

Children with Congenital Heart Disease Are Active but Need to Keep Moving: A Cross-Sectional Study Using Wrist-Worn Physical Activity Trackers

Leon Brudy, MSc^{1,2,*}, Julia Hock, MSc^{1,*}, Anna-Luisa Häcker, MSc^{1,2}, Michael Meyer, MSc^{1,2}, Renate Oberhoffer, MD^{1,2}, Alfred Hager, MD¹, Peter Ewert, MD¹, and Jan Müller, PhD^{1,2}

Objective To compare daily physical activity of children with congenital heart disease (CHD) with healthy peers measured using wearables bracelets in a large cohort. Additionally, subjectively estimated and objectively measured physical activity was compared.

Study design From September 2017 to May 2019, 162 children (11.8 ± 3.2 years; 60 girls) with various CHD participated in a self-estimated and wearable-based physical activity assessment. Step-count and moderate-to-vigorous physical activity were recorded with the Garmin vivofit jr. for 7 consecutive days and compared with a reference cohort (RC) of 96 healthy children (10.9 ± 3.8 years; 49 girls).

Results Children with CHD were active and 123 (75.9%) achieved 60 minutes physical activity on a weekly average according to the World Health Organization criteria as 81 (84.3%) of the healthy peers did ($P = .217$). After correction for age, sex, and seasonal effects, only slightly lower step count (CHD: $10\,206 \pm 3\,178$ steps vs RC: $11\,142 \pm 3\,136$ steps; $P = .040$) but no lower moderate-to-vigorous physical activity (CHD: 80.5 ± 25.6 minutes/day vs RC: 81.5 ± 25.3 minutes/day; $P = .767$) occurred comparing CHD with RC. In children with CHD higher age ($P = .004$), overweight or obesity ($P = .016$), complex severity ($P = .046$), and total cavopulmonary connection ($P = .027$) were associated with not meeting World Health Organization criteria. Subjective estimation of daily moderate-to-vigorous physical activity was fairly correct in half of all children with CHD.

Conclusions Even though the majority is sufficiently active, physical activity needs to be promoted in overweight or obese patients, patients with complex CHD severity, and in particular in those with total cavopulmonary connection. (*J Pediatr* 2019; ■:1-7).

Physical activity as a cornerstone of physical and mental health has long been known to ensure regular development in both healthy and chronically ill children.¹ Almost all patients with congenital heart disease (CHD) should therefore achieve general population guidelines for physical activity because it is considered beneficial and without additional risk.^{2,3} Because physical activity behavior is habitual and tracks well into adulthood its promotion in childhood is imperative for optimal cardiovascular health later on.^{4,5} Long-term cardiovascular health and physical well-being are especially important in the context of an ageing cohort of patients with CHD. The lack of physical activity not only takes potential benefits away—inactivity is also associated with tremendous health burden, particular those of cardiovascular origin.⁶

Assessing physical activity in children is challenging and different methodologies entail benefits and flaws alike. Whereas recalling physical activity in questionnaires lacks objectivity, more valid and reliable pedometers and accelerometers are often bulky, require technical expertise, are expensive, and not necessarily appealing to young children.^{7,8} Furthermore, findings on childhood activity in CHD are conflicting. Smaller studies on children with complex CHD reported lower physical activity,⁹⁻¹¹ whereas more recent studies on a broad spectrum of CHD revealed these children to be of similar activity as healthy peers.¹²⁻¹⁶ Commercially available activity trackers, known as wearables, offer an opportunity for unique insights and have already been used in other clinical pediatric settings and in small cohorts of children with CHD.^{17-19,20,21} Although an overall clear picture of physical activity in children with CHD is lacking, the reliability, validity and objectivity of such wearables has been validated.²²⁻²⁴

Therefore, the aim of this study was to find out how active children with various CHD are compared with healthy peers as measured in daily steps and

BMI	Body mass index
CHD	Congenital heart disease
MVPA	Moderate-to-vigorous physical activity
RC	Reference cohort
WHO	World Health Organization

From the ¹Department of Pediatric Cardiology and Congenital Heart Disease, German Heart Center Munich; ²Institute of Preventive Pediatrics, Technical University Munich, Munich, Germany

*Contributed equally.

