APPENDIX 1. LIST OF EXCLUDED PUBLICATIONS AFTER FULL-TEXT REVIEW (PICOS CRITERIA)

PICOS (n=82)
Population (n=0):
NA.
Intervention (n = 28):

- No gamification was considered (e.g., pure games, active video games, exergames) (n=3)
- Gamification was not the main intervention (n=8)
- No app-delivered gamification intervention was considered (n=12)
- No standalone gamified app was considered (n=5)

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Broom DR, Flint SW. Gotta catch 'em all: Impact of Pokemon Go on physical activity, sitting time, and perceptions of physical activity and health at baseline and three-month follow-up. *Games Health J*. 2018;7(6):401–408. https://doi.org/10.1089/g4h.2018.0002.

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Choi NG, Stanmore E, Caamano J, Vences K, Gell NM. A feasibility study of multi-component fall prevention for homebound older adults facilitated by lay coaches and using a tablet-based, gamified exercise application. *J Appl Gerontol*. 2021. https://doi.org/0733464821991024.

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school-based environment. *Cyberpsychol Behav Soc Netw*. 2016;19(3):186–192. https://doi.org/10.1089/cyber.2015.0281.

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Koskimäki H, Siirtola P, Keskitalo E, et al. Computer game and wearable sensors based approach to promote physical activity for young men. *Proceedings of the ACM International Joint Conference and International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers.* 2017;512–517. https://doi.org/10.1145/3123024.3124433.

Lin PJ, Fanjiang YY, Wang JK, et al. Long-term effectiveness of an mHealth-tailored physical activity intervention in youth with congenital heart disease: A randomized controlled trial. *J Adv Nurs*. 2021. https://doi.org/10.1111/jan.14924.

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Comparisons (n=3):

- No comparisons were made (e.g., observational user data or surveys only) (n=3)

Althoff T, White RW, Horvitz E. Influence of Pokémon Go on physical activity: Study and implications. *J Med Internet Res.* 2016;18(12):e315. https://doi.org/10.2196/jmir.6759.

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Outcomes (n=18):

- No actual physical activity was considered (e.g., user engagement, physical activity intention, and movement skills) (n=12)

- Physical activity was not of main interest (e.g., main interest was on app development or app feasibility testing) (n=6)

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Mansart C, Sukitphittayanon S, Pantongkhum P, Thaicharoen S. Go run go: An Android game-story application for aiding motivation to exercise. *Proceedings of the IEEE International Symposium on Multimedia*. 2016;407–410. https://doi.org/10.1109/ISM.2015.49.

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social networking physical activity intervention. *Transl Behav Med*. 2017;7(4):702–708. https://doi.org/10.1007/s13142-017-0499-8.

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Study design (n=33):

- No intervention study was conducted (i.e., no RCT or at least a controlled pre-to-post comparison) (n=26)
- No intervention-dependent outcome of interest could be assessed, because no intervention was designed (n=7)

Abraham O, Thakur T, Brown R. Developing a theory-driven serious game to promote prescription opioid safety among adolescents: Mixed methods study. *JMIR Serious Games*. 2020;8(3):e18207. https://doi.org/10.2196/18207.

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Ferreira C, Guimarães V, Santos A, Sousa I. Gamification of stroke rehabilitation exercises using a smartphone. *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*. 2014;282–285. https://doi.org/10.4108/icst.pervasivehealth.2014.255326.

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APPENDIX 2. KAPPA STATISTIC FOR THE INITIAL AGREEMENT ON FULL-TEXT ELIGIBILITY

The Kappa statistic was reported as the interrater reliability of the 2 reviewers during the full-text screening, according to the Cochrane handbook chapter 7.2.6. Kappa scores of 0.4–0.6, 0.6–0.75, and over 0.75 represent fair, good, and excellent agreement, respectively.

We utilized an online Kappa calculator (https://idostatistics.com/cohen-kappa-free-calculator/) with the following judgements:

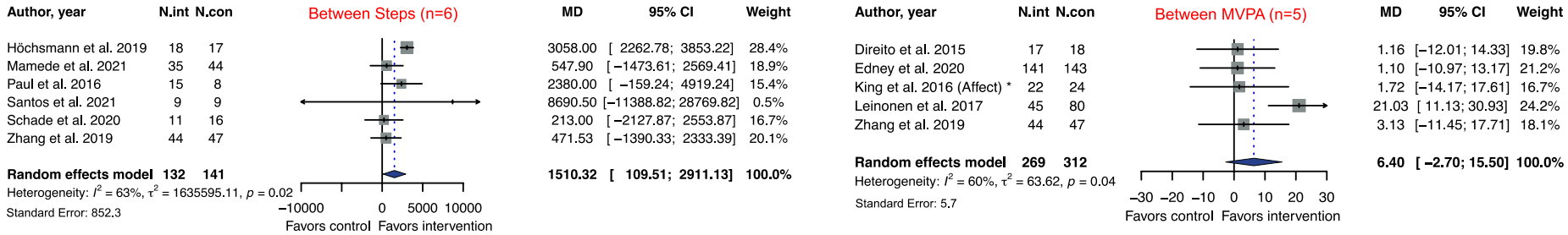
- Both reviewers agreed to include (n=16);
- Both reviewers agreed to exclude (n=75);
- Only the first reviewer wanted to include (n=4);
- Only the second reviewer wanted to include (n=7).

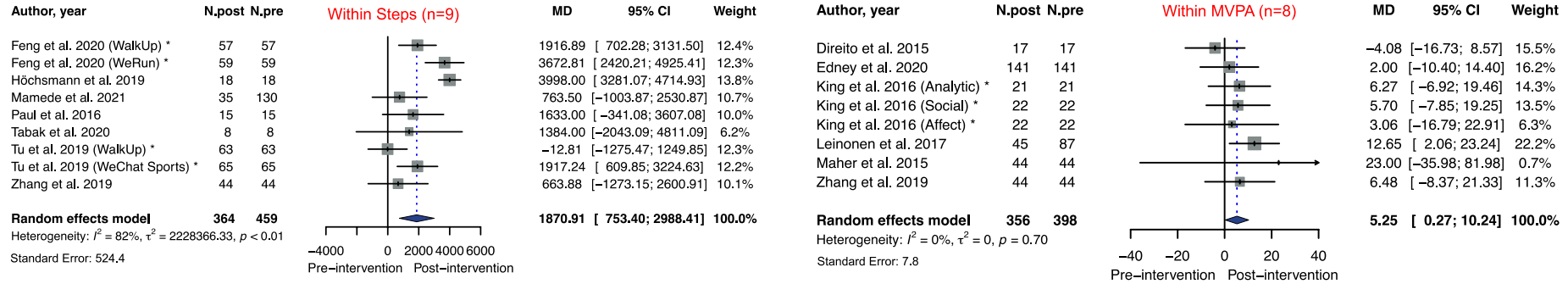
Accordingly, the judgements yielded a Kappa score of **0.68** (good agreement).

