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The Impact of the COVID-19 Lockdown Restrictions on Physical Activity Levels in European Adolescents: A Systematic Review and Meta-Analysis

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Abstract

Aim: To evaluate how the COVID-19 public health lockdown restrictions impacted the physical activity levels of European adolescents aged 10-19. **Methodology:** Databases searched included CINAHL Complete, Medline, APA PsycInfo, AMED, EMBASE, SPORTDiscus, Web of Science, and Cochrane Library. Search terms comprised database-specific synonyms of "Physical Activity" AND "COVID-19" AND "Adolescents". Included studies compared continuous, quantitative pre-COVID and during-COVID physical activity measurements of healthy adolescents aged 10-19 living in the European Union. The references of relevant systematic reviews were hand-searched for pertinent studies. Included studies were independently appraised using the Newcastle Ottawa Scale for Cohort Studies followed by meta-analysis. **Findings:** 1397 studies were retrieved via database search and three further studies through hand searches. After removing duplicates, 898 articles were independently screened in Covidence by two reviewers, resulting in five included studies. Quality Assessment ratings were 'poor' (4/5) or 'fair' (1/5). Random effects meta-analysis demonstrated a significant decline in European adolescent physical activity levels, with a Standard Mean Difference of 0.44 (95% CI, 0.03, 0.84; P=0.005, 4 studies, n=2286). When analyzed by gender, a non-significant trend of decreased physical activity was found in both boys (0.43, 95% CI, -

0.07, 0.93; P=0.09, 3 studies, n=1030) and girls (0.25, 95% CI, -0.33, 0.84; P=0.40, 3 studies, n=1017). **Conclusion:** These results validate concerns that the COVID-19 lockdowns significantly negatively impacted already-poor adolescent physical activity levels, which could lead to long-term adverse effects on this cohort's health and well-being. This research demonstrates the importance of interventions to encourage physical activity participation in this demographic.

Keywords: COVID-19; physical activity; exercise; children; adolescents

Introduction

The World Health Organization (WHO) recommends that children and adolescents aged 5-17 years accumulate 60 minutes of moderate-to-vigorous intensity physical activity (PA) per day (WHO, 2020a). PA is defined as "any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2020c). Concerningly, only one in five adolescents, or individuals aged 10-19 years, met WHO PA guidelines in 2016 (WHO, 2020a, 2022b). These worrying statistics persist despite the well-documented short and long-term physical and mental health benefits of PA in youth (John et al., 2022; WHO, 2020a). Furthermore, PA attitudes and behaviours developed in childhood and adolescence have been shown to carry over to adulthood, significantly impacting the life-long risk of chronic disease (Telama, 2009).

When the WHO declared the worldwide SARS-CoV-2 (COVID-19) pandemic on 11 March 2020, public health lockdown restrictions and stay-at-home orders in most countries caused the extended closure of in-person school, work and organized events, including sports (Cucinotta & Vanelli, 2020; Islam et al., 2020). Concerns have been raised that adolescents, who typically accumulate a large portion of their daily PA from highly impacted activities such as active transport to and from school, in-school physical education lessons and organized leisure-time activities, have been particularly negatively affected by the COVID-19 lockdowns (Bates et al., 2020; Slingerland et al., 2012; WHO, 2022a). It has therefore been suggested that adolescents may be even less active post-COVID-19 and that these changes in lifestyle behaviours could lead to long-term adverse effects on their health and well-being (Bates et al., 2020).

Decreases in physical activity levels during the COVID-19 lockdowns have been demonstrated in adults (Silvia Isela Ramírez et al., 2023). An overall analysis of the literature evaluating the impact of the COVID-19 lockdowns on children and adolescent physical activity levels (PALs) also shows a general trend of declined PA worldwide (Kharel et al., 2022; Mayra et al., 2022; Neville et al., 2022; Povšič et al., 2022; Saulle et al., 2021; Stockwell et al., 2021; Wunsch et al., 2022; Zaccagni et al., 2021). It was identified that those who were highly active pre-COVID were more likely to maintain higher PAL within-COVID, though their total PA still decreased (Wunsch et al., 2022; Zaccagni et al., 2021). Access to outdoor space was another factor that was determined to be significantly correlated with the likelihood of meeting WHO PA guidelines (Okely et al., 2021).

Preliminary data supports the hypothesis that adolescent PALs may be more negatively impacted than those of younger children (Mayra et al., 2022; Schmidt & Pawlowski, 2021; Wunsch et al., 2022). When attempting to stratify the data by gender, however, the results are mixed (Kharel et al., 2022; Mayra et al., 2022; Neville et al., 2022; Povšič et al., 2022; Saulle et al., 2021; Stockwell et al., 2021; Wunsch et al., 2022; Zaccagni et al., 2021). Further exploration differentiating the impact of the lockdowns on male and female children's PALs is warranted.

Individual countries' responses to COVID-19 differed in timing and severity worldwide (Koh, 2020). Vaccine access and policy also varied, with 95% of the COVID-19 vaccines going to 20% of the world's population in the early months of the pandemic (Tatar et al., 2021). This disparity makes an accurate comparison of the impact of lockdowns across developed and less-developed nations problematic. In this systematic review, only the responses of the countries part of the European Union (EU) were examined (EU, 2021). This limitation of scope was selected to reduce bias due to vaccine access given that the EU negotiated on behalf of its member countries to ensure equitable and timely access to vaccines (Sciacchitano & Bartolazzi, 2021).

Furthermore, while systematic reviews examining the impact of the lockdowns on children and adolescents in regions such as the United States and Italy have been performed, none have yet attempted to encompass the EU region (Mayra et al., 2022; Zaccagni et al., 2021). Moreover, our literature review also revealed several outlier studies with the same or increased, rather than decreased, PA uniquely from the EU region (Nigg et al., 2021; Wunsch et al., 2021). Therefore, it becomes necessary to use a systematic approach to determine the magnitude and direction of the impact of the COVID-19 lockdowns on EU adolescent PALs. To our knowledge as of this writing, no published reviews have quantitatively isolated the impact of COVID-19 lockdowns on PA in EU adolescents.

The impact of this review will be to inform governments and similar organisations of any identified marginalized EU cohorts in need of intervention. Should it be discovered that certain countries within the EU were more successful at maintaining or improving their PALs, future research might evaluate why and how these countries improved their outcomes.

Therefore, the primary aim of this systematic review and meta-analysis was to quantitatively determine the impact of the COVID-19 public health lockdown restrictions on the physical activity volume of EU adolescents aged 10-19. The secondary aim was to differentiate the impact of the lockdowns on the PA volume of EU adolescent boys as compared with girls.

Methods

This systematic review was registered as a protocol with PROSPERO (CRD42022342649) (O'Brien & Lynch, 2022). A systematic search using database-specific vocabulary was carried out on 16 May 2022. Search terms contained the words (Physical Activity OR Exercise OR activity) AND (COVID-19 OR Covid OR Sars-cov-2 OR Coronavirus Pandemic OR Cov-19 OR 2019-ncov) AND (Adolescents OR Youth) (Appendix 1). Databases included CINAHL Complete, Medline, APA PsycInfo, AMED, EMBASE, SPORTDiscus, Web of Science, Cochrane Library and PEDro. A hand-search of the references from relevant systematic reviews and included citations was also performed.

