

Physical activity in children and adolescents with CHD: review from a measurement methodological perspective

Review

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Abstract

Aim: To compile a literature overview of physical activity in children with CHD and to critically evaluate the methodology used for physical activity assessment. **Methods:** A review of the literature was performed using PubMed to identify studies examining accelerometer and subjectively assessed physical activity in children and adolescents with CHD. **Result:** A total of 15 studies were included (6 studies using subjective measures and 9 articles using accelerometers for the assessment of physical activity). The patients generally failed to meet the recommendations of physical activity. When compared to healthy controls, the results were widely divergent in the subjectively assessed measures and the accelerometer-based studies showed a tendency of no difference in physical activity. Neither subjective methods nor accelerometer-based studies reported any difference in physical activity in general, in relation to the severity of the heart disease. **Conclusion:** Methodological variation and limitations in the assessment of physical activity largely explain the divergent results and the inability to establish differences in physical activity between children with CHD of different severity and compared to healthy controls. Methodological knowledge and guidelines are provided for improved assessment of physical activity using accelerometers in clinical research.

Take home message

- A physically active lifestyle is important for health and development in all children.
- Methodological variations and limitations in previous research interfere with the ability to establish whether the physical activity patterns in children with CHD differ compared to healthy controls, or due to the severity of the heart disease.
- By supporting methodological understanding and providing guidelines for physical activity assessment using accelerometers, this review targets improved knowledge about the physical activity patterns in children with CHD.
- The outcome of physical activity assessment using accelerometer is affected by measurement protocol, device settings, body placement (e.g. hip, thigh, wrist), raw data processing, value calibration method, and statistical methods.

The incidence of CHD is approximately 8 out of 1000 live births.¹ However, the survival rate has radically improved due to advances in clinical care and surgical techniques.^{2,3} A recently published, nationwide Swedish study shows that since the beginning of this century, over 97% of children born with CHD can be expected to reach adulthood. Still a relatively high mortality is associated with the most complex diagnoses, especially during the first years of life.⁴ Among survivors, the severity of the CHD determines the physical capacity and complications experienced later in life.^{5–7}

The severity of the CHD may be divided into three broad categories (four categories may also be applied).^{5–8} The most severe category includes complex CHD for which the long-term prognosis is uncertain, with serious complications and a peak oxygen uptake at 30 ml/kg/minute or lower, for example, univentricular heart lesions, pulmonary atresia with ventricular septal defect, and major aortopulmonary collaterals. The moderately severe category includes individuals treated with surgery and/or catheter intervention, who are followed up regularly due to risk for further complications and have a peak oxygen uptake varying around 40 ml/kg/minute, for example, transposition of great arteries, tetralogy of Fallot, and aortic stenosis. The mild severity category consists of individuals who are treated once with surgery or catheter intervention, are in most cases no longer followed up due to low risk of further complications, and may have a peak oxygen uptake similar to individuals with no CHD, that is, 40 ml/kg/minute or higher. Individuals with CHD have lower peak oxygen uptake than their healthy peers, especially those

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with more severe heart defects. Lower peak oxygen uptake is associated with lower cardiovascular health, academic achievement, and well-being.⁹

Concerns have been raised about the increased risk of being overweight and having additional cardiometabolic disease later in life in patients with CHD and the risk is even higher with more severe CHD.^{10–12} Due to limitations in physical capacity,^{6,7} but also because of restrictions from parents and caregivers and low self-efficacy,^{8,13} it may be assumed that children and adolescents with CHD are less physically active than children and adolescents in general. This creates a need to focus on aspects of health-related quality of life, physical activity, and prevention of acquired cardiovascular disease in this group of patients. As physical activity, sports participation, and aerobic fitness have been acknowledged as crucial for health and development in children and adolescents, their promotion has been emphasised by international cardiology associations.^{12,14,15} A recent review conducted by Caterini et al¹⁶ especially argued for the importance of actively promoting physical activity in the younger CHD population for fostering a healthy, active lifestyle and also highlights the existing evidence gap in lack of models for implementing strategic physical activity in CHD populations as well as reliable and valid wearable technology for increasing and measure physical activity.