Reasons for Disagreement:
For both reviewers, the uncertainty about inclusion or exclusion was mainly based on the intervention of the studies (PICOS). In particular, they were unsure about whether the intervention of the study could be considered as "standalone" (reviewer 1, n=1; reviewer 2, n=4) or not. Also, they were unsure about the outcomes of physical activity (e.g., studies measured physical activity via questionnaires but focused on behavioral intentions instead of actual physical activity). The disagreement was solved by discussion until reaching consensus (n=19 studies were finally included).

APPENDIX 3. CONVERTING AND RE-EXPRESSING THE SMDS WITH ORIGINAL UNITS (MD) FOR MVPA AND STEP COUNTS

Step 1. Conduct meta-analyses for moderate-to-vigorous physical activity (MVPA, minutes/day) and step counts (steps/day) with the mean difference (MD) method, based on studies with the same units of measure only. The SEs (figure below) of the effect size were obtained.





Step 2. Use the above SEs to calculate the pooled SDs of the effect size for the above studies:

- SD (between-group steps) = SE / sqrt(1 / N.int + 1 / N.con) = 852.3 / sqrt(1/132 + 1/141) = 7037.3
- SD (between-group MVPA) = SE / sqrt(1 / N.int + 1 / N.con) = 5.7 / sqrt(1/269 + 1/312) = 68.5
- SD (Within-group steps) = SE / sqrt(1 / N.post + 1 / N.pre) = 542.4 / sqrt(1/364 + 1/459) = 7471.7
- SD (Within-group MVPA) = SE / sqrt(1 / N.post + 1 / N.pre) = 7.8 / sqrt(1/356 + 1/398) = 106.9

Step 3. Use the above SDs, along with the standardized mean differences (SMDs) from the main meta-analysis (between-group: SMD=0.34 [95% CI=0.06, 0.62]; within-group: SMD=0.38 [95% CI=0.17, 0.59], Figure 3), to extrapolate the mean differences in the main meta-analyses (Figure 3).

- Mean difference (between-group steps) = SMD * SD = 0.34*7037.3 = **2392.7** (95% CI 422.2 to 4363.1)
  (→ extrapolate an increase of 2392.7 steps/day)
- Mean difference (between-group MVPA) = SMD * SD = 0.34*68.5 = **23.3** (95% CI 4.1 to 42.5)
  (→ extrapolate an MVPA increase of 23.3 minutes/day)
- Mean difference (Within-group steps) = SMD * SD = 0.38*7471.7 = **2839.2** (95% CI 1270.2 to 4408.3)
  (→ extrapolate an increase of 2839.2 steps/day)
- Mean difference (Within-group MVPA) = SMD * SD = 0.38*106.9 = **40.6** (95% CI 18.2 to 63.1)
  (→ extrapolate an MVPA increase of 40.6 minutes/day)

Note: The results are exploratory, because the extrapolation is based on the studies with same measurement units only (i.e., step counts: steps/day; MVPA: minutes/day). For step counts, only 6 out of 12 studies (n=12 apps, Figure 3) for between-group studies and 9 out of 12 studies for within-group studies could be used for the analysis. For MVPA, only 5 out of 18 studies (n=18 apps, Figure 3) for between-group studies and 8 out of 18 studies for within-group studies could be used in the analysis.

References

Cochrane handbook chapter 12.6.4

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APPENDIX 4. JUSTIFICATION OF DEVIATIONS FROM THE PROTOCOL

Published protocol: PROSPERO CRD42020209502

1. Review Questions

Due to the criticism related to the classification of studies into immersion-, achievement-, and social interaction-related types, this review eliminated the third research question in the protocol ("What types of gamified apps or gamification affordances are potentially more effective?").

2. Search Strategy

The current review considers the grey literature by searching the reference lists of relevant articles (as described in Figure 1). In addition, deviating from the protocol, relevant journals (e.g., JMIR) were not considered as additional sources, because they were indexed in the databases that we searched. We are not aware of a relevant journal that we might have missed. Lastly, although we conceptually distinguished between gamification, game, and game-based, all terms were used as keywords to increase the coverage of potentially included articles.

3. Interventions

The interventions in the current review are further restricted to standalone gamified apps (i.e., without additional supervision or support) or exclusive app use (i.e., without additional intervention types), to assess the effects of purely app-based interventions.

4. Review Team Members

The research assistant (second author of the review, H.H.) was not involved at the time of the protocol registration.

Appendix Table 1. Search Strategy

1A. Combined three groups of keywords.

Domains	Keywords	References
Gamification	game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*	[1–6]
Smartphone app	"mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*"	[7–9]
Physical activity	exercise* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting	[10,11]

1B. Databases-specific search strategy.

Database	Results [a]	Search strategy
PubMed	330: (284+46)	(("Games, Recreational"[Mesh]) OR game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*) AND (("Mobile Applications"[Mesh]) OR "mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*") AND ((("Exercise"[Mesh]) OR ("Sports"[Mesh]) OR ("Exercise Therapy"[Mesh])OR exercis* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting)) Filters: English, from 2008 - 2021
Scopus	1103: (998+105)	TITLE-ABS-KEY(game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*) AND TITLE-ABS-KEY("mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*") AND TITLE-ABS-KEY(exercise* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting) AND PUBYEAR > 2008 AND LANGUAGE (English) Filters: limited to journal and conference proceedings
Web of Science	770: (696+74)	TS = (game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*) AND TS = ("mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*") AND TS = (exercise* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, CCR-EXPANDED,

		IC Timespan=2008-2021; Filters: limited to journal and conference proceedings
PsycINFO	165: (149+16)	(game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*).mp AND ("mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*").mp AND (exercise* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting).mp [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures; Filters: English, from 2008 - 2021]
ACM Digital Library	179: (158+21)	(game OR "game-based" OR "game-themed" OR "game-like" OR gamif* OR gamification OR gameful*) AND ("mobile phone" OR smartphone* OR mHealth OR app OR apps OR "mobile app*" OR "smartphone app*") AND (exercise* OR sport* OR fitness OR "physical activit*" OR "leisure activit*" OR "physical inactiv*" OR walk* OR step* OR pedomet* OR acceleromet* OR sedentary OR sitting) [Title (hits = 4+1), Keyword (hits = 11+3), and Abstract (hits = 142+17) were searched separately and then finally combined (hits = 158+21)]

[a]The final search results are the combination of the initial search date (until December 20, 2020) and the updated search date (until August 31, 2021).