All articles were limited to peer-reviewed studies written in English or with English translation available, published between 1 March 2020-15 May 2022. Protocols, case studies, commentaries, letters to the editor, experimental trials, pre-print, and abstract-only articles were excluded.

A PICOTS Framework (Population, Intervention, Comparison, Outcome, Timeframe, Study Type) (Brown et al., 2006) was utilized to specify the inclusion and exclusion criteria as described in Table 1:

Table 1. Eligibility Criteria and PICOTS Framework

Study Characteristics	Inclusion Criteria	Exclusion Criteria
Population	Healthy, typically developing adolescents aged 10-19 living in the EU	Children aged 0-9, adults 20+ Children and adolescents aged 10-19; results not separated by age Individuals living outside the EU Special populations such as elite athletes, adolescents with diabetes, obesity, and any other chronic illness.
Intervention	Evaluate impact of COVID-19 public health lockdown restrictions on PALs	COVID-19 pathology COVID-19 management COVID-19 susceptibility
Comparison	Pre-COVID PA levels vs within-COVID PA levels	No comparison between pre-COVID and within-COVID activity levels
Outcome	Continuous, quantitative units of measurement of	Categorical outcomes, e.g. meeting/not meeting WHO PA guidelines

	PA change, e.g. minutes, distance, steps.	No continuous, quantitative PA measurements
Timeframe	March 1, 2020- May 15, 2022	Outside the specified timeframe
Study Type	Longitudinal, observational, quantitative study designs with data time points both pre- and within-COVID	Qualitative studies Studies not in English Systematic reviews Unrefereed preprint or protocol articles

Both self-reported and device-reported findings using valid and reliable objective measurement instruments were included due to the inherent difficulties of collecting data during the pandemic. Only continuous outcomes for measuring PA were included for meta-analysis, as it was determined that categorical data such as meeting/not meeting WHO 60 minutes per day guidelines might fail to capture any change that did not cross this threshold.

Results from the search were imported into EndNote 20.3 Desktop and duplicates removed, then transferred into Covidence Online Review Management Software. The remaining articles were independently screened first by title and abstract, then by full text as required by two researchers. Any disagreements were resolved by discussion for consensus. Where relevant data was missing from the published articles, study authors were contacted by email requesting the specified data. The study was excluded if no response was received by two weeks after a second follow-up email. A PRISMA flow diagram (Moher et al., 2009) demonstrating the screening process i s included in the Results section .

Quality Assessment

The Newcastle-Ottawa Scale (NOS) for Cohort Studies (Wells et al., 2000), which has been established for content validity and inter-rater reliability (Wells et al., 2014a), was selected for use in this review (Appendix 2). This scale was also employed in similar reviews, such as Povšič et al. (2022) and López-Valenciano et al. (2021), who examined the impact of COVID-19 restrictions on children and adolescents and university students, respectively. Quality assessment was performed independently by two researchers, followed by discussion to reach consensus. A summary table was completed for Quality Assessment (Appendix 2).

The NOS for Cohort studies divides its assessment into three categories: selection, comparability, and outcome (Wells et al., 2014b). After a tally of the stars awarded, studies were deemed good, fair, or poor quality based on the recommended NOS star thresholds. For each question, the NOS was applied to this specific review in the following way:

Table 2. Application of the NOS for Cohort Studies Quality Assessment Tool

Category	Section	Star Allocation
Selection	Representativeness of the exposed cohort	One star if the included cohort was a true representative or somewhat representative sample of all healthy, typically developing adolescents from the included area
	Selection of the non-exposed cohort	One star if the included 'pre-COVID' (non-exposed) cohort was representative of and drawn from the same community as the 'during-COVID' (exposed) cohort
	Ascertainment of exposure	One star if data collection included objective measures (e.g. device-reported PA measures using accelerometers)
	Demonstration that outcome of interest was not present at the start of the study	One star if the 'pre-COVID' (non-exposed) cohort was measured before 11 March 2020, the date that the WHO declared the worldwide pandemic (WHO, 2020b), and 'during-COVID' data was measured after 11 March, 2020.
Comparability	Comparability of cohorts on the basis of design or analysis controlled for confounders	An evaluation was made as to whether a significant difference in age, sex, marital status, etc., might exist between the included 'pre-COVID' and 'during-COVID' cohorts. One star if 'pre-COVID' cohort was comparable to 'during-COVID' cohort
Outcome	Assessment of outcome	One star if outcome measures such as objective, device-measured physical activity were included (independent blind assessment, record linkage)
	Was follow-up long enough for outcomes to occur	One star if the 'during-COVID' cohort was measured regarding a period after 11 March 2020, when the WHO declared the pandemic and public health restrictions had begun (WHO, 2020b)
	Indicate the median duration of follow-up and a brief rationale for the assessment above	The declared duration of time between 'pre-COVID' and 'during-COVID' measurements was included. Star ratings are not employed by the NOS for this question.
	Adequacy of follow-up cohorts	One star if all subjects completed both pre-COVID and during-COVID assessments subjects lost to follow-up were deemed unlikely to introduce bias and totalled δ20%.

Data Extraction

A bespoke data extraction template was designed and agreed upon for this study, adapted from the standard Covidence data extraction template and tested for suitability. This template included study location, aim, design, data collection timeframes, data collection instrument, participant details, results, strengths, and weaknesses. Data extraction was performed independently by two researchers, followed by a discussion for consensus. Once data extraction in Covidence was complete, the quantitative data was transferred from Covidence into Microsoft Excel for data preparation and synthesis. If data was not separated by gender, study authors were contacted to attempt to retrieve this information. Gender-specific data was left blank if study authors did not respond by two weeks after a follow-up email.

Data Preparation

All included studies used quantitative, continuous variables to measure physical activity for adolescents aged 10-19, as per the WHO definition of the adolescent age range (WHO, 2022b). These resulted in singular numbers describing daily or weekly physical activity pre-COVID and during-COVID, with standard deviations (e.g. pre-COVID: XX min/week, SD xx, post-COVID: YY min/week, SD yy).

If published data was separated by age, e.g. 11-13 and 14-17, the means, SDs and sample sizes were combined using the formulae recommended by the Cochrane Handbook (Figure 1) (Higgins & Green, 2011). These formulae combine mean, SD, and sample size into a single group as if the original group had never been divided (Higgins & Green, 2011).

	Group 1 (e.g. males)	Group 2 (e.g. females)	Combined groups
Sample size	N_1	N_2	$N_1 + N_2$
Mean	M_1	M_2	$\frac{N_1M_1 + N_2M_2}{N_1 + N_2}$
SD	SD_1	SD_2	$\sqrt{\frac{(N_1 - 1)SD_1^2 + (N_2 - 1)SD_2^2 + \frac{N_1N_2}{N_1 + N_2}(M_1^2 + M_2^2 - 2M_1M_2)}{N_1 + N_2 - 1}}$

Figure 1. Cochrane Handbook v 5.1.0 Formulae for Combining Groups (Higgins & Green, 2011)

If the published data was separated into different types or intensities of physical activity per day or week (e.g. habitual activity and sports activity, or low-intensity and moderate-to-vigorous intensity), the means were added together to create one total daily or weekly mean. The standard deviations were summed using the equation presented in Figure 2 (Boddie, 2022).

Step 1: Name the independent random variables X and Y, and identify the standard deviations σ_X and σ_Y.

Step 2: Calculate the standard deviation of the sum of the random variables using the formula $\sigma_{X+Y} = \sqrt{\sigma_X^2 + \sigma_Y^2}$.

