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REVIEW ARTICLE

# Effects of Gamified Smartphone Applications on Physical Activity: A Systematic Review and Meta-Analysis

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**Introduction:** This systematic review and meta-analysis aims to examine the impacts of standalone gamified smartphone application-delivered interventions on physical activity.

**Methods:** Web of Science, Scopus, PubMed, PsycINFO, and ACM Digital Library were searched for publications that were published between January 1, 2008 and August 31, 2021. Eligibility criteria were RCTs or single-arm pre-to-post interventions delivered by standalone gamified applications and targeting physical activity. Study-specific results were analyzed using random-effects meta-analysis, with a standardized mean difference. Meta-regressions, subgroup analyses, and sensitivity analyses were performed. PRISMA guidelines were followed, and the Grading of Recommendations Assessment, Development and Evaluation system was used to determine the strength of the evidence.

**Results:** A total of 19 studies with 24 gamified applications were eligible, and 16 studies were included in the meta-analysis. Standalone gamified applications had a small-to-moderate effect on physical activity in both the between-group RCTs ($n$=12 applications, standardized mean difference=0.34, 95% CI=0.06, 0.62, $I^2$=72%, $p$<0.01; Grading of Recommendations Assessment, Development and Evaluation: moderate) and the within-group pre-to-post interventions ($n$=18 applications, standardized mean difference=0.38, 95% CI=0.17, 0.59, $I^2$=74%, $p$<0.01; Grading of Recommendations Assessment, Development and Evaluation: very low). Leave-one-out sensitivity analyses sustained the main effects with lower heterogeneity ($I^2$ of 31.0% and 47.8%, respectively).

**Discussion:** Using gamified smartphone applications as standalone interventions may increase physical activity. Future research could investigate the impacts of gamified applications on physical activity by isolating the role of specific single or clustered groups of application features.
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## INTRODUCTION

Physical activity of any intensity has been proven to help prevent and manage several chronic diseases and improve health.[1,2] Despite this, many adults and adolescents fail to achieve the recommended levels of physical activity.[3] Technology-based tools have been developed to help individuals initiate and maintain physical activity. Smartphone applications (apps) are regarded as particularly promising,[4] although their effectiveness might be modest and impaired by poor user adherence.[5,6] Therefore, strategies are needed to increase the effectiveness of physical activity interventions delivered by smartphone apps.[7]

Gamification is a prominently used design strategy in promoting physical activity.[8] *Gamification* is defined as the use of game design elements in non-game contexts.[9] Gamification commonly incorporates features,[10] also referred to as affordances,[11] such as storytelling, the

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implementation of challenges that need to be mastered, and points to be collected.[9,12] In the context of fitness, gamified apps include features to increase user motivation, particularly intrinsic motivation (i.e., the joy of performing the activity per se), and sustain physical activity habits over time.[13] Although gamification features have been widely implemented in health and fitness apps,[14−16] they often insufficiently rely on behavioral theories,[14] behavior change techniques (BCTs),[15] or behavioral economic principles.[16]

The literature on gamification and physical activity lacks systematic reviews and meta-analyses of studies that assess the impacts of standalone gamified apps on physical activity. One previous systematic review presented an overview of the appropriateness of gamified apps for physical activity.[7] The authors emphasized the importance of gamified app usage in physical activity as a new research field, where the effectiveness could neither be determined nor subjected to meta-analysis. Another systematic review assessed whether previous studies revealed positive, null, or negative effects but did not provide any further quantification.[8] Although the inclusion of multiple intervention factors besides gamification (e.g., studies that added in-person counseling to gamified app interventions) benefited the pooled effect size, it also increased the between-study heterogeneity. Importantly, none of the previous reviews[7,8,17,18] focused on standalone gamified apps (i.e., without additional supervision or support) or exclusive app use (i.e., without additional intervention types). Assessing the impacts of standalone gamified apps on physical activity is important to study cause-effect relationships without influence from confounds. Indeed, most individuals use their apps without any additional support. Furthermore, it has been claimed that entirely app-based interventions are cost effective to be generalized in free-living conditions.[19]

This systematic review and meta-analysis aims to synthesize the effects of standalone gamified smartphone app-delivered interventions on physical activity in both RCTs and single-arm pre-to-post interventions. Given the need to promote physical activity in all age groups, this study does not limit its analysis to 1 particular age group.

# METHODS

This study follows the PRISMA guidelines[20] and the Cochrane Collaboration handbook.[21] The review protocol was registered with the International Prospective Register of Systematic Reviews (CRD42020209502).

## Search Strategy

A systematic search was performed in 5 databases (Web of Science, Scopus, PubMed, PsycINFO, and ACM Digital Library) through August 31, 2021. The publication year was restricted to the period beginning in 2008 when the term *gamification* originated in the literature.[9] The search was restricted to peer-reviewed journal or conference articles with English full texts. The search string combined 3 groups of keywords: *gamification, smartphone app*, and *physical activity* (details are in Appendix Table 1, available online). Serious games, video games, or exergames were excluded from the review. Forward and backward tracking was performed by examining the reference list of relevant articles.