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Appendix Table 2. Characteristics of Included Studies (n=19)

Source (country, in which study took place)	Design	Participants; Mean age (range [years])	*N*; Female %; BMI mean [kg/m^2]	App name (OS)	Intervention arm	Control arm	Duration (week)	PA measure	PA outcome	Risk of bias
Direito et al., 2015 (New Zealand)	RCT	Young adults; 15.66 (14–17)	35; 60; 23.3	Zombies, Run! 5K Training (both)[a]	Immersive app use	Usual behavior	8	Actigraph GT1M[b]; PAQ-A	LPA (min/day); MPA (min/day); VPA (min/day); MVPA (min/day); SED (min/day); PAQ-A	Low
Edney et al., 2020 (Australia)	RCT	Adults; 41.79 (18–65)	284; 75; 29.94	Active Team (both)	Gamified app use	Waitlist control	12	GENEActiv[b]; Active Australia Survey (8 items)	MVPA (min/day)	Some concerns
Feng et al., 2020 (China)	RCT	Undergraduates; NA (18–34)	116; 43.1; Normal	WalkUp; WeRun (both)[a]	WalkUp use	WeRun use	5	Smartphone built-in	Steps/day	Some concerns
Garde et al., 2015 (Canada)	RCT	Children;10.24 (8–13)	47; 66; 70% normal	MobileKids Monster Manor (IOS)[a]	Gamified app use	Daily activity feedback	1	Tractivity monitor	Steps/day	Some concerns
Gremaud et al., 2018 (U.S.)	RCT	Healthy office workers; 40.45 (21–65)	144; 76.4; 29.7	MapTrek (web-app)	MapTrek app + Fitbit use	Use of Fitbit only	10	Fitbit Zip	Active min/day; Steps/day	Some concerns
Haque et al., 2020 (Finland, England, Ireland, Bangladesh)	RCT	Office workers; 39 (24–49)	27; 52; 24.72	iGO (Android)	iGO app use	Paper diary	4	Self-developed, unvalidated single item	Perceived PA increase	High
Höchsmann et al., 2019 (Switzerland)	RCT	Inactive and overweight T2D patients; 58.5 (45–70)	35; 47; 32	MOBIGAME (NA)	Gamified app use	Lifestyle counseling	24	Garmin Vivofit 2	Steps/day	Some concerns
King et al., 2016 (U.S.)	RCT	Underactive adults; 59.5 (>45)	89; 66.7; 29.7	Analytic; Social; Affect (Android)	Use of 3 framed apps	Use of diet-tracker app (Calorific)	8	Smartphone built-in	MVPA (min/day); SED (h/day)	High
Leinonen et al., 2017 (Finland)	RCT	Young men; 17.85 (NA)	354; 0; 23.1	MOPOrtal (web-app)	Gamified app use	Active control, no feedback	24	Polar Active	MVPA (min/day)	Some concerns
Maher et al., 2015 (Australia)	RCT	Healthy adults; 35.6 (18–65)	98; 74.5; 42% normal	Active Team via Facebook app (both)	Gamified app use	Waitlist control	8	Active Australia Survey (8 items)	MPA (min/week); VPA (min/week); Overall PA (min/week); Walking (min/week)	Some concerns
Mamede et al., 2021 (The Netherlands)	RCT	Office workers; 46.8 (>18)	246; 62; 26.3	SelfCarePro app (both)[a]	Gamified app use	Basic version app	5	Fitbit Flex; SQUASH (10 items) and sedentariness (2 items)	Steps/day; LPA (h/week); MVPA (h/week); SED (h/week)	Some concerns
Paul et al., 2016 (Scotland)	RCT	Adult stroke patients; 55.95 (NA)	23; 52; 24.34	STARFISH (Android)	Gamified app use	Usual care	6	ActivPAL[b]	SED (h/day); Steps/day; Walking (h/day)	Some concerns
Santos et al., 2021 (Japan)	RCT	Healthy older Adults; 63.4 (>50)	18; 77.8; NA	Shinpo (Android)	Gamified app use (with social	No social interaction	4	Smartphone built-in	Steps/week	Some concerns

					interaction features)					
Schade et al., 2020 (U.S.)	RCT	Healthy undergraduates; 20.97 (>18)	27; 48; 27.4	Pokemon Go (both)[a]	PG-playing group participation	Non-players	2	Fitbit Charge HR	Steps day; distance traveled/day	Some concerns
Tabak et al., 2020 (The Netherlands)	Single-arm	Older adults; 71 (65–75)	20; 50; NA	WordFit (NA)	Gamified app use	NA	3	FitBit	Steps/day	Moderate[c]
Tu et al., 2019 (China)	RCT	Undergraduates; 21.7 (19–24)	128; 67; Normal	WalkUp; WeChat Sports (both)[a]	WalkUp use	WeChat Sports use	7	Smartphone built-in	Steps/day	Some concerns
Wong et al., 2020 (China)	Single-arm	Children; 10.38 (6–15)	67; 15.38; NA	Family Move (NA)	Gamified app use	NA	8	ActivPAL[b]; IPAQ-SF	MVPA (h/week); MET-minutes/week	Moderate[c]
Zhang et al., 2019 (U.S.)	RCT	African American women; 26.8 (18–35)	91; 100; 31.6	PennFit (Android)	App-Based small group participation	Individual active control	12	FitBit	Steps/day	Low
Zuckerman & Gal-Oz, 2014 (Israel)	RCT	Undergraduates; 23.39 (20–27)	59; 75; NA	StepByStep (Android)	Use of points version vs leaderboard version	Use of quantified version (for monitoring)	1.4	Smartphone built-in	Walking (min/week)	Some concerns

[a]The app is commercially available, otherwise self-designed.
[b]Physical activity was measured by accelerometers designed for research purposes.
[c]Risk of bias was assessed by ROBIS-I, otherwise by RoB-2.