Figure 2. Calculating the standard deviation of the sum of two independent random variables (Boddie, 2022)

Following these calculations, the prepared data was exported from Microsoft Excel into RevMan 5.4 Desktop to proceed with the meta-analysis which is described next.

Data Synthesis

A meta-analysis was planned as the primary data synthesis method for this systematic review to analyse firstly, whether the COVID-19 lockdowns significantly affected European adolescent physical activity levels, and secondly, the magnitude and direction of that effect. Studies that published changes in physical activity levels before and during COVID using continuous variables were included in this review to combine them in a Standardised Mean Difference (SMD) meta-analysis as none of the included studies utilized the same outcome measure.

First, a Fixed Effect model with 95% Confidence Intervals (CI) meta-analysis was attempted. As an I^2 of more than 50% was reported following analysis, a Random Effect Analysis model was then performed to account for the high heterogeneity. The resulting Forest Plots and overall significance from both the Fixed Effect and Random Effects models were then exported from RevMan. Based on the available extracted data, further meta-analyses were run to determine the impact of the COVID-19 lockdowns on European adolescent boys compared to girls. Fixed Effects models were run first, followed by Random Effects models when the I^2 was greater than 50%. These Forest Plots and overall significance reports were also exported for inclusion in this review.

Results

Search and Selection

One thousand three hundred ninety-seven articles were retrieved via the electronic database searches, and three further articles via hand search of relevant systematic reviews. After removing duplicates, 898 papers remained to be screened in Covidence for inclusion. After independent screening, five studies were included. The search and selection strategy are summarised in the Prisma diagram (Figure 3).

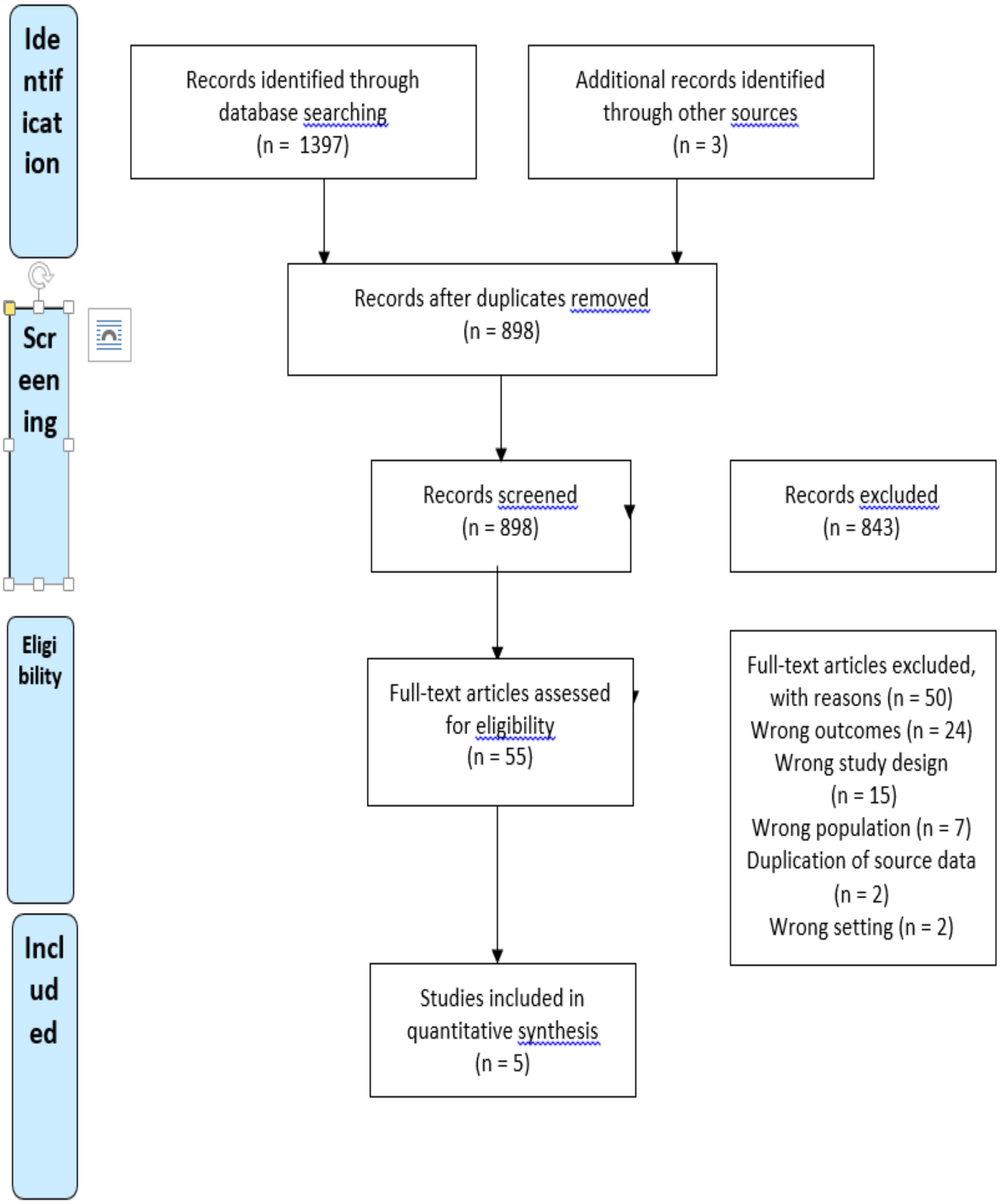

Figure 3. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Moher et al., 2009)

Inter-rater reliability before discussion for consensus in the title and abstract screening was high, with a proportionate agreement of 0.92 and a Cohen's Kappa of 0.46. Inter-rater reliability during the full-text review achieved 0.80 proportionate agreement and a 0.34 score for Cohen's Kappa.

These Cohen's Kappa scores illustrate the necessity of discussion after independent review to reach a final consensus for included studies.

Characteristics of Included Studies

All five included studies reported successful ethical approval from their respective relevant institutions. Three of the included studies collected data from participants living in Spain, one from Croatia, and one from Germany. Only Schmidt et al. (2020)'s German study, which included participants from the long-running Motorik-Modul study, and López-Bueno et al. (2020)'s Spanish study included participants from all areas of their respective countries rather than one specific region.

All five of the studies were non-randomized, observational studies which utilized some form of a self-report questionnaire for data collection. Two of the included studies collected data longitudinally before and during COVID-19 (Schmidt et al., 2020; Sekulic et al., 2020). The remaining three studies collected data cross-sectionally using a retrospective technique: all participants filled out their questionnaire regarding their present (within-COVID lockdowns) activity levels and completed the same questionnaire again regarding their memory of their behaviour before the onset of the COVID-19 pandemic (Carrillo-Diaz et al., 2022; López-Bueno et al., 2020; Villodres et al., 2021). Table 3 illustrates the descriptive characteristics of the included studies.

