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Original Article

Trends in Physical Fitness in Children and Adolescents Within the Past 18 Years (DONALD Study)

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Abstract

Objective: To evaluate the trends in physical fitness in children and adolescents. **Method**: The present study focusses on a longitudinal analysis of the single two-legged jump (S2LJ) from children and adolescents, who participated in the DONALD study from 2004 till 2022. P_{max}/body mass (power, surrogate for muscular performance), V_{max} (bounce speed, surrogate for coordination), F_{max}/body mass (force, surrogate for muscular strength) and $\frac{V_{max}}{F_{max}/BM}$ (Nerve-Muscle Index, surrogate for jump efficiency) were examined by linear mixed models and propensity-score(PS)-matching analysis. **Results**: Data from 1,485 measurements from males and 1,445 from females were included. Mean age was 10.9 years for males and 11.4 years for females. The range of the number of repeated S2LJ was 1 to 8, the median was 3. In PS-matching analysis, there was a dose-effect relationship between the test date and the S2LJ parameters in such a way that P_{max}/body mass and F_{max}/body mass decreased with more recent test dates (effect size at a difference in the test date of 1.7 decades: 0.25 – 0.3) whereby V_{max} and $\frac{V_{max}}{F_{max}/BM}$ showed no consistent trend. **Conclusion**: Motor performance in children, assessed by the S2LJ, has decreased over the last two decades, mainly due to lower muscular strength, while motor efficiency and coordination seemed to be unchanged.

Keywords: Adolescents, Children, Jump Test, Muscular Strength, Physical Fitness

Introduction

There is no consistent definition for physical fitness (PF) in the literature. One of the definitions was published by Bös[1] and established five main dimensions of PF: endurance, strength, speed, coordination and flexibility.

It is important to monitor the PF of children and adolescents as this impact their health. A study by Ortega et al.[2] suggests that there is a correlation between cardiorespiratory fitness and adiposity. It also suggests a correlation between cardiorespiratory as well as muscular fitness and cardiovascular risk factors, a correlation between muscular strength as well as speed/agility and skeletal health and positive effects of cardiorespiratory fitness on aspects of mental health, like depression, anxiety, mood status, self-esteem and academic performance. In a study by Twisk et al.[3] lipoprotein, systolic and diastolic blood pressure, skinfolds, waist to hip ratio and waist circumference in adolescents between 13 and 16 years was associated with a risk profile for cardiovascular diseases in adulthood.

Högström et al.[4] examined the correlation of aerobic fitness and the risk of cancer and cancer-associated mortality in adulthood. For this purpose, Swedish men who took part in compulsory military service were examined between 1950 and 1980 and the results showed a lower risk of cancer and associated mortality with increasing fitness levels in late adolescence.

Various studies described a decreasing PF in children

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over the last years[5-8], but there are also studies that show consistent or improved PF[9,10]. Eberhardt et al.[5] have conducted a review in July 2019 of large-scale studies about the secular trends in PF of children and adolescents. There were 24 studies included with a total of more than 860,000 children and adolescents. The five dimensions endurance, strength, speed, flexibility and coordination were examined. The majority of the examined studies (63%) showed a negative trend in PF, 24% showed an increase in PF and in another 13% there were no significant changes in the PF.

In a study by Radulovic et al.[6] PF of Slovenian boys and girls between 7 and 15 years was examined in the period from 1989 till 2019. There was a decreased PF until 2010 and then an increased PF in the period up to 2019. Führer et al.[7] also examined the secular trends in PF of children and adolescents. In this review, 22 studies from the period 1972 till 2015 were included. The result of the investigation was that cardiorespiratory endurance initially increased and then decreased, the relative muscle strength and speed increased and the proxies of muscle power decreased.

Kryst et al.[8] examined the trends in PF in 4,106 children and adolescents from Kraków aged 8 till 18 years and it was shown with various motor tests that there was a decline in overall motor performance in the examined children and adolescents.

Masanovic et al.[11] conducted a systematic review that examined the international development in the trends of PF from children and adolescents. The 19 articles included in the analyses contained data from 1,746,023 children and adolescents from 14 different countries collected from 1969 to 2017. The result of this study was that most studies showed a trend for decreases in strength, endurance and flexibility. For agility, speed, balance and coordination, trends depended on the regions of data collected.