IPAQ-SF, The International Physical Activity Questionnaire-Short Form; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; OS, operation system of smartphone (Android, IOS, or both); PA, physical activity; PAQ-A, Physical Activity Questionnaires for Adolescents; SED, sedentary time; SQUASH, Short Questionnaire to Assess Health Enhancing Physical Activity; T2D, type 2 diabetes; VPA, vigorous physical activity; min, minutes; h, hours; NA, not applicable.

Appendix Table 3. Full List of Gamification Features and Associated Behavior Change Techniques

Study	Gamification features *(leveraging features)*	Description/example of features *(and eventual leveraging features)*	Associated BCTs
Direito et al., 2015	1. Storytelling; 2. Virtual progress visualization; *(Performance stats & feedback; Social networking)*	1. Embed training program with a story: users collect supplies and protect a town from zombies; 2. Tracked and virtually displayed progress throughout the program; *(Virtual self-monitoring and receiving feedback on training; Links to associated websites to interact with other users)*	1. NA; 2. Feedback and monitoring; *(Feedback and monitoring; Social support)*
Edney et al., 2020	1. Badges & achievements; 2. Virtual teams & cooperation; 3. Virtual competition; 4. In-game rewards; 5. Virtual Challenges; *(Goal setting; Social networking; Reminders & notifications)*	1. Unlock badges for reaching PA goals; 2. Teammates participating the study together; 3. Compete for highest PA; 4. Virtual gifts for reaching PA goals; 5. Implementation of mini challenges that encourage bursts of PA; *(State predefined goal of daily step count; Post photographs and messages on a Facebook-style newsfeed; Weekly email and push notification)*	1. Imaginary reward; 2. Social support; 3. Comparison of behavior; 4. Imaginary reward; 5. Goals and planning; *(Goals and planning; Social support; Prompts/cues)*
Feng et al., 2020 (WalkUp)[a]	1. Points & scores; 2. Badges & achievements; 3. Levels; 4. In-game rewards	1. Earn points according to walking performances; 2. Earn a badge if the requirement of daily 5,000 step counts are met; 3. Advancement to the next (higher) levels according to walking performances; 4. Earn digital rewards according to walking performances	1. Imaginary reward; 2. Imaginary reward; 3. Imaginary reward; 4. Imaginary reward
Feng et al., 2020 (WeRun) *	1. Leaderboards & rankings; *(Peer-rating; Social networking)*	1. See friends' ranking via WeChat; *(Get likes from friends; Personal profile integrated with friends' profiles as part of the social media platform WeChat)*	1. Comparison of behavior; *(Social reward; Social support)*
Garde et al., 2015	1. Leaderboards & rankings; 2. Virtual competition; 3. Badges & achievements;	1. Team members see the team's relative standing on the team leaderboard; 2. Competition on which team collectively accumulates the most gold; 3. Achievement of milestones;	1. Comparison of behavior; 2. Comparison of behavior;

	4. Virtual progress visualization; 5. Levels; 6. In-game rewards; 7. Storytelling; 8. Virtual teams & cooperation; 9. Virtual Challenges; *(Real world interaction)*	4. Countdown on progress toward player's activity goal; 5. Advancement to the next (higher) levels; 6. Rewards of currency and rare items; a player builds a collection of virtual goods, including monsters, furnishing, and pets; 7. Unlocking all of the hidden monsters in 4 multilevel mansions; 8. Encouraging teammates and seeing the team ranking; 9. Creating a complete collection of monsters and manors; *(Real-world physical activity thereby generates gaming currency)*	3. Imaginary reward; 4. Feedback and monitoring; 5. Imaginary reward; 6. Imaginary reward; 7. NA; 8. Social support; 9. Goals and planning; *(NA)*
Gremaud et al., 2018	1. Leaderboards & rankings; 2. Virtual competition; 3. Virtual progress visualization; 4. In-game rewards; 5. Avatar; 6. Virtual teams & cooperation; 7. Virtual Challenges; *(Performance stats & feedback; Real world interaction; Reminders & notifications)*	1. Race leaderboard; 2. Virtual walking races; 3. Seeing and tracking virtual progress along the route; 4. Reward with a predetermined number of bonus steps (+500 steps); 5. A user's avatar is implemented along the race path; 6. Establishment of competition-based leagues; 7. Step challenges; *(Seeing step achievements; self-monitoring of PA behavior; Seeing real time routes via the Google Street View feature; Daily messages)*	1. Comparison of behavior; 2. Comparison of behavior; 3. Feedback and monitoring; 4. Imaginary reward; 5. NA; 6. Social support; 7. Goals and planning; *(Feedback and monitoring; NA; Prompts/cues)*
Haque et al., 2020	1. Leaderboards & rankings; 2. Points & scores; 3. In-game rewards; *(Performance stats & feedback; Reminders & notifications; Social networking)*	1. Monitoring activities on the leaderboard; 2. Every 5 minutes of PA results in 1 point; 3. Reception of progress-related rewards; *(Automated feedback; Receiving notifications; Connection with colleagues for the purpose of PA)*	1. Comparison of behavior; 2. Imaginary reward; 3. Imaginary reward; *(Feedback and monitoring; Prompts/cues; Social support)*