Acosta-Dighero et al¹⁷ and Van Deutekom and Lewandowski¹⁸ provided recent reviews of original studies using either subjective or objective methods to assess physical activity in children and adolescents with CHD. These reviews suggest similar physical activity level in children and adolescents with CHD compared to healthy controls, or in relation to the severity of the CHD, although several inconsistencies between studies were reported. This finding is somewhat unexpected, considering the physical limitations and other restrictions reported in children and adolescents with CHD. However, a deeper and more critical analysis of the measurement methodological limitations was missing from these review studies. This knowledge is crucial for explaining the unexpected finding, in order to determine the methodological progression required in future assessment of physical activity in clinical research.

Assessment of physical activity is mainly divided into two areas: subjective and objective measures. Former research of physical activity was primarily conducted using subjective methods like interviews and questionnaires as they are considered to be cost efficient, easily administrated, accessible, and is claimed to put little strain on patients.¹⁹ However, extensive methodological limitations such as recall ability, memory, age, language, perception, understanding, and overestimation of both quantity and intensity of the performed physical activity have been identified, especially in the younger populations, causing poor reliability and validity.^{15,19–24} In 2013, the American Heart Association stated: “. . . use of self-reports is recommended only when more objective measures cannot be obtained”.¹⁵ Thus, the quantification of physical activity is now merely performed using objective measures.

Objective devices to assess physical activity involve pedometers, accelerometers, heart rate monitors, multisensors (e.g. acceleration, heart rate, heat, sweat), indirect calorimetry, and doubly labelled water. Indirect calorimetry and doubly labelled water are considered golden standards of objective physical activity measures. Nevertheless, they are expensive and resource-intensive, thus not very convenient in most physical activity studies.²⁵ As an alternative, accelerometers are considered as cheap, well developed, and easy to use, showing greater validity than subjective measures.^{22,26,27} However, even if being the most frequently used and evaluated objective method for assessing physical activity,²⁸ the use of

accelerometers to assess physical activity holds certain limitations. Generally, there is a lack of knowledge regarding the field and function of accelerometers, how the specific settings and data management affect the outcome, and how these may be the source of measurement errors. Many accelerometer-based studies also fail to provide a transparency in the settings and data processing used, preventing others to uncover impacts on the measurement outcome or possible underlying measurement errors. In addition, the methodological transparency by the manufacturer may be quite low. Epoch lengths (time resolution of physical activity measures investigated), cut-points (threshold markers for the classification of physical activity intensity categories), and raw data filtration method represent three major issues that are seen to especially affect the outcome of the accelerometer-assessed physical activity.^{25,29} Thus, even if the results are presented equally, the parameters may imply dissimilar aspects of the assessed physical activity, complicating comparisons of the physical activity measure.³⁰

The first objective of this study was to compile and organise the existing studies assessing physical activity in children and adolescents with CHD by subjective and objective (accelerometers) methods. The second objective was to critically evaluate the physical activity measurement methodology in the accelerometer studies and the consequences on results and conclusions. An important outcome from the second objective was to provide guidelines on the assessment of physical activity using accelerometers, in order to improve clinical research.

Methods

Search strategy

A literature search and a data extraction were performed between April 2020 and October 2020 in PubMed database. Two separate searches were conducted. The first search concerned subjectively assessed physical activity and the second search concerned accelerometer-assessed physical activity. We combined the following search terms in search one: Congenital heart disease OR defect, acquired heart defect OR disease, physical activity, exercise, children OR adolescents OR youth, surveys and questionnaires OR self-scattered OR self-reported OR subjective OR questionnaire; and search two: Congenital heart OR disease OR defect, acquired heart defect OR disease, physical activity, exercise, children OR adolescents OR youth, accelerometer OR accelerometry.

Inclusion/exclusion criteria

Inclusion and exclusion criteria are listed in Table 1. We included original articles studying children or/and adolescents with treated CHD, written in English, and published in peer-reviewed journals with a quantified physical activity outcome. Articles published in 2000 and later were included for subjectively assessed physical activity and 2009 and later for accelerometer-assessed physical activity due to developmental aspects in accelerometers. The patient group was set to children and adolescents with CHD between 3 and 20 years. Articles studying patient groups with known extensive health issues other than CHD were excluded.