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moderate-to-vigorous physical activity (MVPA), which refers to an energy cost of ≥ 3 metabolic equivalents, using wearables. Furthermore, subjectively estimated and objectively measured physical activity in children with CHD was compared.

Methods

From September 2017 to May 2019, 162 children with various CHD (11.8 ± 3.2 years; range, 5.8-17.6 years; 60 girls) participated in a wearable-based physical activity assessment for 7 consecutive days. Detailed information on the study subgroups is given in [Table I](#).

All patients were recruited during their routine follow-up at the outpatient department of the German Heart Center Munich to participate in an ongoing cardiovascular screening study. They were free of any neurologic diseases or acute infections and in good general health without sport restrictions. CHD severity according to American College of Cardiology criteria was distributed as follows: 74 complex, 58 moderate, and 29 simple.²⁵ For 1 patient with arrhythmia, severity class could not be defined.

For comparisons, 96 healthy controls (10.9 ± 3.8 years; range, 5.8-17.6 years; 49 girls), who had to meet the same inclusion criteria as the clinical population (free of neurologic diseases or acute infections, good general health, no sports restrictions) were recruited from several schools, after-school care facilities, and kindergartens, with parts of these data already published elsewhere.²²

Children and parents gave written informed consent after being provided with information about the study protocol. The study was conducted in accordance with the Declaration of Helsinki (revised 2008) and approved by the local ethical board of the Technical University of Munich (project number: 314/14) and is part of the FOOTLOOSE (Functional outcome in children and adolescents with congenital heart disease) project (Deutsches Register Klinische Studien: DRKS00018853).

Objective Physical Activity Assessment

For objective physical activity assessment, all children were in presence of their guardians instructed to wear a Garmin vivofit jr. (Garmin Ltd, Olathe, Kansas) wrist bracelet for 7 consecutive days starting 1 day after they received the device. The Garmin vivofit jr. is a wearable specifically designed for children that tracks physical activity in steps and every single MVPA minute throughout the day. All children were instructed to wear the bracelet during all their waking hours, including during showering, swimming, leisure time, and organized sports, with possible removal overnight. They were further instructed to transfer accumulated steps and MVPA at the end of each day on a provided report card. Overall, 238 children (92.2%) had complete and valid reports for objective physical activity on 7 consecutive days. Twenty patients (7.8%) had incomplete data but ≥ 3 weekdays and 1 weekend day (4 days in total) were present which allowed to calculate a weekly average.

For statistical purposes, steps and MVPA minutes for every day were analyzed and also computed to a weekly average according to current World Health Organization (WHO) criteria.²⁶ Currently the WHO recommends the following levels of physical activity for children aged 5-17 years: (1) ≥ 60 minutes of MVPA daily; (2) amounts of physical activity > 60 minutes provide additional health benefits; and (3) most of the daily physical activity should be aerobic. Vigorous-intensity activities should be incorporated, including those that strengthen muscle and bone, ≥ 3 times per week.

Subjective Physical Activity Assessment

In addition to the objective MVPA measurement, children with CHD subjectively estimated their days of activity before receiving the wearable ("On how many days of an average week are you active for ≥ 60 minutes per day?"). This question was answered by the child on a Likert scale from none to 7. The answer of the subjective physical activity assessment was used to analyze the number of days children with CHD subjectively estimate themselves to be active for ≥ 60 minutes. For healthy children, subjectively estimated data were not recorded.

Statistical Analyses

All data are shown as mean \pm SD. Data were analyzed via the *t* test and χ^2 test. To compare the primary outcome variables daily steps and MVPA between children with CHD and healthy peers an adjusted univariate ANOVA with covariates sex, age, and season (spring, summer, fall, and winter according to calendar season) was used.