Höchsmann et al., 2019	1. Avatar; 2. In-game rewards; 3. Storytelling; *(Goal setting)*	1. Restoration of a garden, used as a metaphor for one's own body (as avatar); 2. Implementation of appealing in-game rewards for doing PA; 3. Taming of the Schweinehund and restoration of a garden; *(Meeting in-game personalized PA goals)*	1. NA; 2. Imaginary reward; 3. NA; *(Goals and planning)*
King et al., 2016 (Analytic)[a]	1. Levels; *(Performance stats & feedback; Goal setting)*	1. History of prior PA is displayed graphically at individual and group level; *(Numerical feedback, problem-solving information and advice; User-specific goal-setting occurring weekly)*	1. Imaginary reward; *(Feedback and monitoring; Goals and planning)*
King et al., 2016 (Social)[a]	1. Leaderboards & rankings; 2. Virtual teams & cooperation; *(Social networking)*	1. Implementation of live wallpaper; 2. Implementation of virtual group and confederates; *(Message board to share messages with others)*	1. Comparison of behavior; 2. Social support; *(Social support)*
King et al., 2016 (Affect)[a]	1. Badges & achievements; 2. Increasing difficulty; 3. In-game rewards; 4. Avatar; *(Real world interaction)*	1. Bird is happy after 30 min of MVPA; 2. Once the participant surpasses daily levels, additional levels are accessible; 3. Giving person a thumbs-up while making a melodious sound; 4. Use of avatars in the form of a bird; *(Larger jackpot-type reinforcers for extended vocalizations and unexpected arrivals of the bird were provided at different real-world locations)*	1. Imaginary reward; 2. Repetition and substitution (graded tasks); 3. Imaginary reward; 4. NA; *(NA)*
Leinonen et al., 2017	1. Leaderboards & rankings; 2. Virtual competition; 3. Points & scores; 4. Storytelling; 5. Virtual teams & cooperation; 6. Virtual Challenges; *(Performance stats & feedback; Real world interaction; Reminders & notifications)*	1. Personal ranks and team ranks; 2. Implementation of tasks to be solved and combats with another team; 3. Points can be earned based on PA activity; 4. Visual appearance clan game, youth cultures, and conquering; 5. Working together to reach goals to conquer areas; 6. Random new tasks that need to be solved; *(Feedback on PA and sitting time; Track location with GPS; Automated tailored information on health, exercise, and PA instructions)*	1. Comparison of behavior; 2. Comparison of behavior; 3. Imaginary reward; 4. NA; 5. Social support; 6. Goals and planning;

			(Feedback and monitoring; NA; Prompts/cues)
Maher et al., 2015	1. Leaderboards & rankings; 2. Virtual progress visualization; 3. In-game rewards; 4. Virtual teams & cooperation *(Goal setting; Reminders & notifications; Social networking)*	1. Implementation of team tally boards; 2. Implementation of dashboards for progress; 3. Awards for individual and team step-logging and step-count achievements, named by a comedian; virtual gifts such as a high five and a pink leotard; 4. Teams of 3 to 8 existing Facebook friends *(Setting small achievable goals (daily step count); Instructions, daily tips by comedian; Team message board, sending virtual gifts to teammates)*	1. Comparison of behavior; 2. Feedback and monitoring; 3. Imaginary reward; 4. Social support *(Goals and planning; Prompts/cues; Social support)*
Mamede et al., 2021	1. Leaderboards & rankings; 2. Points & scores; 3. Increasing difficulty; 4. Virtual teams & cooperation; 5. In-game rewards; 6. Storytelling; 7. Avatar; *(Real world interaction; Goal setting; Reminders & notifications; Performance stats & feedback)*	1. A leaderboard serves for intrateam cooperation and competition between teams; 2. Earning points by team or individuals; 3. Challenges start easy and become increasingly more difficult; 4. Virtual teams; 5. Rewarding participants with virtual awards for both individuals and team achievements; 6. Virtual walking tour (e.g., a roundtrip across Rotterdam); 7. Virtual avatars crossing the virtual tour scenarios; *(Charity representations sponsored by the municipality; Virtual walking tour as a goal to achieve, goal setting starting from 8500 steps; Biweekly newsletters during the challenges; Weekly personalized feedback on step count progress)*	1. Comparison of behavior; 2. Imaginary reward; 3. Graded tasks; 4. Social support; 5. Imaginary reward; 6. NA; 7. NA; *(NA; Goals and planning; Prompts and cues; Feedback and monitoring)*
Paul et al., 2016	1. Leaderboards & rankings; 2. Increasing difficulty; 3. In-game rewards; 4. Avatar; 5. Virtual teams & cooperation;	1. Participant's fish swims and blows bubbles and others can see; 2. If achieved, the target will increase by 5%; 3. Exclamation mark attached to their fish, fish's fins and tail grows; 4. Each person gets a metaphor by colored fish within a fish tank; 5. There are 4 members per group; team rewards for another sea creature; *(Real-time feedback; Individualized step goals, daily step count target)*	1. Comparison of behavior; 2. Graded tasks; 3. Imaginary reward; 4. NA; 5. Social support;

	(Performance stats & feedback; Goal setting)		*(Feedback and monitoring; Goals and planning)*
Santos et al., 2021	1. Levels; 2. In-game rewards; 3. Avatar; 4. Virtual teams & cooperation; 5. Virtual competition; 6. Points & scores; 7. Storytelling; *(Peer-rating; Real world interaction; Social networking)*	1. Colors feature 4 levels; advancement to the next (higher) levels 2. One card is received for every unique hotspot and for every 1,000 steps player walked; 3. Players choose a public avatar and nickname and can make a short self-introduction; 4. Players are randomly assigned to a challenge group; 5. Battling other players within the game; 6. Gaining experience points; 7. Capturing and hatching virtual creatures; *(When players receive cards as the result of other players' actions, they have a chance to give them a like; Players must collect virtual cards by visiting shrines and temples in Kyoto city; Leaving gifts to other people)*	1. Imaginary reward; 2. Imaginary reward; 3. NA; 4. Social support; 5. Comparison of behavior; 6. Imaginary reward; 7. NA; *(Social reward; NA; Social support)*
Schade et al., 2020	1. Avatar; 2. Points & scores; 3. Virtual competition; 4. Levels; *(Social networking)*	1. Users can walk indoors and outdoors to capture and hatch virtual creatures; 2. Users can gain experience points; 3. Users can battle other players within the game; 4. Users with high physical activity can increase levels within the game; *(Social and exploration aspects to increase the adherence)*	1. NA; 2. Imaginary reward; 3. Comparison of behavior; 4. Imaginary reward; *(Social support)*
Tabak et al., 2020	1. Leaderboards & rankings; 2. Badges & achievements; 3. Increasing difficulty; 4. In-game rewards; 5. Storytelling; 6. Virtual Challenges; *(Performance stats & feedback; Personalization; Social networking)*	1. Achievements are present through leaderboards; 2. Elements enabling achievement; 3. Implementation of difficulty levels; 4. Improved activity behavior enhances rewards, unobtrusive rewarding (hammers); 5. Obtaining as many hammers as possible to finish puzzles, with 3 themes: Forest-lake, Snow-mountain, and Rocks-coast; 6. Solving and creating challenges, providing challenges to unlock themes;	1. Comparison of behavior; 2. Imaginary reward; 3. Graded tasks; 4. Imaginary reward; 5. NA; 6. Goals and planning;