## Eligibility Criteria

This review included studies based on the predetermined Population, Intervention, Comparison, Outcomes, and Study design criteria.[21] Specifically, studies were eligible if they meet the following conditions: (1) population of any health status and age (adults, children, or adolescents were considered, given the need to promote physical activity in all age groups[2]); (2) interventions are standalone (with no additional supervision or support) gamified smartphone apps targeting physical activity; (3) comparisons are either control groups in RCTs or pre-to-post measures of single-arm intervention groups; and (4) outcomes are indicators of physical activity.

## Study Collection and Data Extraction

Duplicates of the records were excluded. Titles, abstracts, and full texts were screened independently by the first (YY) and second (HH) authors. Any disagreements were discussed with the last author (JK) until a consensus was reached. The information on the included studies was then extracted into a Microsoft Excel, version 16.44, spreadsheet.

For qualitative synthesis, the following information was extracted: author name and publication year, study region, study design, participants' demographics, information concerning the gamified app, design and duration of intervention, and physical activity outcome. The gamification features used in the smartphone apps were extracted according to an established framework of features[11] adapted to the context of this research. In particular, this study considered core gamification features from the following domains: achievement (e.g., leaderboards and rankings, points, and scores—features whose main purpose is to increase users' competency, mastery, and growth) and immersion (e.g., storytelling and use of avatars—features whose main purpose is to immerse the user in a self-directed inquisitive activity). Additionally this paper refers to leveraging gamification features; they have the potential to enhance the gamification experience. Examples of leveraging features are social networking, real-world interactions, as well as reminders and notifications. The associated BCTs[22] were identified on the basis of authors' arguments as well as the conceptual origin of the respective feature and their linkage with specific BCTs.[15,23]

For the pooled meta-analysis, the means and SDs of the pre-to-post interventions were extracted. For studies that only provided either SEs and 95% CIs or medians and IQRs, the means and SDs were calculated using equations suggested by the Cochrane Collaboration handbook.[21] The mean values of sedentary time were multiplied by −1 to ensure that their effects had the same direction as those of other physical activity outcomes.[21] When studies involved multiple outcomes, only 1 main outcome (determined by the study's main purpose) was used for the main meta-analysis.

When studies considered ≥2 intervention groups, only the one using a gamified app was included. Data from 4 studies[24−27] were extracted at the authors' request. The data extraction was performed by the first 2 authors (YY and HH) and cross-checked by the last author (JK).

### Risk of Bias Assessment

Two reviewers (YY and HH) independently assessed the risk of bias and resolved any disagreements by consensus with another reviewer (JK). The Risk of Bias 2[28] was used for the RCTs ($n$=17), and the Risk of Bias in Non-randomized Studies of Interventions[29] was used for the single-arm pre-to-post interventions ($n$=2).

### Meta-Analysis

First, between-group analyses examined the differences between intervention and control groups for the RCTs. Second, within-group analyses assessed the changes from pre-to-post interventions among all the intervention groups in the included studies. Standardized mean differences (SMDs) were calculated on the basis of the different physical activity outcomes and units. Hedge's $g$ values of 0.2, 0.5, and 0.8 represent small, moderate, and large effect sizes, respectively.[21] A random-effects model was used on the basis of the assumption of different true effect sizes.[21] SMDs were back transformed to original units of measures for step counts (steps/day) and moderate-to-vigorous physical activity (minutes/day) to extrapolate the estimated effect size.[30] Statistical heterogeneity was tested with $I^2$ and $p$-value for the Q statistic. $I^2$ values of 25%, 50%, and 75% indicate small, medium, and large degrees of heterogeneity, respectively.[21] Publication bias was assessed by Egger's test[31] and was visually presented with contour-enhanced funnel plots to differentiate any sources of asymmetry (e.g., due to publication bias), where necessary.[32] The levels of evidence for the primary outcomes were assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) guidelines[33] (the detailed methodology is presented in Appendix Table 6, available online). All statistical analyses were performed with R studio software, version 1.4.1103, and the meta-analysis was conducted with the meta package.[34]

### Meta-Regression, Subgroup, and Sensitivity Analyses

Two meta-regressions were performed: one for intervention durations and another for sex (% female). A total of 6 subgroup analyses were conducted for the different study populations (healthy, patients), age groups (children and adolescents, adults, older adults), study designs (RCT, single arm; within group only), physical activity measurements (rather subjective, rather objective), physical activity outcomes (moderate-to-vigorous physical activity, step counts), and type of control group (waitlisted, active control; between-group only). The selection of the moderators was inspired by previous publications.[23] Significance levels were set at 0.1 for subgroup analyses[35] and 0.05 for meta-analyses and meta-regressions.[21] A total of 3 sensitivity analyses were performed: (1) the leave-one-out analysis for 1 study[36] with potential heterogeneity, (2) an analysis after removal of 2 studies[24,37] with a high overall risk of bias, and (3) an analysis that only included studies with ≥4 low risk of bias categories.[38]

## RESULTS

The initial database search yielded 1,268 records after removal of duplicates (Figure 1). After further title and abstract screening, 101 records were retrieved for full-text assessment. On the basis of the Population, Intervention, Comparison, Outcomes, and Study criteria, 82 articles were excluded (Appendix 1, available online, includes the full list of excluded studies with reasons). Inter-rater reliability was good ($\kappa$ statistic of 0.68) for the full-text assessment before reaching consensus among reviewers (Appendix 2, available online). A total of 19 studies[24−27,36,37,39−51] were finally included in the systematic review, and 16 studies[24−27,36,39−45,47,48,50,51] provided sufficient data for the meta-analysis.