Self-reported physical activity was compared with objectively measured physical activity data with intraclass correlation coefficient. Logistic regression was used to determine possible variables such as age, sex, body mass index (BMI), CHD severity, CHD type, and whether CHD underwent surgery or not, are associated with meeting the WHO guidelines of 60 minutes of physical activity on a weekly average. We defined meeting the WHO guidelines as mean daily MVPA of ≥ 60 minutes/day like Voss et al.¹² Thereby, we are applying the soft WHO criteria for MVPA as a weekly average. The much harder variant to interpret the criteria is ≥ 60 minutes of physical activity on every single day. However, because it has been shown that every minute of MVPA is beneficial, this article focuses more on MVPA minutes and not on threshold levels.²⁷

All data were analyzed using SPSS 25.0 software (IBM Inc, Armonk, New York) with a 2-tailed level of significance at a *P* value of $\leq .05$. Figures were drawn using R Studio (RStudio Team, RStudio: Integrated development for R. Boston: RStudio, Inc 2015, Vienna, Austria).

Results

Children with CHD were remarkably active. According to the WHO criteria 123 children with CHD (75.9%) and 81 healthy peers (84.3%) (*P* = .217) accumulated 60 minutes

Table I. Study participants

Variables	n	Sex (female)	Age	BMI z-score	Steps	MVPA
Left heart obstruction	28	9 (32.1)	10.4 ± 3.4	-0.80 ± 1.04	10889 ± 3447	88.7 ± 28.6
Right heart obstruction	53	19 (35.8)	12.0 ± 2.6	-0.34 ± 1.30	9424 ± 2915	73.5 ± 23.2
Isolated shunts	20	12 (60.0)	13.0 ± 3.5	-0.02 ± 0.91	9428 ± 3172	78.2 ± 27.9
TGA after switch	19	3 (15.8)	12.1 ± 3.2	-0.30 ± 1.05	11546 ± 4107	89.4 ± 25.6
TCPC	25	8 (32.0)	12.4 ± 3.4	-0.55 ± 1.93	8701 ± 2540	69.9 ± 22.9
Miscellaneous	17	9 (52.9)	10.5 ± 3.8	-0.53 ± 1.36	9587 ± 2852	82.4 ± 25.1
CHD	162	60 (37.0)	11.8 ± 3.2	-0.42 ± 1.32	11772 ± 9832	84.1 ± 24.2
RC	96	49 (51.0)	10.9 ± 3.8	-0.15 ± 0.92	9832 ± 3225	79.0 ± 26.5
<i>P</i> value*	-	.037	.035	.083	<.001	.125

RC, reference cohort; TCPC, total cavopulmonary connection; TGA, transposition of the great arteries.

Values are number (%) or mean ± SD.

Bold indicates a statistically significant finding with $P < .05$

* $P < .05$, *t* test comparing CHD with RC.

of physical activity on a weekly average. After correction for age, sex, and seasonal effects, only a slightly lower step count (CHD: 10 206 ± 3178 steps vs RC: 11 142 ± 3136 steps; $P = .040$) but no lower MVPA (CHD: 80.5 ± 25.6 minutes/day vs RC: 81.5 ± 25.3 minutes/day; $P = .767$) occurred.

Evaluating the distribution on weekends and weekdays, both groups were more active during weekdays and less active on the weekend ($P < .050$ for MVPA and step count). Only during the weekend children with CHD performed fewer steps (mean difference, 1687 ± 526; $P = .004$) than their healthy peers (Table II).

Variables Associated with Meeting the WHO Guidelines

As seen in Table III, in the logistic regression, older age ($P = .004$), and higher BMI ($P = .002$) were associated with not meeting the WHO criteria of 60 minutes of physical activity on a weekly average. Per definition of a BMI above the 90th percentile,²⁸ 12 children (7%) with CHD and 7 healthy peers (7%) were overweight or obese. Furthermore, 7 overweight/obese children with CHD (58%) and 1 overweight healthy peer (14%) failed to reach the WHO criteria of 60 minutes of physical activity on a weekly average.

Univariate logistic regression (Table III) showed that, in overweight or obese children with CHD, the likelihood of meeting the WHO criteria of 60 minutes of physical

activity on a weekly average was just 21.2% of children with CHD with normal weight ($P = .016$). In children with complex CHD, the likelihood of meeting the WHO criteria was 46.7% ($P = .046$) of healthy peers (Table III). In patients with total cavopulmonary connection, the likelihood was only 32.9% ($P = .027$).