		(In-game statistics; Unique playing boards; Sharing with other users, social accounts [buddy, guest])	*(Feedback and monitoring; NA; Social support)*
Tu et al., 2019 (WalkUp)[a]	1. Points & scores; 2. Badges & achievements; 3. Levels; 4. In-game rewards	1. Energy points: value of energy required to travel around the virtual world; 2. Travel badges: visa to countries across seven continents; 11 types of walking achievements (e.g., reach a certain number of steps/day); 3. Levels of progression: advancement to the next (higher) levels depending on the number of steps taken; 4. Virtual supplement: virtual goods that can speed up users' walking progress	1. Imaginary reward 2. Imaginary reward 3. Imaginary reward 4. Imaginary reward
Tu et al., 2019 (WeChat Sports)[a]	1. Leaderboards & rankings; 2. Virtual teams & cooperation; *(Peer-rating)*	1. Ranking based the number of step-counts per day; 2. Users can add friends to a team; *(Likes: users can like the walking performance of their friends in the WeChat social network)*	1. Comparison of behavior; 2. Social support; *(Social reward)*
Wong et al., 2020	1. Points & scores; 2. In-game rewards; *(Performance stats & feedback; Reminders & notifications; Social networking)*	1. Points system and simple exercise scoreboard; 2. Gift redemption; *(Personal record/performance; Push notifications: text messages; Joyful interactions between two people)*	1. Imaginary reward; 2. Imaginary reward; *(Feedback and monitoring; Prompts/cues; Social support)*
Zhang et al., 2019	1. Leaderboards & rankings; 2. Virtual progress visualization; 3. Virtual teams & cooperation; *(Social networking)*	1. Seeing one's PA and other 3 group members' PA; 2. App homepage displays all 4 women's PA data in form of colored bars in real time; 3. Four members per group; *(Sending messages to their group through an instant chatting tool, allowing for individual profiles)*	1. Comparison of behavior; 2. Feedback and monitoring; 3. Social support; *(Social support)*
Zuckerman & Gal-Oz., 2014 (Points)[a]	1. Points & scores; *(Performance stats & feedback; Goal setting)*	1. Implementation of a point-collecting tool; *(Continuous measurement and real-time feedback; Goal-setting of a 10% increase of daily walking)*	1. Imaginary reward; *(Feedback and monitoring; Goals and planning)*

Zuckerman & Gal-Oz., 2014 (Leaderboard)[a]	1. Leaderboards & rankings	1. Installment of a real-time leaderboard ranking users	1. Comparison of behavior

[a]The manuscripts contained 2 or 3 different gamified apps. Separate analyses were made for these different apps.

BCT, behavior change technique; GPS, global positioning system; MVPA, moderate-to-vigorous physical activity; NA, not applicable; PA, physical activity.

Appendix Table 4. Risk of Bias of the Included Studies (n=19)

Study	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	-	-	Overall bias
RoB-2								
Direito et al., 2015	Low	Low	Low	Low	Low	-	-	Low
Edney et al., 2020	Low	Low	Low	Some concerns	Low	-	-	Some concerns
Feng et al., 2020	Low	Low	Low	Some concerns	Some concerns	-	-	Some concerns
Garde et al., 2015	Low	Low	Low	Low	Some concerns	-	-	Some concerns
Gremaud et al., 2018	Low	Some concerns	Low	Low	Low	-	-	Some concerns
Haque et al., 2020	Low	Some concerns	Low	High	Low	-	-	High
Höchsmann et al., 2019	Low	Low	Some concerns	Low	Low	-	-	Some concerns
King et al., 2016	Low	Low	High	Low	Low	-	-	High
Leinonen et al., 2017	Low	Low	Some concerns	Low	Low	-	-	Some concerns
Maher et al., 2015	Low	Some concerns	Low	Low	Low	-	-	Some concerns
Mamede et al., 2021	Low	Some concerns	Low	Low	Low	-	-	Some concerns
Paul et al., 2016	Some concerns	Some concerns	Low	Some concerns	Low	-	-	Some concerns
Santos et al., 2021	Low	Some concerns	Low	Low	Low	-	-	Some concerns
Schade et al., 2020	Low	Low	Some concerns	Low	Low	-	-	Some concerns
Tu et al., 2019	Low	Low	Low	Some concerns	Some concerns	-	-	Some concerns
Zhang et al., 2019	Low	Low	Low	Low	Low	-	-	Low
Zuckerman & Gal-Oz, 2014	Some concerns	Some concerns	Low	Low	Low	-	-	Some concerns
-	**Bias due to confounding**	**Bias in selection of participants into the study**	**Bias in classification of interventions**	**Bias due to deviations from intended interventions**	**Bias due to missing data**	**Bias in measurement of outcomes**	**Bias in selection of the reported result**	**Overall bias**
ROBINS-I								
Tabak et al., 2020	Critical	Low	Low	Moderate	Low	Low	Low	Moderate
Wong et al., 2020	Low	Low	Low	Moderate	Low	Moderate	Low	Moderate

RoB, risk of bias; ROBINS-I, Risk of Bias In Non-randomized Studies - of Interventions.

Appendix Table 5. Sensitivity Analyses

Sensitivity analysis	Studies	SMD (95% CI)	I^2 %	*p*-value
Between-group				
Leave-one-out[a]	11	0.20 (0.02, 0.38)	31.0	0.030
Remove studies with high overall risk of bias	11	0.37 (0.07, 0.68)	74.2	0.016
Risk of bias: over 4 categories as low	10	0.33 (0.01, 0.64)	76.0	0.042
Risk of bias: less than 4 categories as low	2	0.44 (–0.08, 0.96)	0.0	0.095
Within-group				
Leave-one-out[a]	17	0.30 (0.15, 0.45)	47.8	<0.001
Remove studies with high overall risk of bias[b]	15	0.42 (0.18, 0.66)	78.3	0.0007
Risk of bias: over 4 categories as low	13	0.31 (0.06, 0.56)	71.4	0.015
Risk of bias: less than 4 categories as low	5	0.53 (0.17, 0.90)	75.0	0.004

[a]Leave one study out due to high heterogeneity (Höchsmann et al., 2019).
[b]There were 2 studies with high overall risk of bias (Haque et al., 2020; King et al., 2016).