### Study Characteristics

The 19 studies included in this systematic review were published between 2014 and 2021 (Appendix Table 2, available online). A total of 17 studies were RCTs, and 2 were single-arm pre-to-post interventions.[40,41] Participants were children and adolescents (2 studies), adults (15 studies), and elderly (2 studies). Two studies were conducted with patients,[36,47] and the remainder were with healthy people. The overall sample size was 1,908 (median=67 per study, range=18−354). All interventions were delivered by standalone gamified apps. For the RCTs, 6 were waitlisted control studies, and 11 were active control studies. The gamified apps were either self-designed (13 studies) or commercially available (6 studies). The duration of the intervention ranged between 1 and 24 weeks (median=7 weeks). Physical activity was measured either rather objectively (e.g., accelerometers, activity trackers, smartphone built-ins; 13 studies), rather subjectively (e.g., questionnaires; 2 studies), or with both types of assessments (4 studies). The main outcomes were moderate-to-vigorous physical activity and step counts. The quality assessment revealed some concerns (15 studies), whereas 2 studies were of high quality,[44,50] and 2 were of low quality.[24,37] Most of the studies were RCTs (17 of 19), in which 12 studies had ≥4 low categories of risk of bias. The full results of the quality assessment are provided in Appendix Table 4 (available online).

### Gamification Features

A total of 24 gamified apps were used in the 19 studies (Appendix Table 3, available online). In most of the apps, multiple features were input (from 1 to 9, a median of 4 per app). Figure 2 illustrates the frequency of 12 core gamification features that were identified (besides 7 leveraging features). In-game rewards, leaderboards and rankings, virtual teams and cooperation, and points and scores were the most frequently used core features for

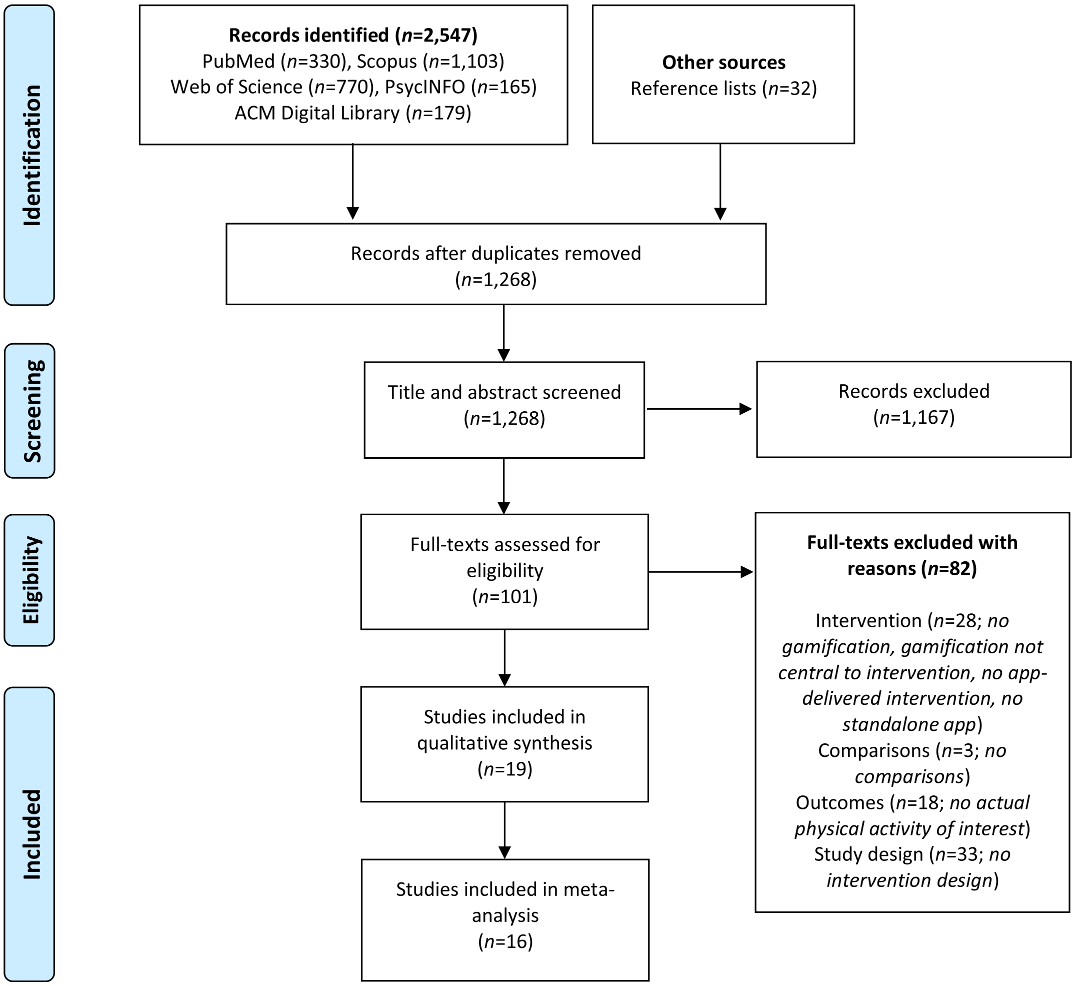



**Figure 1.** Flowchart of the included studies.

gamification (with an overall frequency of 4–14 and a median of 6.5). The most frequently implemented BCTs in the 19 studies were imaginary reward, comparison of behavior, and social support (Appendix Table 3, available online).