Table 3. Characteristics of Systematic Review Included Studies

Study I D	**Study Setting**	**Population Description & Recruitment**	**Study Design**	**Age Range**	**Sample Size**
Lopez-Bueno 2020	Spain: All Spanish regions	All adults residing in Spain with children, recruited via social media	Cross-sectional retrospective	13-16	239
Schmidt 2020	Germany: 167 cities and municipalities	Wave 3 of ongoing representative sample MoMo study participants	Longitudinal	11-17	747
Sekulic 2020	Croatia: Split-Dalmatia County	Secondary school students participating online, unclear recruitment	Longitudinal	15-18	401
Villodres 2021	Spain: Granada & Malaga	Convenience sample of secondary school participants recruited through their school	Cross-sectional retrospective	10-14	899
Carrillo-Diaz 2022	Spain: Madrid	Convenience sample of adolescent patients from private dental clinics	Cross-sectional retrospective	11-17	213

All studies examined the same cohort of individuals for their pre- and within-COVID measurements, whether completed longitudinally or cross-sectionally. Most studies had a relatively even split of male and female participants (45-50% boys), except for Sekulic et al. (2020), which had 67.6% boys. All five studies gathered ‘within-COVID’ data about the lockdowns in Wave 1 of the worldwide COVID-19 pandemic, dated February-August 2020 (UCD, 2021).

López-Bueno et al. (2020)’s study participants included parents of adolescents reporting on their children's PA behaviour. The remaining four study questionnaires were carried out by adolescents directly.

Quality Assessment

Quality assessment using the NOS for Cohort Studies was performed independently by two researchers, followed by a discussion for consensus. It was noted by the researchers that a joint pilot of the application of the NOS to this type of study would have been helpful in advance of completing the independent review to ensure both researchers applied the scale in the same manner.

Overall, quality was deemed ‘poor’ for 4/5 studies, with the sole exception being López-Bueno et al. (2020) which garnered a ‘fair’ rating. This ‘fair’ rating should be interpreted with caution, as this study was the only one that included parents of adolescents as participants, filling out questionnaires on behalf of their children, which could have introduced bias not captured by the NOS (López-Bueno et al., 2020). Given that most studies had a poor rating, none were individually excluded due to their quality assessment rating. See Table 4 for a summary of the outcomes of Quality Assessment using the NOS for Cohort Studies.

Table 4. Systematic Review Quality Assessment Summary

Citation	Selection	Comparability	Outcome	Quality Rating
Lopez-Bueno 2020	**	**	**	Fair
Schmidt 2020	***	*	*	Poor
Sekulic 2020	**	*	*	Poor
Villodres 2021	*	*	**	Poor
Carrillo-Diaz 2022	*	*	**	Poor

With regards to the representativeness of the exposed cohort, two studies earned one star each as they were deemed to be a ‘somewhat representative' sample (López-Bueno et al., 2020; Schmidt et al., 2020). Of note, these studies included participants from all regions in their respective countries and attempted to form as representative a sample as possible. Three of the included papers were awarded zero stars as they were deemed a selected group i.e. from only a single region or a selected population such as patients from private dental clinics (Carrillo-Diaz et al., 2022; Sekulic et al., 2020; Villodres et al., 2021). Furthermore, Sekulic et al. (2020) included a sample of 67.6% boys; given the well-documented increased PALs in adolescent boys versus girls, this might have biased their results (Pearson et al., 2009).

When examining the selection of the non-exposed cohort, all five studies were awarded one star for being 'drawn from the same community as the exposed cohort'. In each of the five studies, the pre-COVID and within-COVID measurements were taken from the same individuals. All studies were awarded zero stars in the Ascertainment of Exposure section as none utilized device-reported physical activity measures.

In the section titled 'Demonstration that outcome of interest was not present at the start of the study', two studies were awarded one star each as their 'pre-COVID' (non-exposed) cohort data was collected before 11 March 2020 (Schmidt et al., 2020; Sekulic et al., 2020). The remaining studies received zero stars as their data was collected in a cross-sectional, retrospective manner (Carrillo-Diaz et al., 2022; López-Bueno et al., 2020; Villodres et al., 2021).

All five studies were awarded one star in the Comparability of Cohorts section for " controlling for age, sex, and marital status" . In each of the five studies, the pre-COVID and within-COVID measurements were taken from the same individuals. Therefore, there can be no differences in age, sex, marital status, etc., between the pre-and within-COVID groups.

In the Assessment of Outcome section, all studies were awarded zero stars as all utilized self-reported rather than device-reported physical activity measures. All studies were assigned one star when considering if their follow-up was long enough for outcomes to occur as their 'during-COVID' cohorts were measured after 11 March 2020, when the WHO declared the pandemic, and public health restrictions had begun (WHO, 2020b). The duration of pre-COVID to within-COVID follow-up ranged from 0.5 months to 1.5 years.

Lastly, when examining the Adequacy of Follow-up Cohorts, three studies received one star for 'Complete follow-up' as their study design was cross-sectional retrospective and all participants completed the pre-COVID and within-COVID surveys during the same session (Carrillo-Diaz et al., 2022; López-Bueno et al., 2020; Villodres et al., 2021). Sekulic et al. (2020) was awarded zero stars as their source data for pre-COVID measurements had a significantly larger sample size; however, no explanation was made regarding those who did not opt to complete the within-COVID survey. Similarly, Schmidt et al. (2020) was awarded zero stars as they were noted to have a follow-up rate of less than 80%. Only 63.6% of the original MoMo Wave 3 pre-COVID participants completed the within-COVID follow-up questionnaire.

Data Extraction

One of the challenges of any proposed systematic review and meta-analysis that analyses changes in PA participation levels is that PA is measured in a myriad of ways, including meeting/not meeting WHO guidelines, METS/week, PA min/week, PA min/day, and Physical Activity Questionnaire (PAQ) scores. Furthermore, while those who use the IPAQ outcome measure, for example, may calculate the total PA min/week and METS/week of participants, they do not always publish their data using these outcomes, nor do they always publish their raw data. When contacted to access the raw data, authors frequently did not reply to email requests. Alternatively, if they did respond, it was to deny the data requests due to a conflict with a future paper they intend to publish.

All of the included studies employed different self-reported physical activity measurement instruments. Sekulic et al. (2020) used the Physical Activity Questionnaire for Adolescents (PAQ-A), which provides a unique score rated from 1-5, with 5 indicating higher levels of PA. Villodres et al. (2021) used the similar Physical Activity Questionnaire for Older Children (PAQ-C), also with a 1-5 scoring output. López-Bueno et al. (2020) used a unique survey with one question assigned to PA: "How many minutes of physical activity does your child usually perform weekly?" with an outcome score in PA min/week. Carrillo-Diaz et al. (2022) employed the IPAQ-SF and chose to report their results in METs/week.

In the last included study, Schmidt et al. (2020) took a different approach to measuring physical activity. Their questionnaires, a subset of the long-running Motorik-Modul study, divided PA min/day into habitual activity (HA) minutes, such as walking, gardening, and housework, or more traditional sports activity (SA) minutes, such as organised sport and non-organised activities such as running or biking. They also separated their data by age into younger adolescents (11-13 years) and older adolescents (14-17 years), necessitating data preparation calculations.

Data Preparation

Schmidt et al. (2020)'s age-separated data was first combined using the Cochrane Handbook's recommended formulae for combining groups as if they had never been divided (see Table 3.2) (Higgins & Green, 2011) and these values are presented in Table 5.