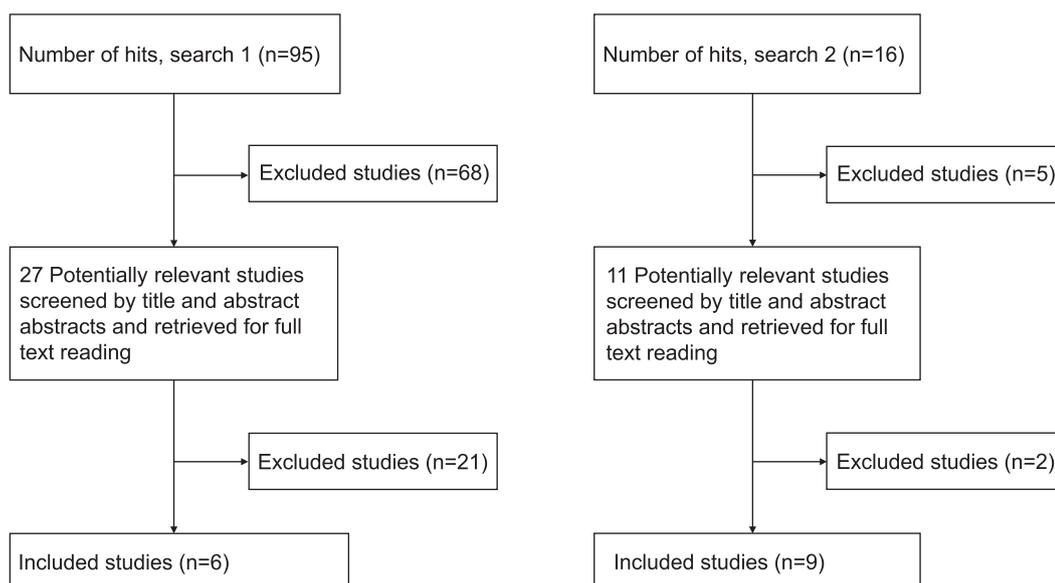
Results

Characteristic of articles

Six articles were included for the subjectively assessed physical activity and nine for the accelerometer-assessed physical activity. Two of

Table 1. Inclusion and exclusion criteria for searches

| Inclusion criteria search 1 | Exclusion criteria search 1 |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Measurement method: subjectively assessed PA | Patient group age: • >20 years • <3 years |
| Articles in English | |
| Articles studying children/adolescents with treated CHDs | Patient group with known extensive health issues/diseases, chromosomal aberrations (e.g., Down's syndrome), or neurological disabilities (severe cerebral paresis) that restricts the possibility to being physically active |
| Articles published in peer-reviewed journals | |
| Quantified PA-based outcome/result | |
| Articles published year 2000 or later | |
| Inclusion criteria search 2 | Exclusion criteria search 2 |
| Measurement method: accelerometer-assessed PA | Patient group age: • >20 years • <3 years |
| Articles in English | |
| Articles studying children/adolescents with treated CHDs | Patient group with known extensive health issues/diseases, chromosomal aberrations (e.g., Down's syndrome), or neurological disabilities (severe cerebral paresis) that restricts the possibility to being physically active |
| Articles published in peer-reviewed journals | |
| Quantified PA-based outcome/result | |
| Articles published year 2009 or later | |

**Figure 1.** Flow chart of study selection process.

the articles were included for both searches as they used both subjectively and accelerometer-assessed physical activities. Figure 1 presents the article extraction. Two researchers reached consensus regarding the included articles. An overview of the included articles from the first and the second search is presented in Tables 2 and 3.

The study populations in the included studies differ substantially. Physical activity results are reported from both populations with mixed CHD,^{31–36} from children and adolescents with one specific diagnosis,³⁷ three specific diagnoses,³⁸ from CHD as divided by mild to severe CHD group (different specifications),^{39–41} between specific CHD diagnosis⁴² or between specific CHD diagnosis and as varied CHD group,⁴³ restricting comparisons and generalisation of the results.