Fiori et al.[12] showed a negative correlation between body mass index and PF in prepubertal schoolchildren from Italy. It is already known that overweight and obesity in children and adolescents are increasing[13-16].

The single two-legged jump (S2LJ) on a platform measuring the ground reaction forces is a simple method for assessing PF ("jumping mechanography")[17]. Different aspects of the PF can be determined simultaneously with the help of the time course of the force application, e.g., power, coordination and muscular strength and motor efficiency (s. also method).

Based on the explanations above, the aim of this study was to evaluate the trends in PF in children and adolescents (6 till 17 years of age) from 2004 to 2022 using the S2LJ.

Method

Study design

The present study focusses on a longitudinal analysis of the single two-legged jump from children and adolescents who participated in the DOrtmund Nutritional and Anthropometric Longitudinally Designed study (DONALD) in the period of 2004 till 2022. The DONALD study is a single center open (dynamic) cohort study from Germany, started in 1985, collecting data about nutrition, growth, development, metabolism and health status. Every year, 30-40 infants between three and nine months will be included every year and values are checked regularly until adulthood. Many of these collected data have already been analyzed and published[18].

Mechanography

In the DONALD study, various health-related parameters are regularly determined. Since 2004, the S2LJ has been carried out every two years in all participants from the age of 6 years to assess PF on the "Ground Reaction Force Platform" (GRFP) from NOVOTEC Medical GmbH. The participants were instructed to reach the maximum height during the jump[19]. The measurement was performed by having the participants stand with each foot on a section of the GRFP. They jumped off with both feet and also landed on both feet and their arms were freely movable during the measurement[17].

Evaluated S2LJ parameters

The GRFP measures force, acceleration and speed during the measurement and the following parameters are derived from the S2LJ: P_{max}/body mass (relative maximum power, surrogate for muscular performance), Vmax (bounce speed, surrogate for coordination), F_{max}/body mass (relative maximum force, surrogate for muscular strength) and $\frac{V_{max}}{F_{max}/BM}$ (Nerve-Muscle Index, surrogate for jump efficiency). Nerve-Muscle Index is a new indicator, which was introduced by Martakis et al. (manuscript under review) to evaluate the jump efficiency. With this parameter it is possible to assess whether the change in performance was due to a change in speed or force.

Two different methods were used to check whether there had been any relevant changes in the various parameters over the period of 18 years; the linear mixed effect model and propensity-score (PS)-matching analysis.

Statistical Analysis

Analysis was performed using "R" version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). Normality was tested with Shapiro-Wilk test. Differences between two groups were analyzed with t-test, if normal distributed, otherwise a Wilcoxon-U test was used (two-sided analysis). Significance level was set to $p < 0.05$.

Linear mixed models

In the first step, linear mixed effect models were used because more than one value per person was included in the analysis. In the present study, the dependent variables are the results of S2LJ. The fixed effect is the date of the assessment and the random effects are the participant ID (because of the repeated measurements in the same participant) and

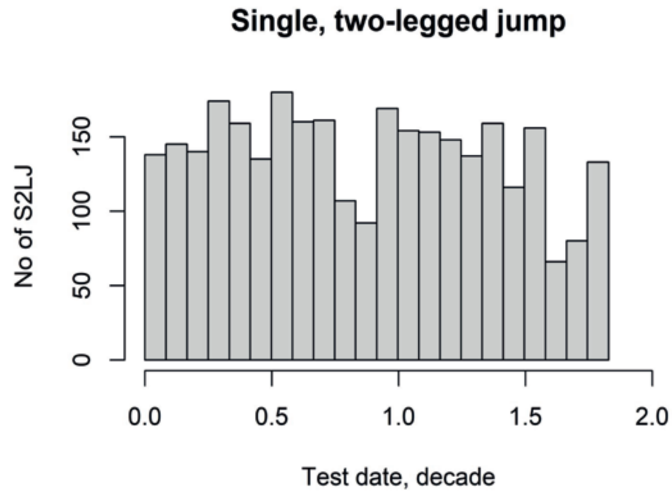

Figure 1. Figure 1 shows the number of S2LJ performed (x-axis) in relation to the test time (y-axis). The earliest measurement was defined as zero time. All other measurements were assigned the value of the time interval from the earliest measurement in decades.

the family ID (because of multiple participants of the same family).