Table 5. Overall Combined Means, SDs, and Sample Sizes for Ages 11-17 Habitual Activity (HA) and Sports Activity (SA) min/day

Schmidt 2020 Boys	Pre-HA Mean	Pre-HA SD	Pre-HA n	Pre-SA Mean	Pre-SA SD	Pre-SA n	During HA Mean	During HA SD	During HA n	During SA Mean	During SA SD	During SA n
Age 11-13	91.8	68.5	343	42.6	27	343	111.1	90.2	343	29.7	40.9	343
Age 14-17	80.3	65.6	404	44.6	30.2	404	97.2	90.3	404	29	25.6	404
Age 11-17	85.58	67.15	747	43.68	28.77	747	103.58	90.46	747	29.32	33.48	747

Schmidt et al. (2020) also provided HA and SA min/day age-separated data sets divided by gender, so these calculations were also performed to combine the 11-13 and 14-17 age groups into single data sets for boys' and girls' HA and SA min/day, aged 11-17. These new means, SDs and sample sizes are presented in Tables 6 and 7.

Table 6. Boys Combined Means, SDs, and Sample Sizes for Ages 11-17 Habitual Activity (HA) and Sports Activity (SA) min/day

Schmidt 2020 Boys	Pre-HA Mean	Pre-HA SD	Pre-HA n	Pre-SA Mean	Pre-SA SD	Pre-SA n	During HA Mean	During HA SD	During HA n	During SA Mean	During SA SD	During SA n
Age 11-13	102.8	77.7	166	44.3	25.7	166	118.7	98.1	166	32.8	44.7	166
Age 14-17	89.1	74.4	178	47.4	30.5	178	99.5	99.4	178	26.7	39.6	178
Age 11-17	95.71	76.21	344	45.90	28.29	344	108.77	99.10	344	29.64	42.19	344

Table 7. Girls Combined Means, SDs, and Sample Sizes for Ages 11-17 Habitual Activity (HA) and Sports Activity (SA) min/day

Schmidt 2020 Girls	Pre-HA Mean	Pre-HA SD	Pre-HA n	Pre-SA Mean	Pre-SA SD	Pre-SA n	During HA Mean	During HA SD	During HA n	During SA Mean	During SA SD	During SA n
Age 11-13	81.2	55.2	177	41.1	28.1	177	104	81.4	177	26.7	36.9	177
Age 14-17	73.4	56.9	226	42.3	29.8	226	95.4	82.6	226	30.9	32	226
Age 11-17	76.83	56.22	403	41.77	29.04	403	99.18	82.08	403	29.06	34.26	403

After completing these calculations, Schmidt et al. (2020)'s HA and SA min/day were summed to create one daily mean PA min/day value. The standard deviations were computed using the calculations shown in Figure 2 (Boddie, 2022). These resulted in the final, prepared data set including mean PA min/day pre-COVID and during-COVID for overall boys and girls, just boys, and just girls. These new means, SDs and sample sizes can be seen in Table 8.

Table 8. Final Prepared Means, SDs, and Sample Sizes for combined Habitual Activity (HA) and Sports Activity (SA) min/day Schmidt 2020

HA+SA	Overall Mean	Overall SD	Overall n	Boys Mean	Boys SD	Boys n	Girls Mean	Girls SD	Girls n
Pre-COVID	129.26	73.05	747	141.62	81.29	344	118.60	63.28	403
During-COVID	132.90	96.46	747	138.41	107.70	344	128.23	88.95	403

Following these preparatory calculations, the data from all five included studies was ready to be presented together in a table displaying the mean pre-COVID and within-COVID PALs (Table 9).

Table 9. Mean Outcomes for Pre-COVID and Within-Covid PALs

Study ID	Units	Mean Pre-COVID	SD	n	Mean During-COVID	SD	n
Carrillo -Diaz 2022	METs/week	856.60	343.50	213	332.80	91.60	213
Villodres 2021	PAQ-C	2.87	0.72	899	2.33	0.69	899
Lopez-Bueno 2020	PA min/week	162.10	165.30	239	86.90	109.30	239
Schmidt 2020	PA min/day	129.26	73.05	747	132.90	96.46	747
Sekulic 2020	PAQ-A	2.99	0.70	401	2.67	0.60	401

Where possible, based on published data, gender-specific data was also extracted (Tables 10 & 11).

Table 10. Mean Outcomes for Pre-COVID and Within-Covid PAL in Boys

Study ID	Units	Mean Pre-COVID	SD	n	Mean During-COVID	SD	n
Villodres 2021	PAQ-C	3.00	0.73	415	2.37	0.72	415
Schmidt 2020	PA min/day	141.62	81.29	344	138.41	107.70	344
Sekulic 2020	PAQ-A	3.10	0.78	271	2.79	0.82	271

Table 11. Mean Outcomes for Pre-COVID and Within-Covid PALs in Girls

Study ID	Units	Mean Pre-COVID	SD	n	Mean During-COVID	SD	n
Villodres 2021	PAQ-C	2.78	0.70	484	2.29	0.65	484

Schmidt 2020	PA min/day	118.60	63.28	403	128.23	88.95	403
Sekulic 2020	PAQ-A	2.71	0.66	130	2.59	0.90	130

Overall Change in PALs

When data synthesis was performed using the Fixed Effects Model in all cases, the I^2 was >50% (see Supplementary D ata, Appendix 3). Therefore, the Random Effects Model was employed and the subsequent results are described next. The Random Effects Model Forest Plot (Figure 5) illustrates the results following the analysis of PA data from boys and girls.

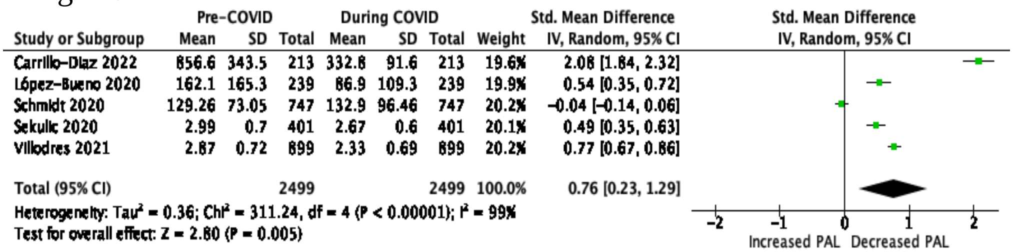

Figure 5. Random Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Overall Boys and Girls together

In the Random Effects meta-analysis, the overall Standard Mean Difference (SMD) was significant at 0.76, with 95% CIs (0.23, 1.29; P=0.005, 5 studies, n=2499). SMDs of 0.2 are rated as small, 0.5 as medium, and 0.8 as large (Andrade, 2020). This indicates a relatively large overall effect for decreased PAL in this meta-analysis. In SMD, smaller SDs lead to higher estimates of SMD, and larger SDs lead to smaller SMD estimates (Riley et al., 2011). This is assumed to be due to between-study variation in measurement scales rather than the reliability of the outcome measures or differences in study populations (Riley et al., 2011). Individually, Schmidt et al. (2020)'s study results, which showed an overall increase in PAL, were deemed insignificant as the 95% CI crosses the line of no effect.

A strength of this meta-analysis was that all five studies were nearly equally weighted, rather than having one study responsible for most of the weighting and possibly skewing the results. This indicates that each study was deemed to have relatively similar precision (Riley et al., 2011). Overall, however, these meta-analysis results should be interpreted with caution. Firstly, the small number of included studies decreases the certainty of the estimated mean effect (Higgins et al., 2009). Secondly, the I^2 remains high at 99%, indicating considerable heterogeneity across the included studies.