Included articles, subjectively assessed physical activity

Six studies using subjectively assessed physical activity were included. Two articles reported physical activity data in CHD children,^{31,36} one article compared different types of CHD and controls,⁴³ two studies compared different types of CHD with control samples from external databases,^{40,41} and one article compared children with Fontan circulation to healthy controls.³⁷ All of the six articles used different physical activity assessment questionnaires: Physical Activity Questionnaire for Older Children,⁴³ Youth Risk Behavior Survey,⁴¹ International Physical Activity Questionnaire-short version,³¹ “The New South Wales Schools Fitness and physical activity Survey”⁴⁰, one question assessment,³⁶ and self-reported physical activity regarding organised physical activity.³⁷

Table 2. Summary of characteristics search 1, methods, main findings and limitations of subjective-based studies

| Author, year | Sample | Type of subjective measure | Other measures | PA outcome measure | Main findings | Limitations |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Brudy et al. 2019 | Descriptives for total CHD group 5.8–17.9 years n = 162 | Subjective PA assessment, 1 question assessment (0–7 Likert scale) | Garmin vivoFit jr. wrist bracelet Controls <i>only</i> for Garmin vivoFit jr. wrist bracelet: 5.8–17.6 years n = 96 | Quantum of days with PA > 60 minutes per week | Children with CHD subjectively estimated to be active on 4.7 days per week on average | No validated subj. PA questionnaire Only one question for assessing PA on weekly basis No matched controls for subjective data |
| Hedlund et al. 2016 | Compared Fontan palliation to controls 8–20 years Fontan palliation gr.: n = 30 Control gr.: n = 25 | Self-reported PA from patient and parents regarding organised PA | AC QoL (PedsQL) | Reported physical exercise, minute/week Mean intensity in Borg-scale per activity | Sign lower physical exercise minute/week for CHD group and sign lower average intensity on Borg scale for patients compared to control group | Self-selection of control patients Only organised PA accounted for, no sporadic |
| Lunt et al. 2003 | Compared CHD severity types (and controls) 12–18 years n = 153 total Mild CHD: n = 110 Severe CHD: n = 43 Compared to published, normative adolescent data, n = 74 | Self-reported PA through “The New South Wales Schools Fitness and Physical Activity Survey” | Self-efficacy | Total PA classified as VPA, adequate, or inadequate according to metabolic equivalent, reported frequency and duration | Male adolescents with CHD were sign. less VPA compared to healthy peers. Same trend at females (not sign.) compared to healthy adolescents and severity group No significant difference between “mild” or “severe” groups 70% participated in adequate PA or VPA | Non-matched, external control group External control group was 9–11 years, skewness in amount of individuals in mild + severe group |
| Ray and Henry 2011 | Compared CHD severity types (and external state-wide data) 10–14 years n = 84 Mild CHD: n = 9 Moderate/no surgical/therapeutic treated CHD: n = 18 Surgically treated CHD: n = 34 Complex/severe CHD: n = 19 | Subjective PA; five item YRBS | Self-efficacy | YRBS responses | 38% of the patients reported being physically active for 60 minutes 7 days a week (62% NOT meeting the recommendations No significant difference towards healthy controls compared to statewide data | Single-site study Non-matched, external control group No reported result for PA between severity groups Relatively few questions to establish habitual PA (one question concerned PA > 60 minutes/past 7 days; two questions concerned TV or video games; one concerned how many days the patients went to PA classes; and one concerned how many sports teams they did play the last year) |
| Schaan et al. 2019 | Descriptives for total CHD group and cyanotic/acyanotic 12.0 ± 3.7 years total n = 25: Cyanotic, n = 11 Acyanotic, n = 14 | Subjective PA; IPAQ short version | 6MWT, fatigue in lower limbs through Borg scale HR, RR, SpO ₂ SBP, DBP, blood analysis for metabolic score | IPAQ score | Low levels of very active: Very active = 24% Active = 32% Irregular activity = 36% Sedentary = 8% | IPAQ mainly as descriptives IPAQ short version – only measures physical activity intensity and time, not activities in overall life/various areas such as work, transportation, domestic activities and leisure |

(Continued)

Table 2. (Continued)

| Author, year | Sample | Type of subjective measure | Other measures | PA outcome measure | Main findings | Limitations |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| Zaqout et al. 2017 | Compared CHD severity types and controls: Control gr.: 6–12 years n = 520 CHD gr.: 6–14 years VSD: n = 19 COA: n = 10 TOF: n = 15 TGA: n = 22 | Self-scattered PA: PAQ-C | AC Physical fitness test Cardiorespiratory fitness Upper-limb isometric strength Standing long-jump 40 m sprint test for max running speed Flamingo balance test Sit-and-reach test Blood analysis for metabolic score | Reported PA, hour/week | Reported PA sign. higher in CHD group compared to control group (17.9 ± 10.4 hours/week vs 14.1 ± 8.9 hours/week) No difference in hour/week between CHD type groups | Unmatched controls from external database |