Because the analysis cannot be done by the original test dates, the test dates were transformed into decades. The earliest measurement was defined as the zero point in time. All other measurements were assigned to the value of time distance to the earliest measurement in decades. The range of the new parameter for the measurement date was 0 to 1.82 decades. A value of 1.82 decades corresponded to the most current jump test. It was then examined whether the test date in decades correlated with the z-score of the evaluated S2LJ parameters (with included random effects). The results are the coefficient and the p-value of the fixed effects. The p-values of the coefficients were calculated with the Satterthwaite method.

The advantage of linear mixed effect models is that the hierarchical structure of the data is taken into account. The disadvantage is that there is no widely accepted method to calculate effect sizes. It is possible to determine whether there is a significant difference, but not whether it is clinically relevant. For this reason, a propensity-score (PS) based analysis was used as the second method.

PS-matching based analysis

To determine the effect size, PS-matching was used as second statistical method. First of all, all measurements were divided into 22 groups (22 bars), which differed in the test date (x-axis). This subdivision is shown in Figure 1. The number of S2LJ in the respective groups is shown on the y-axis.

To investigate whether there are differences in the S2LJ results in regard of the test dates, two groups were formed. The difference in the mean test date of the two compared groups increases with an increasing *comparison-cylce*. These two groups were built by splitting all bars in two groups. Propensity-score matching balances confounders like sex, height and weight. One group had a more recent mean test date (group no. 2 = control group) than the other (group no. 1 = treatment group). PS-matching was performed with the matchit function in the package *matchit* (version 4.5.1). With the PS-matching for every measurement in the treatment group one measurement in the control group (ratio = 1:1) was aligned (with the method = optimal) regarding comparable sex, height and weight. The age did not need to be balanced because age-adjusted z-scores of the jump parameters were compared. For this purpose, at the first comparison-cycle the first group was built up to the first 11 on left. The second group was built up of the last 11 bars on the right side. For the second comparison-cycle 2 bars in the middle was left out and the left bars were compared with the right ones. At the next cycle 4 bars in the middle were omitted and so on until at last only the two outer bars remained for comparison (cycle no 11). At first comparison-cycle, the distance of the mean test dates between the two groups was small. With each additional cycle, the test date distance between the groups increased, but the number of the compared S2LJ tests decreased.

Results

Study population

In this study, 2,930 values for S2LJ were included (Table 1). These values come from 653 families and 882 children. Every two years, the children were summoned to take part

Table 1. Study population.

	Female (n = 1,445)	Male (n = 1,485)
Age (years)	11.4 (3.9)	10.9 (3.4)
Height (m)	1.48 (0.19)	1.48 (0.22)
BMI (kg/m²)	18.7 (3.48)	18.8 (4.0)
BMI, z-score	-0.05 (0.88)	-0.03 (0.96)

Data represents mean values (SD).

Table 2. Results of linear mixed effect models with jump parameters and test date (DONALD Study, 2004 – 2022).

	Coefficient	p-value
P_{max}/mass, Z-score	-0.105	0.008
V_{max}, Z-score	-0.074	0.061
F_{max}/BM, Z-score	-0.157	< 0.001
NMI, Z-score	0.080	0.035

BM = body mass, F_{max} = maximum force, NMI = Nerve-Muscle Index, P_{max} = maximum power, V_{max} = maximum velocity.