## Primary Meta-Analyses

In the between-group RCTs, the gamified smartphone apps had a small-to-moderate effect on physical activity ($n$=12 apps, SMD=0.34, 95% CI=0.06, 0.62, $p$<0.01; GRADE: moderate) (Figure 3). In the within-group pre-to-post interventions, the gamified smartphone apps had a small-to-moderate effect on physical activity ($n$=18 apps, SMD=0.38, 95% CI=0.17, 0.59, $p$<0.01; GRADE: very low). The high heterogeneity identified in both groups ($I^2$ of 72% and 74%, respectively) implies the importance of considering further moderators and sensitivity analyses. The results of the GRADE evidence are provided in Appendix Table 6 (available online).

## Meta-Regression, Subgroup, and Sensitivity Analyses

Figure 4 summarizes the results of the meta-regressions and subgroup analyses for the between-group RCTs and within-group pre-to-post interventions. In the meta-regressions, the effects of gamified apps on physical activity were significantly modified by the duration of the intervention ($n$=12 apps, SMD=0.05, $p$=0.006; positive effects with increasing duration) as well as sex ($n$=12 apps, SMD= −0.01, $p$=0.036; positive effects for male [versus female] participants) in the between-group RCTs. No significant effects were identified in the within-group meta-regressions ($p$>0.05).

In the between-group RCTs subgroup analyses, the effects were significantly modified by the study populations (with smaller, yet positive effects for healthy people [versus for patients], $p$=0.09). In the within-group pre-to-post interventions subgroup analyses, larger effects were identified for step counts ($n$=8 apps, SMD=0.69)

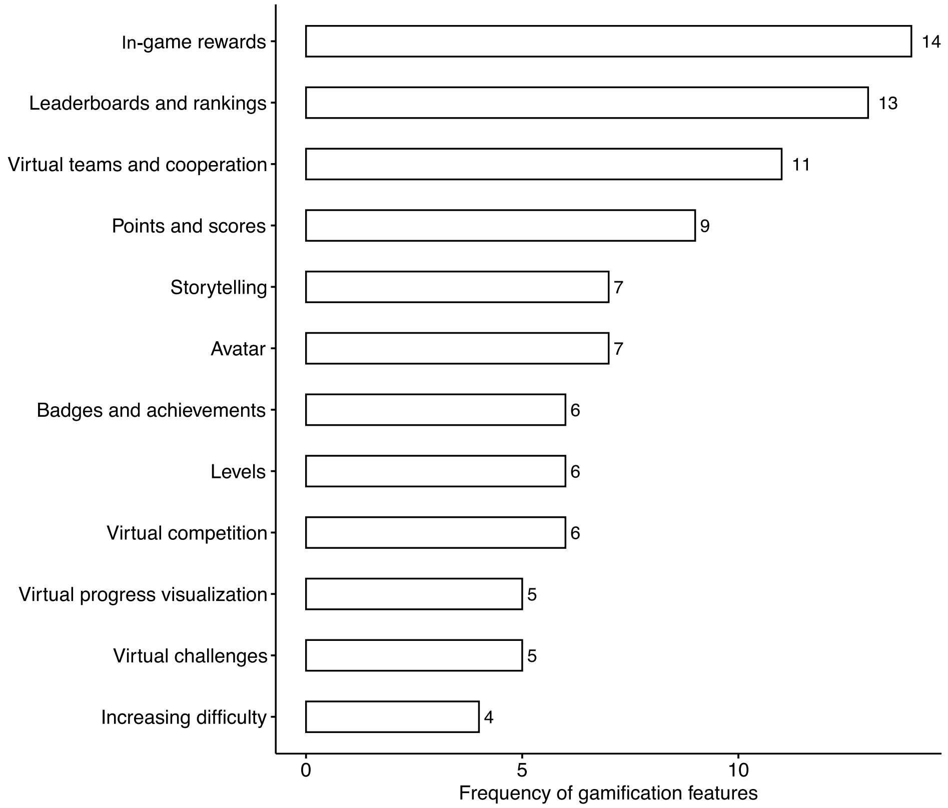



**Figure 2.** Prevalence of gamification features.
*Note*: The following leveraging features were identified: social networking (10), performance stats and feedback (9), goal setting (7), reminders and notifications (6), real-world interaction (5), peer rating (3), and personalization (1).

than for moderate-to-vigorous physical activity ($n$=10 apps, SMD=0.18, $p$=0.03).

A total of 3 sensitivity analyses (Appendix Table 5, available online) were conducted. The results were conducted. The results showed that the positive effects in the main analyses remained, supporting the overall results with a higher degree of certainty, with 1 exception: for studies with <4 low categories of risk of bias in the between-group studies, the effect was not significant using the conventional 0.05 cut off values for significance ($p$=0.095).