6MWT: 6-minute walk test; AC: accelerometer; COA: coarctation of aorta; DBP: diastolic blood pressure; HR: heart rate; IPAQ: International Physical Activity Questionnaire; PA: physical activity; PAQ-A: Physical Activity Questionnaire for Adolescents; PAQ-C: Physical Activity Questionnaire for Older Children; PedsQL: Pediatric Quality of Life Inventory; QoL: quality of life; RR: respiratory rate; SBP: systolic blood pressure; SpO₂: peripheral oxygen saturation; TGA: transposition of the great arteries; TOF: tetralogy of Fallot; VPA: vigorous physical activity; VSD: ventricular septal defects

When looking at the comparison of children and adolescents with CHD towards healthy controls, contrasting results were present. Ray and Henry⁴¹ reported *no significant difference* in physical activity between patient and control groups in children with mild, moderate, and surgically treated CHD. Relatedly, Lunt et al⁴⁰ reported *lower physical activity* in male patients with mild and severe CHD and a similar trend in females, while as Zaqout et al⁴³ presented the opposite – a *higher physical activity* in the overall CHD patient group (ventricular septal defect, coarctation of aorta, transposition of great arteries, and tetralogy of Fallot) when compared to controls. Hedlund et al³⁷ presented *significantly lower physical exercise* and *significantly lower average intensity* on Borg scale in patients with Fontan circulation than in healthy controls.

When comparing patients with different severity of CHD, two studies reported no significant differences in physical activity,^{40,43} whereas one failed to report the results for physical activity divided by the different severity groups.⁴¹

In the studies providing informative physical activity data, Schaan et al³¹ reported low levels of patients in the “very active” (24%) and “active” (32%) output variables. Brudy et al³⁶ found that the patients reported themselves as active 4.7 days/week, generally not meeting the World Health Organisation recommendations for children and adolescents in 60 minutes of moderate-to-vigorous-physical-activity a day.⁴⁴ These results are similar to those reported by Ray and Henry⁴¹ who reported that only 38% of the patients were physically active for at least 60 minutes and 7 days a week. Similarly, Hedlund et al³⁷ reported a mean value of self-reported physical exercise of 135 minutes/week, indicating that the Fontan circulation patients generally fail to meet the World Health Organisation recommendations of physical activity. In contrast to these findings, both Zaqout et al⁴³ and Lunt et al⁴⁰ stated that most of the children and adolescents with CHD did meet the World Health Organisation recommendations of physical activity.

Included articles, accelerometer-assessed physical activity

In the accelerometer-based studies, nine articles were included (Table 4), whereas six studies compared children and adolescents with CHD towards healthy controls,^{32–35,37,38} two studies compared types of CHD,^{39,42} and one study compared children and adolescents with CHD to a healthy control group and type of CHD.⁴³

Epoch lengths of 60 seconds were reported in three of the articles,^{35,37,38} 30 seconds epoch lengths were listed in one study,³² 15 seconds in two of the studies,^{39,42} and a 3 seconds epoch length in one study.³⁴ Two of the included articles using accelerometer-assessed physical activity did not report the epoch length used in the study.^{33,43}

Eight articles reported the use of hip-worn accelerometers,^{32–35,38,39,42,43} whereas one reported using wrist-worn accelerometers.³⁷

Considering the cut-points used for defining the physical activity intensity categories, three articles^{37–39,43} reported using Evenson⁴⁵ cut-points for classification of physical activity intensity categories, one article³⁴ reported using Pate’s⁴⁶ cut-points, one article³² reported using age-appropriate intensity levels from a metabolic equivalent prediction equation^{47,48} for generating cut-points, one article⁴² reported using Puyau⁴⁹ cut-points but did not submit how the threshold of moderate-to-vigorous-physical-activity > 1600 counts per minute was calculated, one article³⁵ reported using the ActiReg monitor with calibration equation