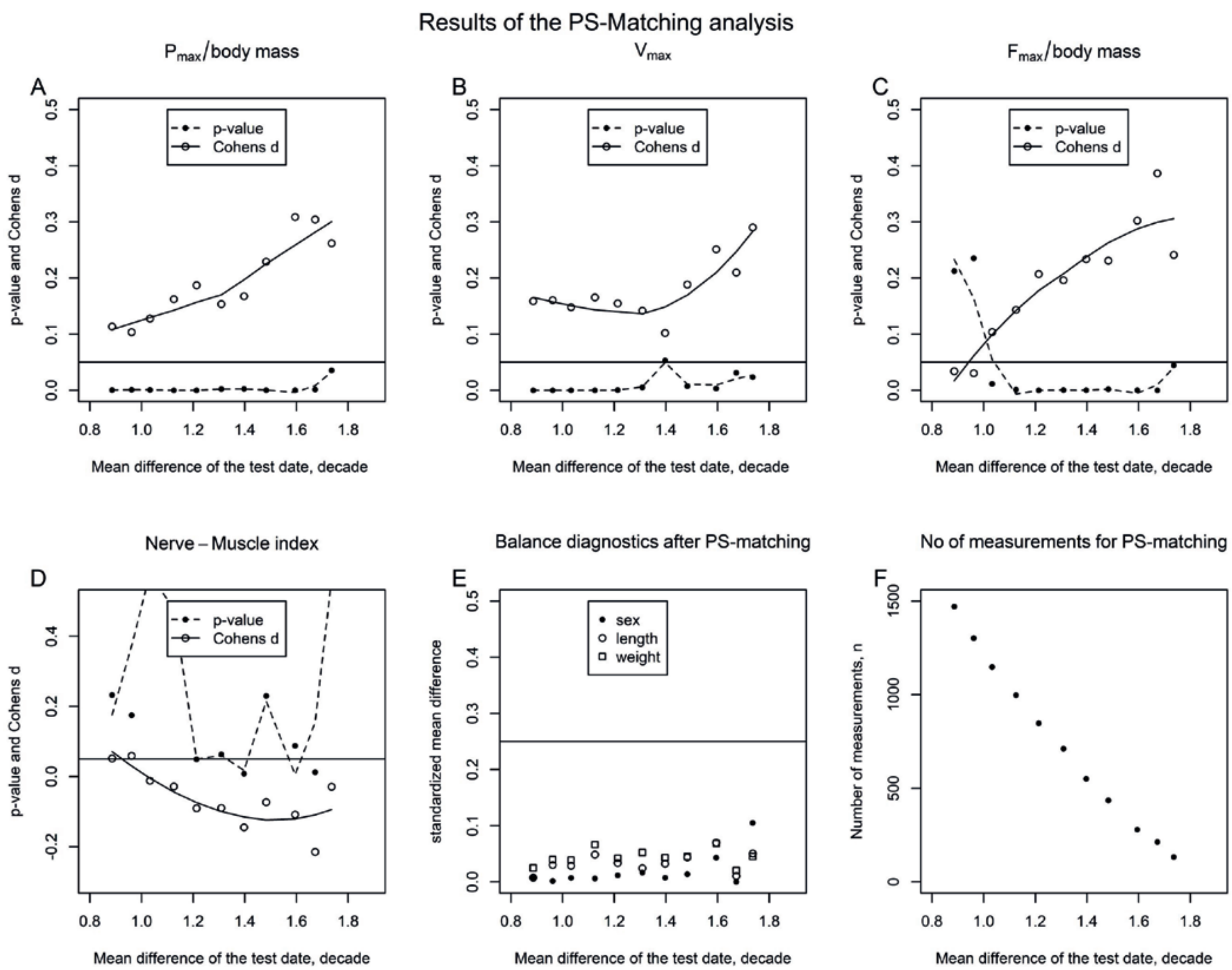

Figure 2. Figure 2 shows the results of the PS matching analysis. Every result of the comparison cycles is shown as a point. The x-axis shows the increasing difference between the compared groups in decades. The y-axis shows the effect size and thus the clinical relevance. A-D shows the results of each measurement value (A: P_{max}/mass, B: V_{max}, C: F_{max}/body mass, D: NMI). E indicates the confounding factors like sex, height and weight and F the number of S2LJ tests and the difference between the mean test dates between the two compared groups in decades. BM = body mass, F_{max} = maximum force, NMI = Nerve-Muscle Index, P_{max} = maximum power, V_{max} = maximum velocity.

in the S2LJ. 1,445 values from female children and 1,485 values from male children were included. The mean age was 11.4 years (SD 3.9) for female and 10.9 years (SD 3.4) for male.