## Publication Bias

Contour-enhanced funnel plots and Egger's tests are presented in Appendix Figure 2 (available online). Egger's tests were nonsignificant for the between-group ($t$[df]=1.62 [10], $p$=0.14) and within-group ($t$[df]=1.61 [16], $p$=0.13) studies. They remained nonsignificant after the leave-one-out sensitivity analyses (between-group studies: $t$[df]=0.87 [9], $p$=0.41; within-group studies: $t$[df]=0.45 [15], $p$=0.66). The results indicated no publication bias.[31]

## Secondary Meta-Analysis

Further secondary meta-analyses were performed separately for each physical activity outcome in the within-group and between-group studies (Appendix Figure 1, available online). In the between-group studies, the effects of the gamified apps were significant for walking ($n$=3 apps, SMD=0.64, 95% CI=0.31, 0.96), with moderate-quality evidence. In within-group studies, the effects of gamified apps were significant for moderate-to-vigorous physical activity ($n$=10 apps, SMD=0.13, 95% CI=0.00, 0.25; GRADE: very low), step counts ($n$=10 apps, SMD=0.61, 95% CI=0.23, 0.98; GRADE: very low), total physical activity ($n$=2 apps, SMD=0.45, 95% CI=0.02, 0.88; GRADE: very low), and walking time ($n$=2 apps, SMD=0.77, 95% CI=0.39, 1.14; GRADE: very low). The analyses, in which SMDs were converted to original units, revealed an increase of 2,393 steps/day (95% CI=422, 4,361) in the between-group studies and of 2,839 steps/day (95% CI=1,270, 4,408) in the within-group studies and an increase in moderate-to-vigorous physical activity of 23.3 minutes/day (95% CI=4.1, 42.5) and 40.6 minutes/day (95% CI=18.2, 63.1) (Appendix 3, available online).

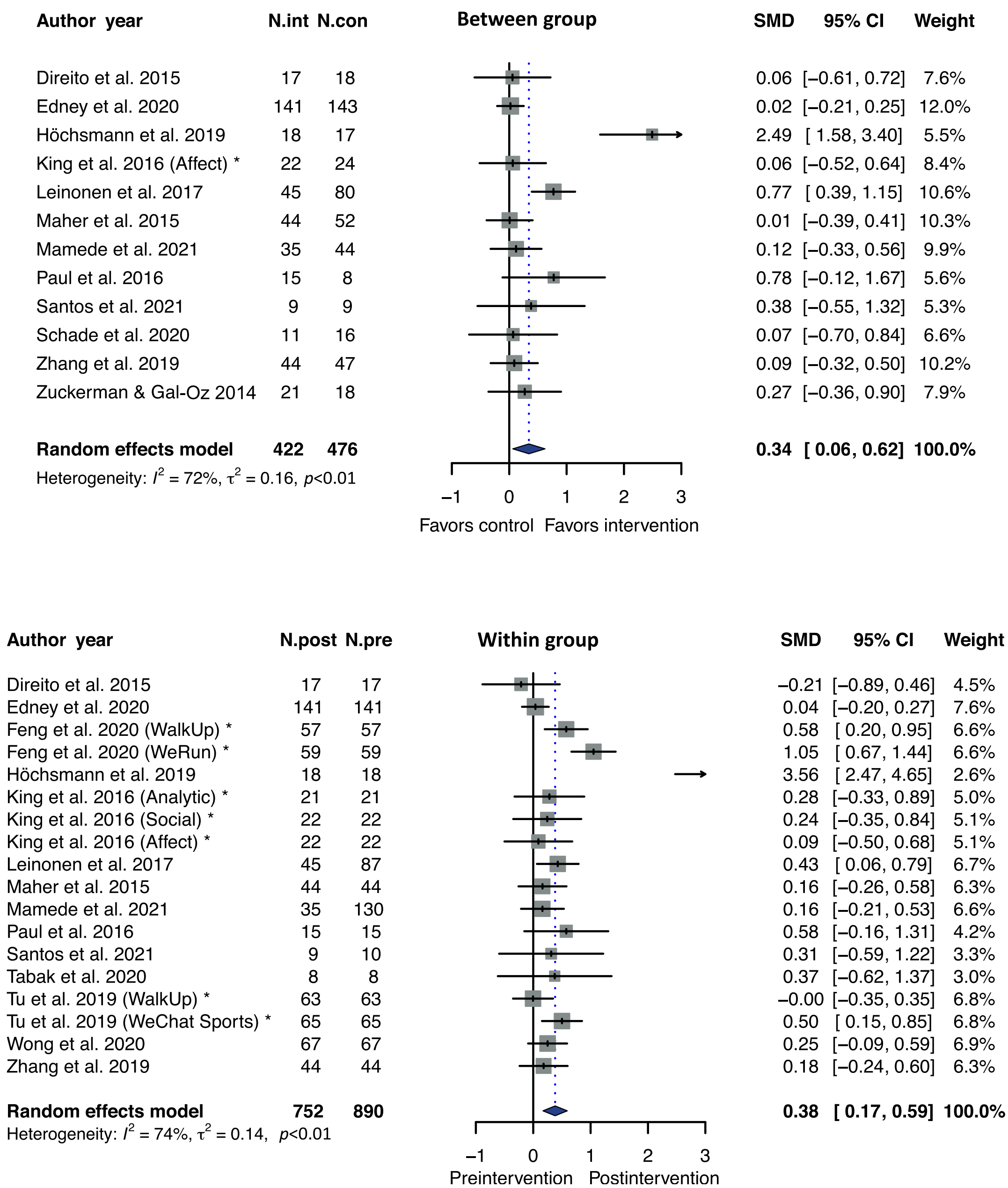
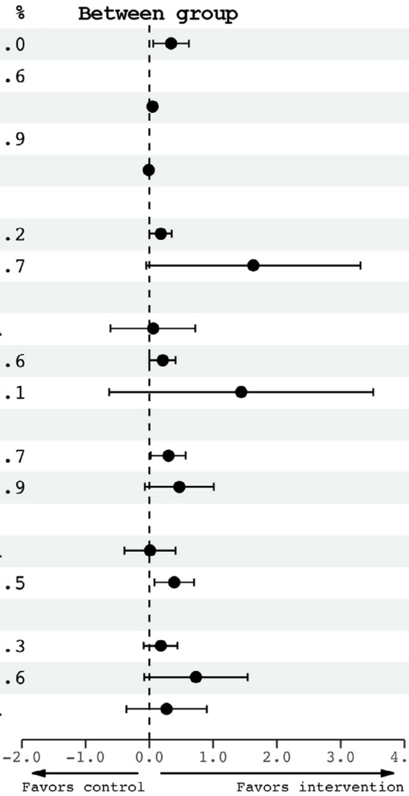