Table 3. Summary of characteristics search 2, methods, main findings and limitations of an accelerometer-based studies

| Author (year) country | Sample | AC protocol | Other measures | PA outcome measure | Main findings, PA | Limitations |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Arvidsson et al. 2009 | Compared to age and gender paired controls 9–11 years CHD n = 32 14–16 years CHD: n = 25 9–11 years control group n = 61 14–16 years control group n = 45 | 60-second epoch length Hip worn 7 days record Valid days: >80% wear time on each of the 7 days Cut-points: ActiReg monitor with calibration equation for predicting intensity measures developed and evaluated by Arvidsson et al. ⁵⁰ | Interview in sports participation Max exercise test with VO ₂ uptake | PAL, total PA, time spent in MVPA | No differences in PA level between CHD group and control group Most patients did not meet recommendations of PA | 60-second epoch length Not accounting for CHD severity or functionality |
| Banks et al. 2017 | Compared CHD types and controls 4–12 years ASD: n = 31 TG4: n = 34 TOF: n = 37 SV: n = 35 | 15-second epoch length Hip worn 7 days record Valid days: 10 hours/day, 3 weekdays, 1 weekend day Cut-points thresholds: Puyau's cut-points ⁴⁹ did not submit how the threshold of MVPA > 1600 counts per minute (cpm) was calculated | Self-efficacy questionnaire CSAPPA Gross motor skill assessment Cardiopulmonary exercise test | Weekly total time spent in MVPA | No differences in PA level between CHD severity/type groups Many met recommendations of PA (not stating how many) | External control group (published normative data) – cannot account for the same AC data gathering or data processing protocol. Incomparable Applied pre-calibrated cut-points, calibrated for 60-second epochs in 7–18 year olds Scaled cut-points |
| Ewalt et al. 2012 | Compared CHD to controls 6–19 years divided into three age groups CHD gr.: n = 21 Control gr.: n = 21 | 30-second epoch length 7 days record Hip worn Valid days: 10 hours/day, 3 weekdays, 1 weekend day Cut-points: Calibrated via metabolic equivalent prediction equation ^{47,48} | | Minute/day: MPA, VPA, SED | No difference in PA level between CHD group and control group Most patients did not meet recommendations of PA – 19% of patients reached recommendations of PA | Small sample size initially, even smaller when divided into smaller age groups Not accounting for CHD severity or functionality Applied pre-calibrated cut-points, calibrated for 60-second epochs in 7–18 year olds Scaled cut-points |
| Hedlund et al. 2016 | Compared to controls 8–20 years Fontan palliation gr.: n = 30 Control gr.: n = 25 | 60-second epoch length 7 days record Wrist worn Cut-points: Evenson ⁴⁵ | Self-reported PA QoL (PedsQL) | Total PA, SED, LPA, MPA, VPA | No difference in total PA, MPA and VPA between CHD group and control group MVPA mean: 148 ± 60 minutes/day patients; 141 ± 54 minutes/day controls | Epoch length at 60 seconds Unknown valid measure criteria (valid day, number of valid days) Applied pre-calibrated cut-points for hip-worn sensor, calibrated for 15-second epochs in 5–8 year olds |
| Kao et al. 2009 | Compared to controls 9–12 years CHD gr.: n = 34 Control gr.: n = 34 | Unknown epoch length 3 days record Hip worn Cut-points/basis for cut-points: transferred accelerometer (RT3) originated energy expenditure as intensity measure | Self-reported TEE via 3D PAR | TEE EE in MVPA PAL | TEE in CHD group was significantly lower than control group in boys. No difference in girls | No description of RT3 data handling Small sample size Unknown epoch and cut-points for PA Only 3 days data-collection for capturing PA Unknown valid measure criteria (valid day, number of valid days) |

(Continued)

Table 3. (Continued)

