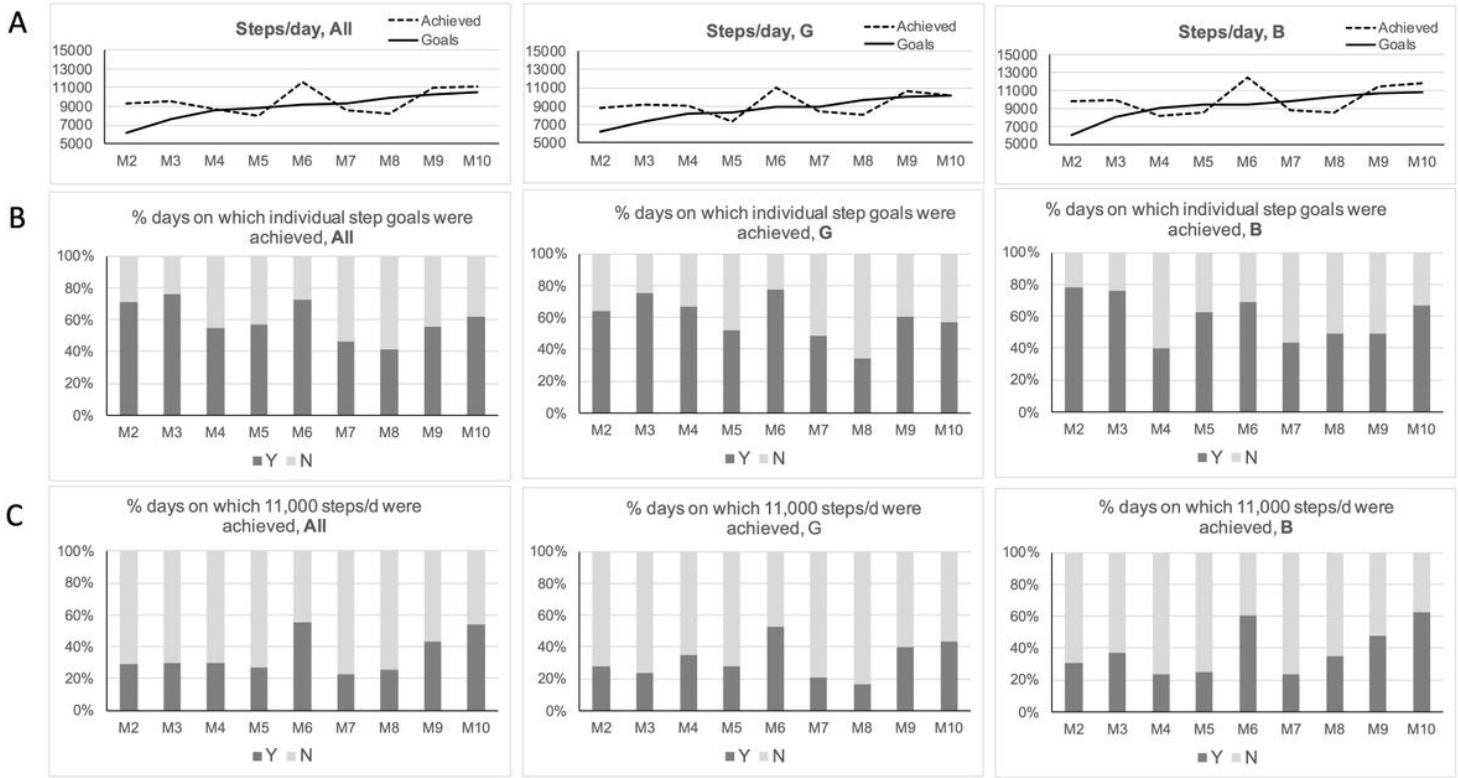

Figure 4

Self-reported Achievements. Daily steps reported by the adolescents in each module. The step value reported for each module is the average of daily steps performed during the 2 or 3 previous days (between 2 modules). Panel A: averaged daily steps goals and achievements reported by adolescents in the app as part of each module's self-monitoring activities. Panel B: proportion of days on which individual step goals were achieved (Based on self-report of step data). Panel C: % of days on which 11,000 steps/d were achieved calculated from self-reported step data. **: P<0.01, Chi Square test. Compared to predicted form M2 (30% Yes and 70% No). All: all participants, B: boys, G: girls.