**Figure 3.** Overall effect size (SMD) and 95% CIs for the effects of standalone gamified smartphone apps on physical activity.
*Note*: *Multiple apps were used within one study. For studies with multiple physical activity outcomes, only one main outcome (e.g., MVPA, step counts) was extracted for the main analyses as defined in the methods.
Abbreviations: app, application; SMD, standardized mean difference; N.int, sample size in the intervention group; N.con, sample size in the control group; MVPA, moderate-to-vigorous physical activity.

## DISCUSSION

This is the first systematic review and meta-analysis to examine the impacts of standalone gamified smartphone apps on physical activity. Although other authors have conducted meta-analyses on the influence of app usage on physical activity, they did not specifically look at gamification and included not only apps but also mobile health and fitness devices, such as trackers, as well as studies in which supervision and counseling were provided, beside app-based interventions.[23,52] Therefore, the effects of standalone gamified apps have remained unknown until now. A total of 12 gamification features from 24 gamified apps were identified in RCTs and

| Moderator | $p$ | Studies | $I^2$ % | Estimate |
|---|---|---|---|---|
| All | <0.01 | 12 | 72.0 | 0.34 (0.06 to 0.62) |
| Duration (weeks) | 0.006 | | 60.6 | |
| 3 to 24 | | 12 | | 0.05 (0.01 to 0.08) |
| Gender (F%) | 0.036 | | 60.9 | |
| 0 to 100% | | 12 | | -0.01 (-0.02 to -0.00) |
| Population | 0.09 | | | |
| Healthy | | 10 | 29.2 | 0.18 (0.00 to 0.35) |
| Patients | | 2 | 85.7 | 1.63 (-0.05 to 3.31) |
| Age | 0.46 | | | |
| Children | | 1 | NA | 0.06 (-0.61 to 0.72) |
| Adults | | 9 | 43.6 | 0.21 (0.00 to 0.41) |
| Elderly | | 2 | 90.1 | 1.44 (-0.63 to 3.51) |
| Different control | 0.57 | | | |
| Active control groups | | 6 | 39.7 | 0.30 (0.02 to 0.57) |
| Waitlist group | | 6 | 82.9 | 0.47 (-0.07 to 1.01) |
| PA measurement | 0.14 | | | |
| Rather subjective | | 1 | NA | 0.01 (-0.39 to 0.41) |
| Rather objective | | 11 | 73.5 | 0.39 (0.08 to 0.70) |
| PA outcome | 0.44 | | | |
| MVPA | | 6 | 59.3 | 0.18 (-0.09 to 0.44) |
| Step counts | | 5 | 82.6 | 0.73 (-0.08 to 1.54) |
| Walking | | 1 | NA | 0.27 (-0.36 to 0.90) |




| Moderator | $p$ | Studies | $I^2$ % | Estimate |
|---|---|---|---|---|
| All | <0.01 | 18 | 74.0 | 0.38 (0.17 to 0.59) |
| Duration (weeks) | 0.054 | | 75.3 | |
| 3 to 24 | | 18 | | 0.04 (-0.00 to 0.08) |
| Gender (F%) | 0.17 | | 72.9 | |
| 0 to 100% | | 18 | | -0.01 (-0.02 to 0.00) |
| Population | 0.24 | | | |
| Healthy | | 16 | 50.0 | 0.29 (0.13 to 0.44) |
| Patients | | 2 | 95.0 | 2.04 (-0.89 to 4.97) |
| Age | 0.37 | | | |
| Children | | 2 | 30.5 | 0.11 (-0.30 to 0.53) |
| Adults | | 13 | 57.9 | 0.32 (0.15 to 0.50) |
| Elderly | | 3 | 91.8 | 1.40 (-0.60 to 3.40) |
| Study design | 0.98 | | | |
| RCT | | 17 | 75.5 | 0.38 (0.17 to 0.60) |
| Single-armed | | 1 | NA | 0.37 (-0.62 to 1.37) |
| PA measurement | 0.27 | | | |
| Rather subjective | | 2 | 0.00 | 0.22 (-0.05 to 0.48) |
| Rather objective | | 16 | 78.0 | 0.42 (0.17 to 0.66) |
| PA outcome | 0.03 | | | |
| MVPA | | 10 | 0.00 | 0.18 (0.05 to 0.31) |
| Step counts | | 8 | 85.9 | 0.69 (0.24 to 1.15) |