Removal of Outlying Study

When examining the results of the meta-analysis, it was observed that Carrillo-Diaz et al. (2022)'s study results were an outlier when compared with to rest of the data. This study was the only one to employ METS/week as their outcome rather than PA minutes or IPAQ scores, which may have increased the heterogeneity of this study and skewed the results. Furthermore, this study collected data from adolescents attending private dental care at a dental clinic; this may have introduced bias due to the potentially increased socioeconomic status of adolescents receiving private dental care. The meta-analysis was therefore performed again with this study removed from the calculations (Figure 6).

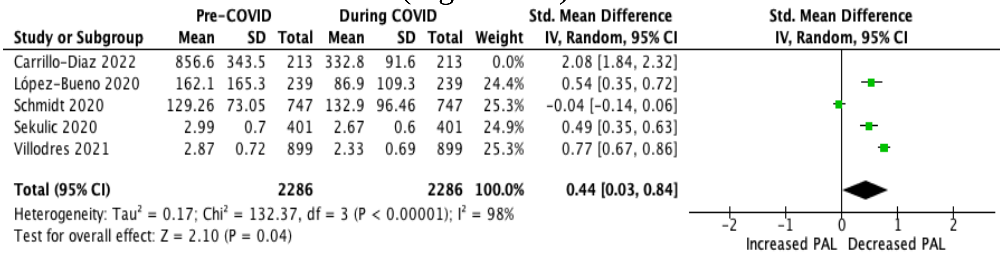

Figure 6 . Random Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Overall Boys and Girls with Carrillo-Diaz et al. (2022) removed

In the Random Effects meta-analysis, the overall SMD remained significant at 0.44, with 95% CIs (0.03, 0.84; P=0.04, 4 studies, n=2286), though the degree of significance declined. All four included studies remained relatively equally weighted.

Change in Physical Activity Level by Gender

Next, the three studies that published separate boys' and girls' data were analysed. The boys' PA data was used to run a Random Effect meta-analysis with 95% Cis, illustrated in Figure 7 .

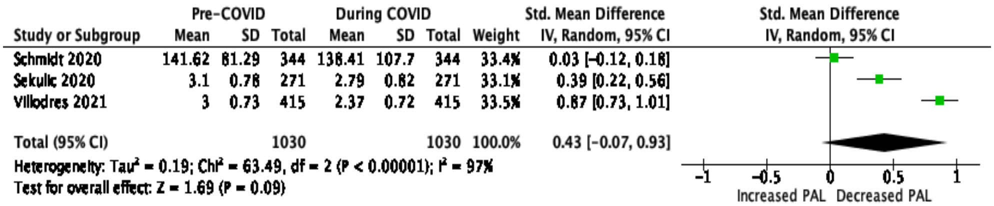

Figure 7 . Random Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Boys

In the Random Effects meta-analysis, the overall SMD was found to be 0.43 (95% CI, -0.07, 0.93; P=0.09, 3 studies, n=1030). However, as the 95% CI crosses the line of no effect, the results are not statistically significant (p>0.05). All three studies were equally weighted. However, the results of the meta-analysis should be interpreted with caution as the I^2 was high at 97%.

The girls' PA data was then used to run a Random Effect model with a 95% CIs meta-analysis , demonstated in Figure 8.

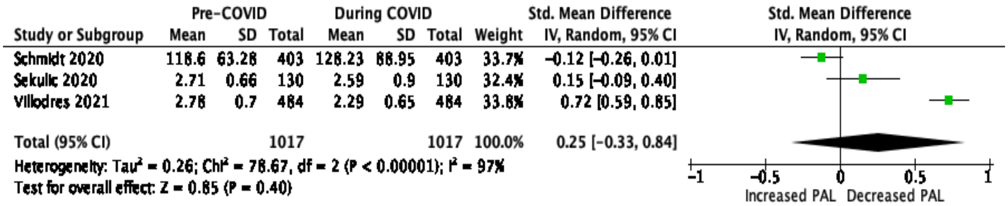

Figure 8 . Random Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Overall Girls

In the Random Effects meta-analysis, the overall SMD was 0.25 (95% CI, -0.33, 0.84; P=0.40, 3 studies, n=1017). Again, as the 95% CI crosses the line of no effect, the results are not significant (p>0.05). All three studies were relatively equally weighted. Once again, the results of the meta-analysis must be interpreted with caution as the I^2 was considerable at 97%.

Publication Bias

Tests for publication bias using funnel plot asymmetry were not performed as it is recommended that a minimum of 10 studies be included to ensure adequate power (Higgins & Green, 2011).

Discussion

Five studies were included in this systematic review and meta-analysis from three EU countries: Spain, Croatia, and Germany. Overall, the results showed a significant decline in within-COVID PALs for adolescents, validating concerns about future trends and health impacts for this cohort. When one study with outlier results showing more significantly decreased PALs was removed from the meta-analysis (Carrillo-Diaz et al., 2022), the results still showed a significant decline in adolescent PA. These results align with the findings from similar systematic reviews examining changes in PALs in children and adolescents worldwide (Kharel et al., 2022; Mayra et al., 2022; Neville et al., 2022; Povšič et al., 2022; Saulle et al., 2021). When the changes in PA were analyzed by gender, the results were not statistically significant but also demonstrated a general trend of decreased PALs.

Four out of five studies demonstrated an absolute decrease in adolescent PALs. The sole exception was the German study based on source data from the Motorik-Modul study, which showed a non-significant increase in adolescent PA (Schmidt et al., 2020). This study by Schmidt et al. (2020) was based on a longitudinal representative sample of children of a variety of ages and was able to demonstrate a more significant negative impact on adolescent PALs as compared with younger children. Their results showed a decrease in Sports Activity in children of all ages alongside an increase in Habitual Activity; however, adolescents showed a more marked decline in Sports Activity and a lower improvement in Habitual Activity compared with younger children.

Dividing PA into Sports and Habitual Activity is a methodological strength of this study, as it is arguably more likely to capture changes in both moderate-to-vigorous activity levels and lower-intensity PA modalities. These lower-intensity Habitual PA modalities, such as gardening and housework, might otherwise be overlooked when participants are questioned about their PA behaviours. While Schmidt et al. (2020)'s study demonstrated an overall increase in adolescent PALs, this author would argue that their results are still concerning for future health trends. Moderate-to-vigorous activity, such as Sports Activity, is known to have greater health benefits than lower-intensity PA, such as Habitual Activity (Whooten et al., 2019). Given that the significant decline in Sports Activity is likely to encompass the majority of moderate-to-vigorous PA in an adolescent's day, it is arguable that the increase in lower-intensity Habitual Activity may not cancel out the negative impact of decreased Sports Activity.

Study Quality

Overall poor-quality assessment scores and high heterogeneity in the analysis indicate that the results should be interpreted with caution. Several overarching methodological flaws led to an increased risk of recall bias in most studies. Recall bias, a form of information bias, refers to the measurement errors that occur due to mistakes in participants' memories of an event or timeline (Hammer et al., 2009). This review included studies that exhibited an overreliance on self-reported rather than device-measured data and cross-sectional retrospective rather than longitudinal study designs.

Due to the nature of the pandemic, researchers could only gather longitudinal PA data if they had already been doing so for a different, related study. Moreover, researchers could not distribute accelerometers for participant measurements due to public health restrictions. In one case, it was deemed unethical to attempt to distribute devices to objectively measure PA during the lockdowns (Schmidt et al., 2020). Therefore, the authors' study design choices are understandable, but there still exists a high risk of recall bias, which should be kept in mind when interpreting the results. It has been noted in the research that self-reported data from adolescents was less reliable during the pandemic and should be interpreted with more caution than usual (Cocca et al., 2021).