Figure 5

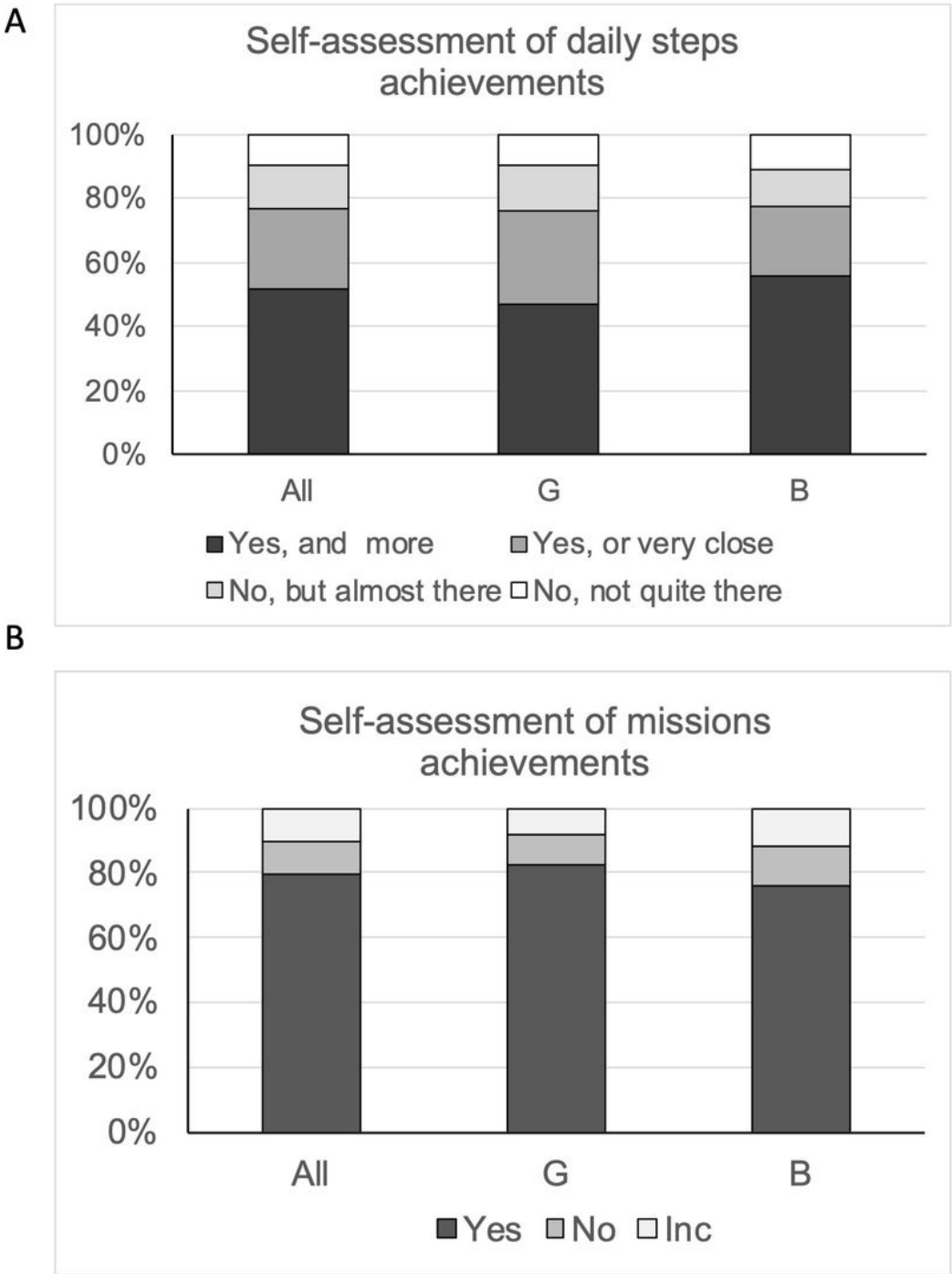

Figure 5

Self-assessment of achievements. Self-assessment of individual step goals achievements (A) and completion of missions (B) during the program (Inc: incomplete, no answer to the question). Results are expressed as percentage of participants. There was no significant difference between boys' and girls' report of achievements based on individual goals. All: all participants, B: boys, G: girls.