Subjective vs Objective Physical Activity

Children with CHD subjectively estimated to be active on 4.7 ± 1.8 days per week. Objective physical activity measurements via the wearable revealed them to reach ≥60 minutes of MVPA on 5.0 ± 1.9 days of the week. Overall, 75 children with CHD (52.1%) estimated their days of reaching ≥60 minutes of physical activity correct or were off by just 1 day, and 28 (19.4%) overestimated and 41 (28.5%) underestimated their daily physical activity by >1 day. Intraclass correlation revealed a moderate association of self-reported and objectively measured physical activity in children with CHD ($r = 0.495$; $P < .001$). A detailed overview on the agreement is given in the Figure.

Discussion

The findings in this study showed the majority of children with CHD to be sufficiently active considering their MVPA on a weekly average against the current WHO guidelines²⁶⁻²⁸ on activity and in comparison to healthy

Table II. Univariate ANOVA for steps and MVPA in children with CHD vs healthy controls, split into weekdays and weekend adjusted for sex, age, and seasonal effects

Variables	CHD (n = 162)	RC (n = 96)	Mean difference ± SEE	<i>P</i> value*
Steps				
Whole week (mean)	10 206 ± 3207	11 142 ± 3341	-936 ± 454	.040
Monday-Friday (mean)	10 717 ± 3525	11 372 ± 3664	-655 ± 499	.191
Weekend (mean)	8917 ± 4072	10 604 ± 4242	-1687 ± 577	.004
MVPA				
Whole week (mean)	80.5 ± 26.2	81.5 ± 27.3	-1.1 ± 3.7	.767
Monday-Friday (mean)	83.6 ± 27.7	83.5 ± 28.9	-0.1 ± 3.9	.987
Weekend (mean)	72.8 ± 33.8	76.8 ± 35.2	-3.9 ± 4.8	.405

SEE, standard error of the estimate.

Values are mean ± SD.

Bold indicates a statistically significant finding with $P < .05$

* $P < .05$.

Table III. Univariate logistic regression for independent variables associated with meeting the recommendation of 60 minutes of MVPA on a weekly average in children with CHD

Variables	OR (95% CI)	P value*
Sex (female)	0.696 (0.334-1.448)	.332
Age (years)	0.841 (0.746-0.948)	.004
BMI (kg/m ²)	0.866 (0.790-0.949)	.002
Body composition		
Normal weight (reference)	1	
Overweight or Obese	0.212 (0.060-0.748)	.016
Status		
Healthy (reference)	1	
Native CHD	0.654 (0.267-1.601)	.353
Surgery for CHD	0.610 (0.305-1.219)	.162
Severity		
Healthy (reference)	1	
Simple	0.889 (0.293-2.697)	.835
Moderate	0.641 (0.280-1.466)	.292
Complex	0.467 (0.221-0.987)	.046
Season		
Summer (reference)	1	
Spring	1.533 (0.623-3.771)	.352
Fall	0.653 (0.255-1.672)	.374
Winter	1.350 (0.491-3.714)	.561
Diagnostic subgroup		
Healthy (reference)	1	
Left heart obstruction	0.852 (0.280-2.593)	.778
Right heart obstruction	0.469 (0.208-1.058)	.068
Isolated shunts	0.741 (0.217-2.525)	.631
TGA after arterial switch	0.988 (0.256-3.812)	.986
TCPC	0.329 (0.123-0.882)	.027
Miscellaneous	0.864 (0.221-3.378)	.834

TGA, tetralogy of Fallot; TCPC, total cavopulmonary connection.

Bold indicates a statistically significant finding with $P < .05$

*Significant with $P < .05$.

peers.²⁶ Nevertheless, physical activity needs to be promoted in overweight or obese patients, patients with complex CHD severity, and in particular in those with total cavopulmonary connection because it is more likely that these subgroups do not meet the WHO requirements.