Several of the included studies also had a high risk of selection bias due to their reliance on convenience sampling (Lines et al., 2022). Selection bias refers to when the sample population is not a random selection from the target population and, therefore, may not be representative (Hammer et al., 2009). Again, the nature of the pandemic would have limited recruitment avenues in many cases. Carrillo-Diaz et al. (2022)'s study, for example, which collected data from adolescents attending private clinics for dental care, may have overestimated PALs as private dentistry services are known to be quite expensive (Eaton et al., 2019). This could have led to a higher-than-representative socioeconomic status of participants. Higher socioeconomic status is a known predictor of higher PALs, including during the pandemic (Nagata et al., 2022).

Two studies exhibited a high risk of non-response bias, another form of selection bias (Schmidt et al., 2020; Sekulic et al., 2020). Non-response bias occurs when there is a significant disparity in those who participate in a study compared with those who do not (Delgado-Rodríguez & Llorca, 2004) This occurred due to the high attrition (>20%) between baseline pre-COVID and within-COVID measurements that was unaccounted for. It is possible that those who did not respond to the within-COVID survey differed in PAL at baseline from those who participated fully.

Finally, for longitudinal studies such as the Motorik-Modul study, it has been demonstrated that the pre-and during-COVID measurements were often 12 months or more apart (Schmidt et al., 2020). This resulted in an age difference of participants at baseline/follow-up and may have introduced confounding bias due to the already well-documented decline in adolescent PALs with increasing age. Confounding bias is observed when an associated risk factor for the studied condition is not considered in the evaluation and may impact the results (Hammer et al., 2009). It is possible that some of the observed decreases were due to normal age-related decline and cannot entirely be attributed to lockdown effects. Sekulic et al. (2020)'s study may have exhibited a further confounding bias, as their research included significantly more boys than girls (271 versus 130), and boys have been shown to have overall higher PALs than girls (Pearson et al., 2009).

The high risk of bias indicates that these results should be interpreted with caution despite the statistically significant outcome of decreased PALs in European adolescents. Furthermore, given the observed variation in between-country results, examining country-specific lockdown factors contributing to PAL declines is warranted.

Conclusion

The aim of this systematic review and meta-analysis was to determine if the coronavirus pandemic lockdown restrictions had an impact on the PALs of European adolescents. After a thorough review and analysis, it can be concluded that the lockdowns, while necessary for public health, caused a significant decline in the already-poor EU adolescent PALs. These findings align with similar systematic reviews examining changes in youth PALs worldwide (Kharel et al., 2022; Mayra et al., 2022; Neville et al., 2022; Povšič et al., 2022; Saulle et al., 2021).

When the results were analyzed by gender, a non-significant trend of decreased PA was found separately in both boys and girls. While not statistically significant, this trend aligns with other studies that have identified significant declines in adolescent PA across both male and female genders (Branquinho et al., 2021; Galluccio et al., 2021; Greier et al., 2021; Medrano et al., 2021).

The overall decline in adolescent PA during the lockdowns is worrying given the established correlations between PA, mental health, and health-related quality of life (WHO, 2020a). It validates concerns that adolescents may be even less active post-COVID-19 and that these changes in lifestyle behaviours could lead to long-term adverse effects on their health and well-being (Bates et al., 2020). It remains to be seen if adolescent PA will recover to pre-pandemic levels or remain lower for years to come.

Future Research and Recommendations

As more data in this area is published over time, meta-analyses including a greater number of studies might demonstrate a statistically significant trend in the impact of the lockdowns on adolescent boys and girls. These reviews might also perform an in-depth analysis of the gender disparities in the impact of the lockdowns to determine how and if adolescent boys and girls were impacted differently.

Future research might also analyze within-lockdown PALs and their relationship with overall mortality during the pandemic. If, as might be surmised, there was no negative impact of increased population PA on COVID transmission and overall mortality, an analysis of how countries such as Germany (as exhibited in Schmidt et al. (2020)'s study) maintained increased PA would be beneficial. This research could examine the nature of the public health messaging that gained compliance with restrictions yet supported PA in order to provide valuable insight for policymakers.

Physical activity interventions will be required to introduce PA to currently inactive demographics and to encourage those who were active pre-COVID to return to their habitual physical activities. An investment in the improvement of outdoor physical activity areas such as public playgrounds, parks, and fields for non-organised sports would improve PA access both immediately and in the event of future lockdowns.

Strengths and Limitations

Strengths of this review included its ability to use meta-analysis to inform the results, as meta-analysis is known to be the highest level of recognised evidence due to its decreased overall bias (Haidich, 2010). The use of continuous measures of PA change was also a strength of this review as it ensured this meta-analysis was more likely to capture change, even in those whose PA changes did not cross the threshold of meeting/not meeting WHO guidelines.

Limitations included a low number of included studies which decreases the power of the calculations. Furthermore, this review's included studies demonstrated an over-reliance on data from Spain (3/5 studies). Spain's country-specific lockdown restrictions may have limited children's activities more than in other countries, which could have biased the overall results. All of the included studies relied on self-reported measures, which are known to overestimate PALs (Adamo et al., 2009; Hardie Murphy et al., 2015). Moreover, it has been shown that the correlation between subjectively and objectively reported PALs in adolescents is weaker during lockdown restrictions as compared with regular daily life (Cocca et al., 2021).

In the data preparation section, it should be noted that the formula used to calculate the SD when the means were summed was intended to be used with two completely independent random variables. In this situation, it is conceivable that the random variables (habitual and sports activity) for an individual might be correlated and, thus, not entirely independent of each other. It is possible that this introduced some bias to the final SDs, though these authors judged that any such bias was likely to be minimal.

Lastly, it is possible that the analysis exhibited bias due to the variation in individual studies' data collection timeframes. Within the same data collection period, within-country lockdown severities varied between moderate and strict levels, which could have impacted individual participants' responses.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

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Supplemental Material

Appendix 1: Search Strategy

EBSCO Database searched from 01/03/2020 to 15/05/2022 including Academic Search Complete, AMED, CINAHL Complete, Health Source: Nursing/Academic Edition, MEDLINE, APA PsycInfo, and APA PsycArticles.

Search ID#	Search Terms	Results ('hits')
S6	S1 AND S2 AND S3 Limiters: Full Text	(1281)
S5	S1 AND S2 AND S3 Limiters: English	(1361)
S4	S1 AND S2 AND S3	(1412)
S3	"Adolescent" or "Teenager" or "Young Adult" or "Teen*" or "Youth" Limiters: Title or Abstract, Peer Reviewed	(206,868)

S2	"COVID-19" or "Covid" or "Sars-cov-2" or "coronavirus pandemic" or "Cov-19" or "2019-ncov" Limiters: Title or Abstract, Peer Reviewed	(407,352)
S1	"Physical Activity" or "Exercise" or "Activity" Limiters: Title or Abstract, Peer Reviewed	(883,280)

EMBASE Database searched from 01/03/2020 to 15/05/2022

Search ID#	**Search Terms**	**Results ('hits')**
S4	S1 AND S2 AND S3	(116)
S3	"Child" or "Adolescent" or "Childhood" or "Juvenile" Limiters: Title or Abstract	(21,151)
S2	"Coronavirus Disease 2019" or "pandemic" Limiters: Title or Abstract	(32,546)
S1	"Physical Activity" or "Exercise" Limiters: Title or Abstract	(15,024)

Appendix 2: Newcastle-Ottawa Quality Assessment Form for Cohort Studies (Wells et al., 2014a)

Newcastle-Ottawa Quality Assessment Form for Cohort Studies

Note: A study can be given a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability.