Figure 6

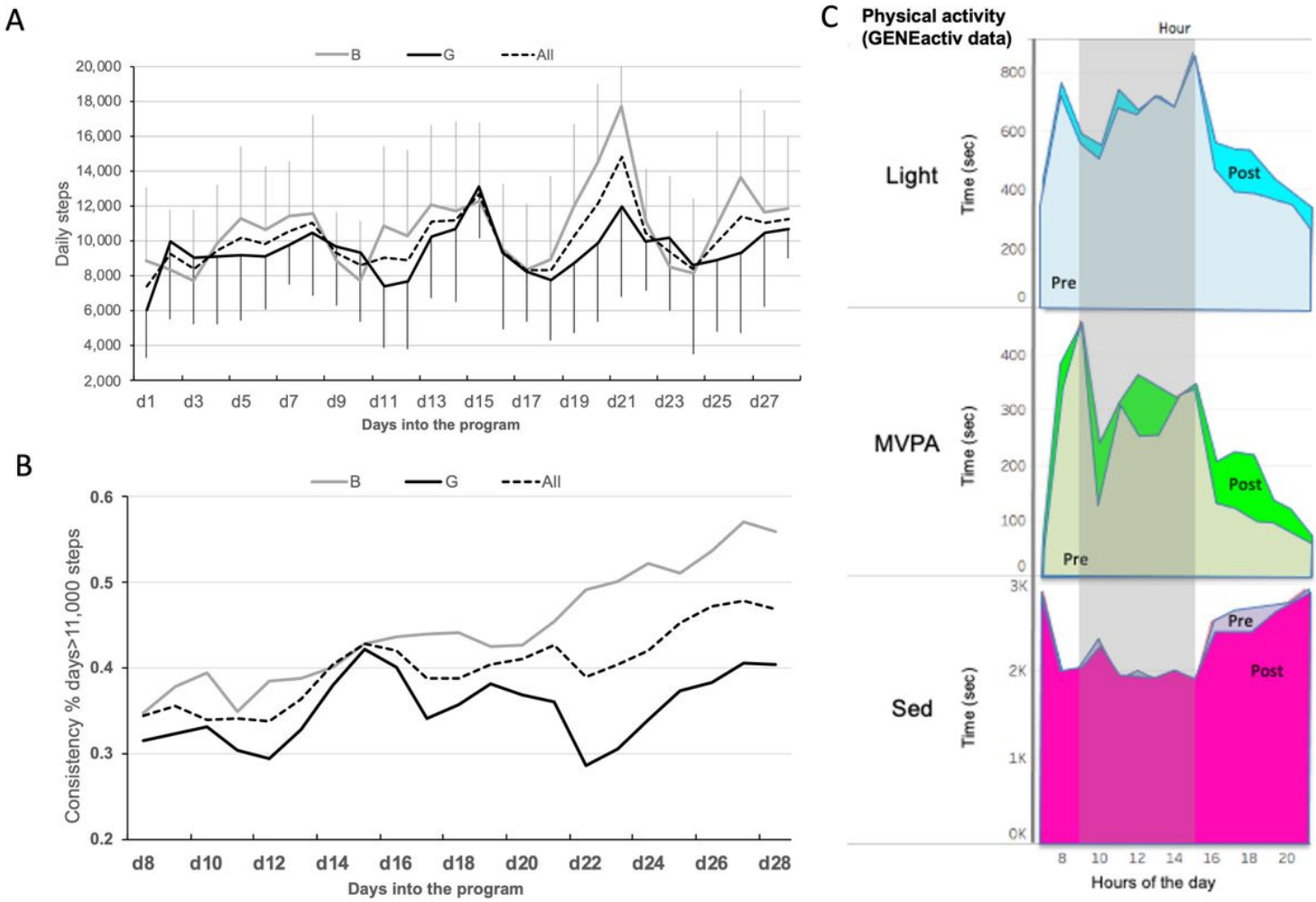

Figure 6

Objective PA data extracted from the Misfit trackers integrated in the platform or GENEactiv acidity trackers. Panel A: daily steps in all students, girls and boys, during the 5 weeks of the iEngage© program. Panel B: consistency (%) of daily steps displaying at least 11,000 steps) over the course of the program. Panel C: hourly average of physical activity per intensity category (SED, light and MVPA) measure by GENEactiv trackers pre and post program from 8am to 8pm. This shows patterns of PA before and after the iEngage© program during a school day. All: all participants, B: boys, G: girls.