Linear mixed effect models

Data of 2,930 measurements from 882 children were eligible for analysis. The calculations for linear mixed effect models gave the results in the following table (Table 2).

PS-matching based analysis

Figure 2A trough 2F shows the results of the PS-matching analysis. The results of each of the 11 comparison-cycles appears as a dot in the chart in Figure 2. The results for Pmax/mass, Vmax, F_{max}/BM and Nerve-Muscle Index can be seen using Figures 2A trough 2D. Figure 2E gives the standardize mean difference (SRM) in the confounding factors like sex, height and weight. A SRM below 0.25 is considered to be sufficiently balanced between the groups to be compared. Figure 2F shows the number of S2LJ test and how large the difference in mean test dates between the two compared groups was in decades. In total, 11 PS-matching analysis were performed with different numbers of S2LJ test (range from 133 to 1471) and different differences in mean test dates (range 0.89-1,74 decades).

For each of the 11 comparisons, Cohens d and the p-value are shown in relation to the difference in mean test dates between the groups in decades. There was a significant dose-effect relationship between test dates of the S2LJ and z-scores for P_{max}/body mass resp. F_{max}/body mass in such a way that z-scores for P_{max}/body mass and F_{max}/body mass decreased with more recent test dates.

The effect size for P_{max}/body mass increased with increasing mean difference of the test dates. At the max. difference of the test dates of 1.7 decades the Cohens d was between 0.25 and 0.3 with p-values < 0.05 (Figure 2A).

The effect size for Fmax/body mass increased with increasing mean difference of the test dates. At the max. difference of the test dates of 1.7 decades the Cohens d was near 0.3 with p-values < 0.05 (Figure 2C).

There was no clear dose-effect relationship between V_{max} and NMI (Figure 2B and D).

The solid horizontal lines in Figure 2A-D shows the significance level ($p = 0.05$). The solid and dotted lines through the circles and dots (Figure 2A-D) are the curves of the LOESS-(locally estimated scatterplot smoothing-) regressions. The LOESS-regression was used for nonparametric regression.

Discussion

The results of this study indicate a significant decrease in some aspects of PF among children and adolescents over a period of almost two decades. The biggest change was in the values for muscular strength. In the linear mixed effect model, there was a statistically significant negative correlation between the test date and the age-adjusted z-scores for the relative maximum strength in such a way that in average lower values were achieved in more recent measurements. In concordance, the PS-matching based analysis showed an almost linear dose-effect relationship between the test date and muscular strength values, which can be seen as an indication of causality. Possible causes for these changes are discussed below.

Since power is the product of speed and strength (force), there was a very similar relationship between the test date and the z-scores for muscular performance (measured as relative maximum power, see methods). With a difference of almost two decades in the test date, the effect size (Cohen's d) reached approximately 0.3 and was therefore in the range of a small effect. Since we have no earlier data from S2LJ tests, we could not evaluate whether this secular trend existed before 2004.

The results were in concordance with the above-mentioned review of Eberhardt et al., in which 63% of the reviewed studies reported a decrease in PF and with the review of Fühner et al. in respect to the decrease of the muscular performance (power). It is important to note that study results on the secular trends of PF in children are not consistent. There are also studies that have found no change or an increase in muscular strength or power in children over the past few decades. In a study by Roth et al.[9], standing long jump was measured in children aged 3 till 7 years from Würzburg and Kitzingen in 2007. The values were compared to past values from the year 1973 and there were no significant changes in the test results for each year. In a study by Tambalis et al.[10] Greek children aged 8 to 9 years, were examined during 11 years (1997-2007) by testing upper body (ball throw) and lower body (vertical jump) strength and the mean values did not change. This data comes from population data derived from 10 consecutive, national school-based health surveys. In a study by Li et al.[20] trends in PF in Chinese children and adolescents between 7 and 18 years was examined in 1985 till 2019. Some of the components of the PF showed increased values and other components showed decreased values. Explanations for these different results could be differences in the study populations, the time periods studied, and the operationalization of PF. The maximum bounce speed (surrogate for coordination) showed no significant negative correlation with the test date and no recognizable dose-response curve in the PS-matching-based analysis. These results indicate that there was no secular trend in motor coordination (as measured by the S2LJ test) in children in the last two decades. Similar results were reported by Roth et al.[9] (description of the study see above) by measuring obstacle course in 1989 to 2007.