Selection

1) Representativeness of the exposed cohort
   a) Truly representative ***(one star)***
   b) Somewhat representative ***(one star)***
   c) Selected group
   d) No description of the derivation of the cohort
2) Selection of the non-exposed cohort
   a) Drawn from the same community as the exposed cohort ***(one star)***
   b) Drawn from a different source
   c) No description of the derivation of the non exposed cohort
3) Ascertainment of exposure
   a) Secure record (e.g., surgical record) ***(one star)***
   b) Structured interview ***(one star)***
   c) Written self report
   d) No description
   e) Other
4) Demonstration that outcome of interest was not present at start of study
   a) Yes ***(one star)***
   b) No

Comparability

1) Comparability of cohorts on the basis of the design or analysis controlled for confounders
   a) The study controls for age, sex and marital status ***(one star)***
   b) Study controls for other factors (list) ________________________________ ***(one star)***
   c) Cohorts are not comparable on the basis of the design or analysis controlled for confounders

Outcome

1) Assessment of outcome
   a) Independent blind assessment ***(one star)***
   b) Record linkage ***(one star)***
   c) Self report
   d) No description
   e) Other
2) Was follow-up long enough for outcomes to occur
   a) Yes ***(one star)***
   b) No

Indicate the median duration of follow-up and a brief rationale for the assessment above:____________________

3) Adequacy of follow-up of cohorts
   a) Complete follow up- all subject accounted for ***(one star)***
   b) Subjects lost to follow up unlikely to introduce bias- number lost less than or equal to 20% or description of those lost suggested no different from those followed. ***(one star)***
   c) Follow up rate less than 80% and no description of those lost
   d) No statement

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Thresholds for converting the Newcastle-Ottawa scales to AHRQ standards (good, fair, and poor):

Good quality: 3 or 4 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain

Fair quality: 2 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain

Poor quality: 0 or 1 star in selection domain OR 0 stars in comparability domain OR 0 or 1 stars in outcome/exposure domain

Appendix 3: Fixed Effect Meta-Analysis Models

Study or Subgroup	Pre-COVID Mean	Pre-COVID SD	Pre-COVID Total	During COVID Mean	During COVID SD	During COVID Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Carrillo-Diaz 2022	856.6	343.5	213	332.8	91.6	213	5.9%	2.08 [1.84, 2.32]
López-Bueno 2020	162.1	165.3	239	86.9	109.3	239	9.8%	0.54 [0.35, 0.72]
Schmidt 2020	129.26	73.05	747	132.9	96.46	747	31.9%	-0.04 [-0.14, 0.06]
Sekulic 2020	2.99	0.7	401	2.67	0.6	401	16.6%	0.49 [0.35, 0.63]
Villodres 2021	2.87	0.72	899	2.33	0.69	899	35.8%	0.77 [0.67, 0.86]
Total (95% CI)			2499			2499	100.0%	0.52 [0.46, 0.57]

Heterogeneity: $Chi^2 = 311.24$, df = 4 ($P < 0.00001$); $I^2 = 99\%$
Test for overall effect: $Z = 17.69$ ($P < 0.00001$)

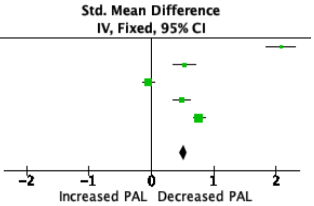

Figure 9. Fixed Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Overall Boys and Girls together

Study or Subgroup	Pre-COVID Mean	Pre-COVID SD	Pre-COVID Total	During COVID Mean	During COVID SD	During COVID Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Carrillo-Diaz 2022	856.6	343.5	213	332.8	91.6	213	0.0%	2.08 [1.84, 2.32]
López-Bueno 2020	162.1	165.3	239	86.9	109.3	239	10.5%	0.54 [0.35, 0.72]
Schmidt 2020	129.26	73.05	747	132.9	96.46	747	33.9%	-0.04 [-0.14, 0.06]
Sekulic 2020	2.99	0.7	401	2.67	0.6	401	17.7%	0.49 [0.35, 0.63]
Villodres 2021	2.87	0.72	899	2.33	0.69	899	38.0%	0.77 [0.67, 0.86]
Total (95% CI)			**2286**			**2286**	**100.0%**	**0.42 [0.36, 0.48]**

Heterogeneity: $Chi^2 = 132.37$, df = 3 ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: $Z = 13.91$ ($P < 0.00001$)

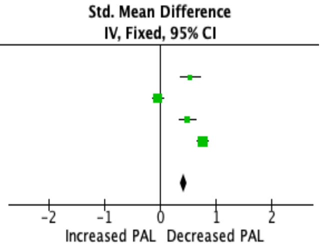

Figure 10. Fixed Effect Meta-Analysis Forest Plot for Overall Boys and Girls together with the Carrillo-Diaz outlier study removed.

Study or Subgroup	Pre-COVID Mean	Pre-COVID SD	Pre-COVID Total	During COVID Mean	During COVID SD	During COVID Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Schmidt 2020	141.62	81.29	344	138.41	107.7	344	34.8%	0.03 [-0.12, 0.18]
Sekulic 2020	3.1	0.78	271	2.79	0.82	271	26.9%	0.39 [0.22, 0.56]
Villodres 2021	3	0.73	415	2.37	0.72	415	38.3%	0.87 [0.73, 1.01]
Total (95% CI)			1030			1030	100.0%	0.45 [0.36, 0.54]

Heterogeneity: $Chi^2 = 63.49$, df = 2 ($P < 0.00001$); $I^2 = 97\%$
Test for overall effect: $Z = 9.97$ ($P < 0.00001$)

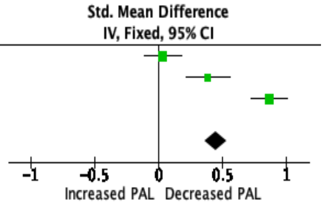

Figure 11. Fixed Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Boys

Study or Subgroup	Pre-COVID Mean	Pre-COVID SD	Pre-COVID Total	During COVID Mean	During COVID SD	During COVID Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Schmidt 2020	118.6	63.28	403	128.23	88.95	403	40.8%	-0.12 [-0.26, 0.01]
Sekulic 2020	2.71	0.66	130	2.59	0.9	130	13.1%	0.15 [-0.09, 0.40]
Villodres 2021	2.78	0.7	484	2.29	0.65	484	46.1%	0.72 [0.59, 0.85]
Total (95% CI)			1017			1017	100.0%	0.30 [0.21, 0.39]

Heterogeneity: $Chi^2 = 78.67$, df = 2 ($P < 0.00001$); $I^2 = 97\%$
Test for overall effect: $Z = 6.73$ ($P < 0.00001$)

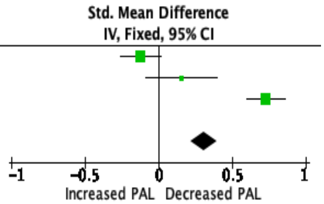

Figure 12. Fixed Effect Meta-Analysis Forest Plot demonstrating the SMD in pre-COVID and During-COVID PALs for Girls