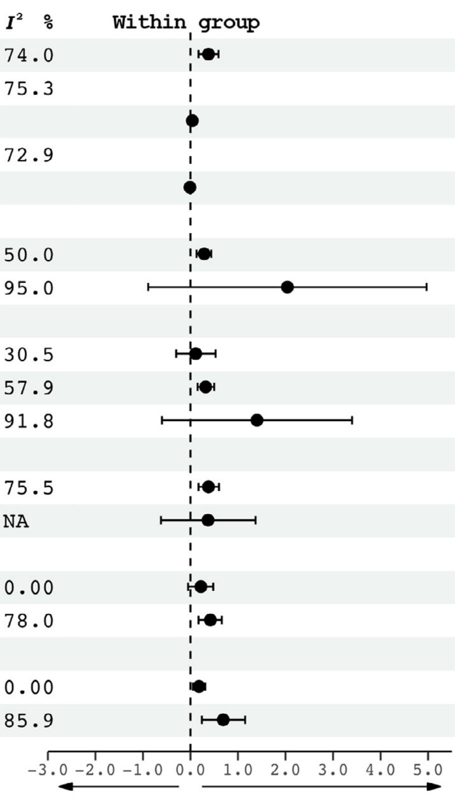



**Figure 4.** Meta-regressions and subgroup analyses for between- and within-group studies.

single-arm interventions. The use of gamified smartphone apps resulted in a significant increase in physical activity, with a moderate level of evidence for RCTs and a very low level of evidence for pre-to-post interventions. The main effects were significantly modified by intervention duration, sex, population, and physical activity outcomes.

### Effects of Standalone Gamified Apps on Physical Activity

The primary meta-analysis found that using gamified smartphone apps as standalone interventions may increase physical activity. The results support findings from previous qualitative systematic reviews of gamification on health and well-being.[8,17,18] Specifically, 2 reviews claimed that gamification has positive effects on health behaviors, including physical activity (59% reported positive effects),[18] reduction in body weight, and maintaining physical activity among children and adolescents.[17] Another systematic review of 16 comparison studies revealed largely positive effects of gamification on physical activity.[8] A methodologic shortcoming of these reviews is that they are all qualitative in nature, with no meta-analyses. This systematic review and meta-analysis partially fills this research gap and presents evidence for the positive impacts of standalone gamified apps on physical activity in free-living conditions. Notably, the very low level of evidence for pre-to-post studies is partly a result of how the classification of observational studies is derived.[33] The GRADE rating does not take into account the fact that 12 of 14 studies in the within-group studies were the intervention arms of RCTs.

Secondary meta-analyses were conducted for different physical activity outcomes. Gamified apps had the largest effects on walking and step counts (SMDs ranging from 0.59 to 0.77) in both between-group and within-group studies. Indeed, most of the gamified apps in the included studies were designed to target step counts (9 studies) and walking.[51] For example, the most popular gamified app for increasing steps and walking—Pokémon Go—had a modest, yet significant effect on daily steps.[53] Steps and walking, in turn, are associated with health benefits.[54,55] However, it should be noted that the secondary meta-analyses considered multiple physical activity outcomes within a single study (e.g., Direito et al.[50] measured 5 outcomes; Appendix Table 2, available online). This leads to duplicated sample size calculations in the meta-analyses.[21] Therefore, the effects of gamified apps on each physical activity outcome were analyzed separately, and no pooled overall effect was calculated.

### Gamification Features

A total of 12 gamification features within 24 gamified apps were identified in this systematic review. Previous systematic reviews of studies[7,18,56,57] or app store-based reviews[14,16] have also reported the implementation of gamification features (sometimes referred to as affordances or elements). However, one limitation of these reviews is that they often include leveraging features, so the nature of gamification is diluted.[18,56] Most importantly, 2 systematic reviews of mobile gaming apps on physical activity and mental health found that the game elements most commonly incorporated were, on one hand, virtual rewards, competition, and avatars (range from 2 to 9)[7] and, on other hand, levels or progress feedback, points or scoring, and rewards or prizes.[57] In the app store-based reviews, virtual rewards and challenges, as well as social pressure and goal setting (the latter 2 being leveraging features rather than gamification features, according to the authors' argumentation) were the most used features.[14,16] In these reviews, there were rarely links between gamification features and BCTs. However, as previous app store-based reviews showed, gamification features were (and should be) based on BCTs or other behavioral theories.[15,16] Consequently, this study summarized 12 core gamification features and linked them to BCTs.[11]

Rewards were implemented most frequently in the 19 studies. This finding is consistent with those of previous reviews.[7,18,56] A reward system is regarded as a fundamental component of gamified interventions.[58] Furthermore, most of the gamified apps were designed with leaderboards, which allowed users to see each other's rank and current status. This was often accompanied by a social networking feature (i.e., a leveraging tool). Besides encouraging self-improvement, social features often created a competitive environment in which users could satisfy their motivational needs (e.g., achievement).[59] Indeed, it has been argued that, for long-term motivation, gamification should focus less on rewards (which increase extrinsic motivation) but more on meaningful gamification; that is, increasing intrinsic motivation (in which "users find personal connections that motivate engagement with a specific context for long-term change"[60]).