The energy efficiency of human movement has been examined in the literature, especially in human gait. For example, it is reported that children with cerebral palsy use two to three times more metabolic energy during walking than typically developing children[21]. It appears that the low energy efficiency in walking in children with CP is related to low motor efficiency[22].

There are some attempts to find kinematic variables to quantify metabolic work in human walking like pelvic tilt or walking speed[23,24].

In order to be able to quantify the energy efficiency of the S2LJ, we suggested the Nerve-Muscle Index. This parameter indicates by how many units the bounce speed of the S2LJ changes if the maximum relative strength is increased by one unit. In other words, the Nerve-Muscle Index is higher if the same bounce speed is achieved with lesser strength.

In a previous study, it was shown that children with obesity had a significantly lower Nerve-Muscle Index than their peers without obesity[25].

The NMI (surrogate for motor efficiency) showed a positive correlation with the test date ($p = 0.035$), but there was no consistent dose-effect curve in the PS-matching based analysis. Therefore, we interpret the results to mean that there are no significant secular trends in motor efficiency. We are not aware of any comparable analyzes of motor efficiency.

As mentioned in the introduction, possible cause of decreasing PF includes an increase in obesity. Raistenskis et al.[26] examined PF and physical activity in children of normal weight compared to overweight or obese children. It turned out that the overweight and obese children in the study were less physically active and had worse values in PF. An increase in screen time can also be a possible cause of the decreasing PF. In a study by Nyström et al.[27] screen time in children and adolescents (6 till 14 years) was examined in a systematic review and an increased screen time was determined around the world. The average time that the examined children and adolescents spent in front of the screen was 2.77 h per day. A study by Fang et al.[28] examined the relationship between screen time and obesity and found a significant association between obesity and screen time over 2 hours per day. According to the World Health Organization (WHO), it is recommended that children and adolescents take at least 60 minutes activity a day. According to the global status report on physical activity 2022 from the WHO, these figures are far from being reached[29].

It is already known that poor PF can have a negative impact on various areas of health. Gonçalves et al.[30] showed that there is an inverse association between PF and cardiovascular risk factors, like diastolic blood pressure, total cholesterol, triglycerides, and insulinemia. There are also connections between PF and mental health. Yin et al.[31] described a negative correlation between PF and anxiety symptoms. There is also a negative correlation of physical activity on depression and panic disorder[32] and physical activity and PF are connected.

Therefore, it is important to promote physical activity in children and adolescents, especially in those with reduced PF, in order to prevent possible physical and psychological subsequent diseases. The S2LJ test is a simple and resource-saving assessment to evaluate different aspects of PF in children and adolescents within few minutes. It would therefore be suitable as a screening method for children and adolescents, for example in preventive examinations.

Conclusion

There are indications, that PF in children and adolescents has decreased over the last two decades, in the present study mainly reflected by a lower muscular strength and jump performance, while motor efficiency and coordination seemed to be unchanged. The S2LJ test enables children and adolescents with limited PF to be recognized and may be used to stimulate them to improve PF again by e.g., increasing their physical activity. The decreasing trend should be counteracted in order to reduce negative health effects in adulthood. Measures are needed to promote physical activity in childhood and adolescence in order to improve PF.

Strength and Limitations

The strengths of this study are, that it involves a large number of measurements and that these were highly standardized. This study was based on data, which was collected at the DONALD study, a regional German study and the sample is non-representative. Families with a high socioeconomic background are overrepresented. These results possibly may not qualify to be transferred to the general population worldwide (selection bias). Furthermore, in the literature, PF isn't defined consistent, which makes it difficult to compare it with other studies that use other definitions.

Ethics approval

The DONALD study was approved by the Ethics Committee of the University of Bonn, Germany (Approval Number 185/20).

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Authors' contributions

KRW drafted the initial manuscript and critically revised it. ID carried out the statistical analysis and critically reviewed and revised the manuscript. UA, NR, EA, KM and ES critically reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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