SMD, standardized mean difference.

Appendix Table 6. Assessment of Level of Evidence With GRADE Guidelines

Certainty assessment							Summary of findings	
	Participants (studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty of evidence	SMD (95% CI)
Between group (RCTs)								
Main effects	898 (12)	not serious	serious [a]	not serious	not serious	none	⊕⊕⊕◯ Moderate	0.34 (0.06, 0.62)
LPA	205 (3)	not serious	not serious	not serious	serious [b]	none	⊕⊕⊕◯ Moderate	0.17 (–0.10, 0.45)
MVPA	756 (7)	not serious	serious [a]	not serious	not serious	none	⊕⊕⊕◯ Moderate	0.12 (–0.13, 0.37)
SED	308 (5)	not serious	not serious	not serious	serious [b]	none	⊕⊕⊕◯ Moderate	–0.07 (–0.30, 0.16)
Step counts	273 (6)	not serious	serious [a]	not serious	serious [b]	none	⊕⊕◯◯ Low	0.59 (–0.01, 1.20)
Total PA	96 (1)	not serious	not serious	not serious	serious [b]	none	⊕⊕⊕◯ Moderate	0.38 (–0.02, 0.79)
Walking	158 (3)	not serious	not serious	not serious	serious [b]	none	⊕⊕⊕◯ Moderate	0.64 (0.31, 0.96)
Within group (Single-armed pre-to-post interventions)								
Main effects	1642 (18)	not serious	serious [a]	not serious	not serious	none	⊕◯◯◯ Very Low	0.38 (0.17, 0.59)
LPA	287 (3)	not serious	not serious	not serious	serious [b]	none	⊕◯◯◯ Very Low	0.05 (–0.21, 0.30)
MVPA	1053 (10)	not serious	serious [a]	not serious	not serious	none	⊕◯◯◯ Very Low	0.13 (0.00, 0.25)
SED	491 (7)	not serious	not serious	not serious	not serious	none	⊕⊕◯◯ Low	–0.02 (–0.21, 0.18)
Step counts	842 (10)	not serious	serious [a]	not serious	not serious	none	⊕◯◯◯ Very Low	0.61 (0.23, 0.98)
Total PA	134 (2)	not serious	serious [a]	not serious	serious [b]	none	⊕◯◯◯ Very Low	0.45 (0.02, 0.88)
Walking	118 (2)	not serious	not serious	not serious	serious [b]	none	⊕◯◯◯ Very Low	0.77 (0.39, 1.14)

[a]Downgrade due to I^2 statistics >50%.
[b]Downgrade due to pooled sample sizes <400. The GRADE level of evidence for within-group (n=18 apps) should be interpreted with caution, because single-armed pre-to-post studies start as low-quality evidence, and 16 out of the 18 included studies (apps) were the intervention groups of RCTs (i.e., there were only 2 observational studies).

LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; SED, sedentary behavior; SMD, standardized mean difference; GRADE methodology, RCTs start as high-quality evidence, while before-after studies start as low-quality evidence. According to the GRADE handbook, the quality of evidence was downgraded by one level for each of the following issues: (1) risk of bias when >25% of the participants were from studies with a high risk of bias; (2) inconsistency when the I^2 statistic >50%; (3) imprecision when pooled sample sizes <400; (4) publication bias based on testing for funnel plot asymmetry.