*Note*: All: Overall effect size of meta-analysis. Moderator: meta-regression for 2 continuous moderators (duration, sex) and subgroup analyses for 6 categorical moderators. Estimate: regression coefficients (95% CI) for meta-regressions or standardized mean difference (95% CI) for subgroup analyses. *p*-value: Test of moderators (meta-regression) or test of subgroup differences (random-effects model). $I^2$ %: Indicator of study-specific heterogeneity.
Abbreviations: F, female; MVPA, moderate-to-vigorous physical activity; NA, not applicable; PA, physical activity.

### Source of Heterogeneity

The leave-one-out sensitivity analyses resulted in low heterogeneity in both the between-group (31%) and within-group (47.8%) studies, which largely explained the source of the high heterogeneity. In the exploration of moderators, the authors found that a longer intervention duration was positively associated with an increase in physical activity in the between-group RCTs but that the effect was of very small magnitude and driven by a 24-week study[36] that had the largest effect of all included studies. Against the background of previous findings that apps were most effective in increasing physical activity at early stages (i.e., <3 months),[6,23] future research is needed to investigate the impacts of gamified physical activity on sustained physical activity for mid- and long-term time periods. Second, the authors found greater effects for male than for female participants, which may be because male individuals might have had higher technology readiness than female individuals,[61,62] and this might have translated into a higher interest in using technology to promote physical activity. Furthermore, male participants might have been more interested in gamified physical activity, particularly against the background of achievement motives[63] and enjoyment of immersive practices.[64] In addition, female participants might have had a higher need for personal, nondigital relations,[63] and this might be associated with a higher preference for nonapp-based physical activity interventions. Thus, gamified apps might need to be designed differently for female and male participants owing to differences in needs and motives. Research on the acceptance of gamified apps is required to study the factors that attract female (versus male) users to initially download and try an app. Thirdly, the effects were modified by the study population in the between-group RCTs and by different physical activity outcomes in the within-group pre-to-post interventions. The moderators of age, study design, and physical activity measurement did not reach significance levels. These null-modifying effects suggest that gamified apps have positive effects on physical activity for all participant ages across all design types and for physical activity measured by devices (rather objectively) or self-reported (rather subjectively).

### Implications and Future Research

The main finding of this systematic review and meta-analysis—the positive impacts of standalone gamified smartphone apps on physical activity—supports the potential relevance of the WHO's strategy of promoting the development and implementation of digital technologies to improve physical activity around the world.[65] In addition, the results have important implications for health professionals. They may design effective unsupervised gamified digital interventions in free-living conditions. Furthermore, the findings are important for gamification research on physical activity because standalone apps with gamification features can be used to promote physical activity. However, researchers should be reminded to provide clear definitions and measurements for gamification features. Because it remains largely unclear how long changes in physical activity last or which gamification features sustain behavior change, longitudinal studies using several waves of data collection are needed. Finally, valid and reliable measurement tools for physical activity should be used. For example, the use of the smartphone itself as an objective measure of physical activity has been criticized because of well-documented limitations.[5]

### Limitations

This study has several limitations. Firstly, both RCTs and single-arm pre-to-post interventions were included, with the latter partially explaining the very low level of evidence. Secondly, high heterogeneity was observed in the pooled analyses, which may be explained by the differences in intervention designs. The measurement tools for physical activity differed greatly between the studies and introduced biases. When combined with trackers, apps might be more effective, simply because wearing trackers reminds participants of the need to be physically active. Thirdly, most apps mixed several gamification features. The underlying mechanisms of specific features and their interactions should be investigated to identify those features that drive the effectiveness of gamified apps. The same arguments can be made for the effectiveness of different BCTs that were identified in this review. In a fourth limitation, this paper relied on established features of gamification. However, a focus on meaningful gamification has been proposed, where play, exposition, choice, information, engagement, and reflection may be relevant.[60] Unfortunately, the authors of the 19 studies that were reviewed did not build on this framework, and the study descriptions mostly did not allow for this analysis to draw inferences about the implementation of these alternative features. As a fifth limitation, there were slight deviations from the protocol; all of them helped in the achievement of the research goals (Appendix 4, available online). Finally, the authors were unable to perform a meta-analysis for 3 included studies[37,46,49] because the necessary data were not available.

## CONCLUSIONS

The use of gamified smartphone apps as standalone interventions may increase physical activity. Future research could investigate the impacts of gamified apps on physical activity by isolating the effects of specific features, thus ruling out the potentially confounding influences of multiple features within a single investigation.

## CREDIT AUTHOR STATEMENT

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