Two studies have used wearables to assess habitual physical activity in small cohorts of children with CHD. Voss et al made a validation study of a wearable against an accelerometer in 30 children with CHD, and Jacobsen et al used wearables to monitor adherence in a home activity program in 14 children with Fontan circulation.^{20,21} Our study used a wearable device along with subjective estimation to assess habitual physical activity in a large sample size of children with various CHD. Furthermore, although many commercially available wearables are intended for adults, the device used in our study is specifically designed for children, therefore allowing conclusions about daily activity in a young cohort.

MVPA has special significance for the cardiovascular system and is imperative for exercise capacity in patients with CHD.²⁹ Considering this cohort in general, a large number

of children accumulated an average of 60 minutes of MVPA throughout the week without there being any difference between children with CHD and healthy controls. Only after looking on steps and MVPA, corrected for confounders, did children with CHD perform about 10% fewer steps, mainly owing to differences on the weekend. Nevertheless, this finding can be regarded as secondary because there was no difference in MVPA minutes between children with and without CHD. These results are impressive because many, mostly older studies and studies with nonobjective measurement methods often come to a different result concluding limited MVPA in children with CHD.⁹⁻¹¹ In contrast, our results now suggest that the recommendations on physical activity in children with CHD are being widely implemented and the physician's advice regarding the potential benefits of exercise for patients with CHD is now better accepted—even at specialist clinics.^{2,30} This is imperative because an active lifestyle or sports participation is not associated with increased risk of adverse events in children with CHD and specific restrictions only apply in case of specific medical issues.^{31,32} In fact, participation in competitive sports and increased frequency of MVPA are independently associated with a higher quality of life, improved physical capacity, and lower BMI in adolescents and young adults with CHD.³³ This finding is especially important in the light of known decreased exercise capacity and its association with hospitalization and death in patients with CHD.³⁴⁻³⁶ Based on the results of our study, together with these previous findings, the earlier mentioned habituality of physical activity and the importance of childhood physical activity for optimal cardiometabolic development, children with CHD still need to be encouraged to be active.^{4,5}

Variables Associated with Meeting the MVPA Guidelines

Although a general physical activity assessment is time consuming and expensive, it is useful to focus on risk groups.⁷ High BMI or overweight and obesity is considered the most crucial measure because it is relevant for all children with CHD and inversely associated with MVPA. Therefore, as a clinical implication, it might be important to assess MVPA, at least in obese, and preferably also in overweight children. Afterward, children and their parents should, if necessary, be counseled on how they can increase MVPA or implement dietary steps to reduce weight and avoid long-term cardiovascular burden.

Also, patients with complex CHD severity, especially those with total cavopulmonary connection, should be in the focus as well, because the probability that these children with complex CHD meet the WHO guidelines is declined by one-half compared with the healthy peers. Lower age-dependent physical activity in patients with total cavopulmonary connection has already been reported previously.³⁷ In several articles, it has been speculated about possible reasons. Overprotection owing to parents and reluctant medical doctors who refrain to prescribe physical activity is one issue.³⁸