Appendix
Effects of Gamified Smartphone Apps on Physical Activity: A Systematic Review and Meta-Analysis
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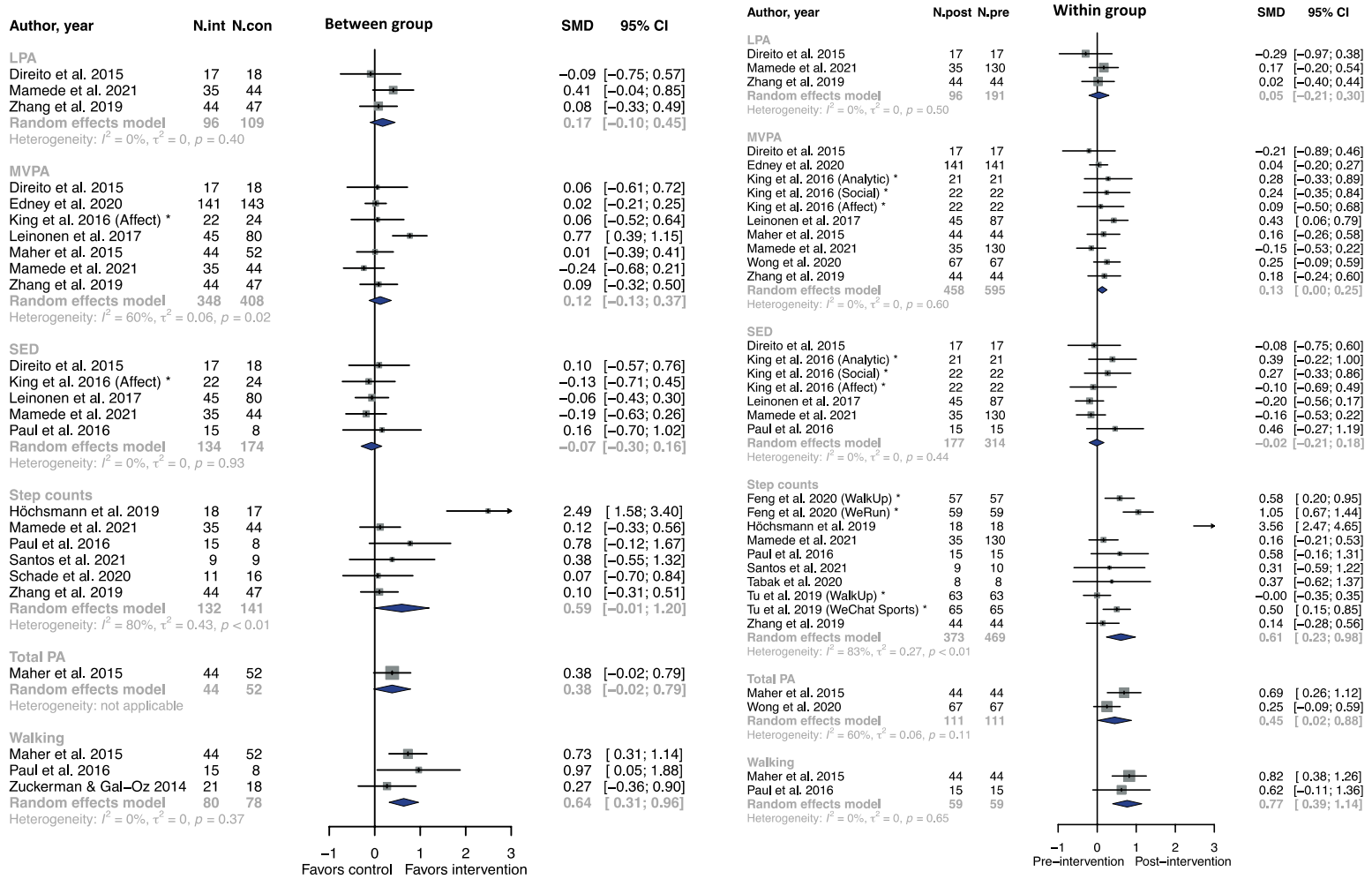
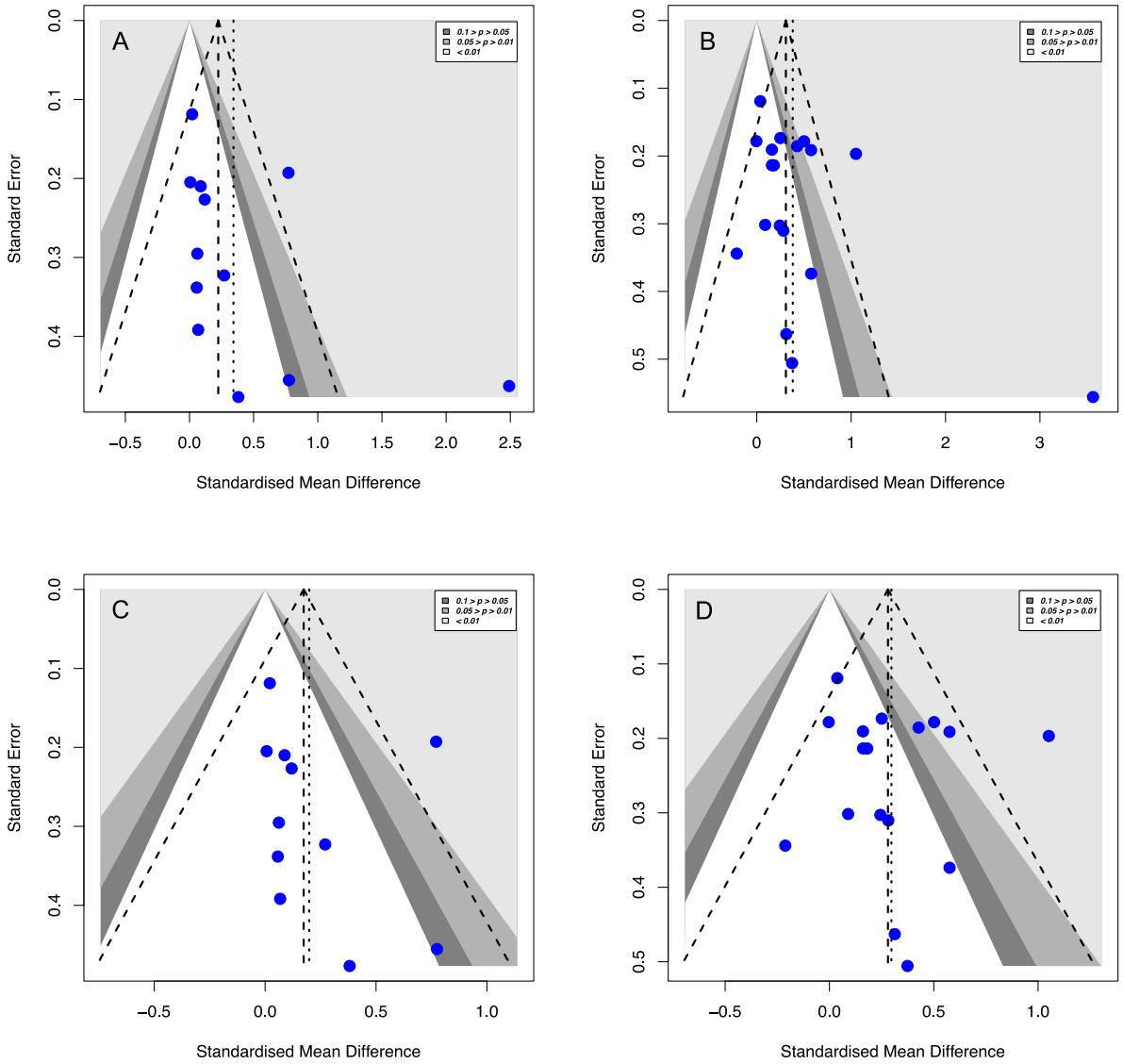
Appendix Figure 1. Secondary meta-analysis: Pooled effect sizes for each physical activity outcomes in between-group RCTs and within-group pre-to-post interventions.



Note. Each PA outcome (e.g., MVPA, step counts) was analyzed separately (since a single study may have more than 5 different PA outcomes); thus, no overall pooled SMD can be estimated.
LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; SED, sedentary behavior; SMD, standardized mean difference.

Appendix Figure 2. Contour-enhanced funnel plots with Egger's test.



Note. A: Funnel plot for between group (Egger's test: t(df)=1.62 (10), p=0.14). B: Funnel plot for within group studies (Egger's test: t(df)=1.61 (16), p=0.13). C: Funnel plot for between group studies after leave-one-out sensitivity analysis (Egger's test: t(df)=0.87 (9), p=0.41). D: Funnel plot for within group studies after leave-one-out sensitivity analysis (Egger's test: t(df)=0.45 (15), p=0.66). p>0.05: no publication bias.