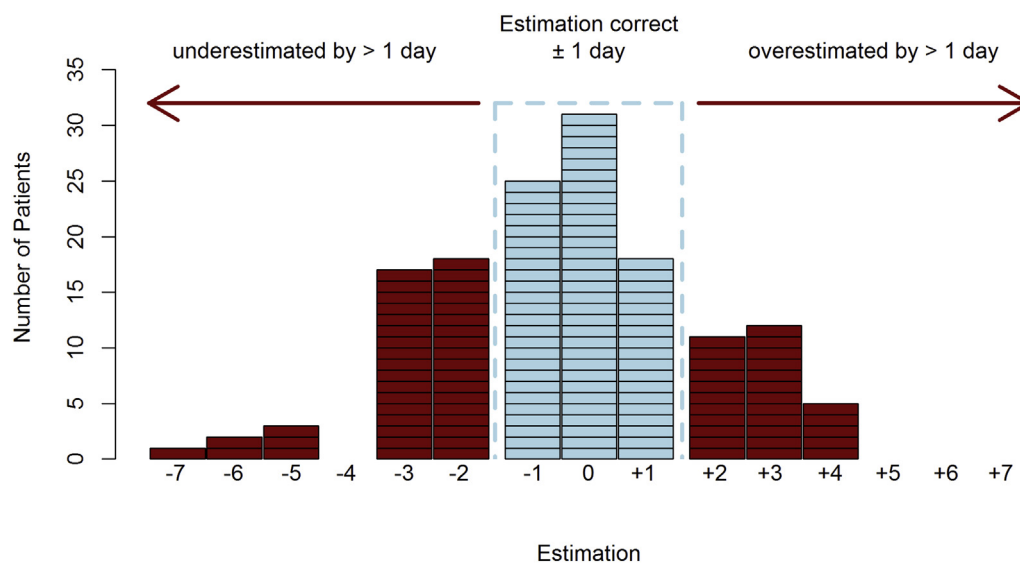


Figure. Agreement of subjective vs objective assessment of physical activity in children with CHD.

Also, the obvious functional limitation of complex lesions make it more difficult to maintain more intense physical activity for a longer time.³⁹ Nevertheless, encouragement, controlled sport classes, and rehabilitation are possibilities to enhance MVPA in these patients.³⁰

Finally, just as in healthy children, older age was associated with fewer MVPA. However, because the recommendation for adults is just 30 minutes MVPA on 5 days of the week this point is negligible.²⁶ It is important to ensure that active exercise behavior is initiated at an early age, because activity patterns track habitually and active children usually remain active during youth and adulthood.^{4,5}

Objective vs Subjective MVPA Assessment

In general, children tend to overestimate their MVPA.⁷ Despite this finding, our results show that one-half of our cohort generally seems to have a good feeling of how active they are as 52% of all children with CHD estimated themselves correctly or were just off by not >1 day. Nevertheless, the other one-half of participants overestimated or underestimated their MVPA. Underestimation might not be as critical as overestimation, because those children at least perform more MVPA than they assume. However, in both cases it still could be too little overall, and both groups could benefit from specific encouragement of reaching sufficient levels of daily MVPA. From our perspective it seems, therefore, reasonable to combine subjective and objective measurements in clinical practice to harmonize perception and reality.

Furthermore, accurately assessing physical activity remains a challenging yet vital research endeavor in children with CHD.⁸ The findings of this study underline the importance of objective and reliable measures in clinical pediatric settings as subjective reports in the form of questionnaires lack accuracy. Routine exercise testing is insightful in determining functional status but lacks the ability to determine

habitual physical activity which is where commercially available wearables offer unique advantages.

All children were instructed to wear the bracelet during waking hours without interruption. However, in certain sports, it is forbidden to wear a wrist bracelet (ie, contact sports) and therefore it is possible that such intense activities were not captured.

Children and parents alike reported the herein used wearable as an exciting new toy; the positive acceptance and feedback of the wearable has already been reported.²² Therefore, it could be suggested that objective measured physical activity is likely to be over-reported and lower in reality. Because this is most likely true for both children with CHD and healthy children, the comparison between the groups should not be biased.

In terms of subjective physical activity estimation in children, our study does not include caregivers, who are mainly responsible for their children's lifestyle, especially at a younger age. For future studies, evaluating subjective physical activity estimation, the parents' estimation could provide other important findings.

Like other studies, we applied the soft WHO criteria for MVPA as a weekly average.^{9,12} The much harder variant to interpret the criteria is ≥ 60 minutes of physical activity every single day. Then, only 27.9% of the CHD and 40.6% of the healthy peers fulfill them. However, because it has been shown that every minute of MVPA is beneficial, this article focuses more on MVPA minutes and not on threshold levels.²⁷ Especially because there is no clearly defined daily step goals for children to analyze the measured step count against.

This cohort of children with various CHD was quite active in general. Nevertheless, MVPA needs to be promoted in overweight or obese patients, with complex CHD severity, and in particular in those with total cavopulmonary connection. Subjective estimation of daily MVPA is fairly correct in

only about half of all children with CHD thereby failing to draw an accurate picture on these patients' activity. This underlines the importance of objective and reliable measures in clinical pediatric settings. ■

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Reprint requests: Leon Brudy, MSc, Lazzarett str. 36, 80636 Munich, Germany. E-mail: leon.brudy@tum.de

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