| Author (year) country | Sample | AC protocol | Other measures | PA outcome measure | Main findings, PA | Limitations |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stone et al. 2015 | Compared to controls 3–5 years CHD gr.: n = 10 Control gr.: n = 10 | 3-second epoch length 7 days record Hip worn Cut-points: Pate ⁴⁶ | Parent-reported PA habits of their child | TPA, LPA, MPA, MVPA, VPA, SED, WT* | No differences in PA level between CHD group and control group Most patients did not meet recommendations of PA | External control group (published normative data) – cannot account for the same AC data gathering or data processing protocol. Incomparable Small sample size Possibly biased recruitment Unknown valid measure criteria (valid day, number of valid days) AC: vertical plane only Applied pre-calibrated cut-points calibrated for 15-second epochs. Scaled cut-points |
| Voss et al. 2017 | Compared CHD severity types 8–19 years Mild CHD: n = 26 Moderate CHD: n = 26 Severe CHD: n = 29 Cardiac transplant: n = 9 | 15-second epoch length 7 days record Hip worn Valid days: 10 hours/day, 3 weekdays, 1 weekend day Cut-points: Evenson ⁴⁵ | Sub-sample completed Physical Activity Questionnaire for Older Children (PAQ-C) or adolescents (PAQ-A) | Total PA, relative PAI, time spent in PAI, counts/day, MVPA, VPA, daily SED (%), adherence to PA guidelines on ≥ 6 days/week | No differences in PA level between CHD severity type groups Most patients did not meet recommendations of PA – 8% of patients reached recommendations of PA | Relatively small sample size Applied pre-calibrated cut-points calibrated for 5–8 year olds |
| White et al. 2020 | Compared three specific CHD (both congenital and acquired HD) to controls 8–18 years CHD gr.: n = 33 Control gr.: n = 22 | 60-second epoch length 7 days record Hip worn Valid days: 10 hours/day, 3 valid days Cut-points: Evenson ⁴⁵ | Physical Activity Questionnaire and the Modifiable Activity Questionnaire for determination of patients involvement in extracurricular sports or extracurricular physical activities during the data collection period | Daily PA intensity (mean acceleration/60 seconds) MVPA bouts as: sporadic sessions of PA (<5 minutes); short bouts of activity (5–10 minutes); medium to long bouts (> 10 minutes) PA patterns (average counts/minute) for each hour 08:00–22:00 + as in-school time (08:00–15:00), late afternoon (15:00–18:00), and evening (18:00–22:00) | No significant between-group differences in PA counts per minute CHD group spent significantly more time LPA and less MVPA than controls CHD group had more sporadic bouts, fewer short and medium-to-long bouts of MVPA than controls CHD group was less active in the late afternoon No differences between groups in sedentary time | Both congenital and acquired HD – three different diagnoses only (single ventricle physiology and Fontan palliation, isolated cardiomyopathy without congenital HD or pulmonary hypertension and NYHA class I–III, and Small sample size Wide age range Epoch length at 60 seconds. Applied pre-calibrated cut-points calibrated for 15-second epochs in 5–8 year olds |
| Zaqout et al. 2017 | Compared CHD severity types + group and controls: Control gr.: 6–12 years n = 520 CHD gr.: 6–14 years VSD: n = 19 COA: n = 10 TOF: n = 15 TGA: n = 22 | Epoch length: unknown Valid days: 6 hours/day, 2 weekdays, 1 weekend day Hip worn Cut-points: Evenson ⁴⁵ | Self-scattered PA: PAQC Physical fitness Cardiorespiratory fitness Upper-limb isometric strength Standing long-jump 40 m sprint test for max running speed Flamingo balance test Sit-and-reach test Blood analysis for metabolic score | MVPA | No differences in MVPA level between CHD group and control group OR Many patients did not meet recommendations of PA | Unmatched controls from external database – cannot account for the same AC data gathering or data processing protocol. Incomparable Few valid days and full day criteria Applied pre-calibrated cut-points calibrated for 15-second epochs in 5–8 year olds. Epoch length unknown |

3DPA: three-day physical activity record; 6MWT: 6-minute walk test; AC: accelerometry; ASD: atrial septal defect; CHD: congenital heart defect, general term; COA: coarctation of aorta; CSAPPA: children's self-perceptions of adequacy and prediction for physical activity; EE: Energy expenditure; HD: heart disease; IPAQ: International Physical Activity Questionnaire; LPA: light physical activity; MET: metabolic equivalent of task; MPA: moderate physical activity; MVPA: moderate-to-vigorous physical activity; PA: physical activity; PAI: physical activity intensity; PAQ-C: Physical Activity Questionnaire for Adolescents; PAQ-A: Physical Activity Questionnaire for Older Children; PedsQL: Pediatric Quality of Life Inventory; QoL: quality of life; SED: sedentary behaviour; SV: single ventricle; TEE: total Energy expenditure; TGA: transposition of the great arteries; TOF: tetralogy of Fallot; TPA: total physical activity; VPA: vigorous physical activity; VSD: ventricular septal defects; WT: wear time

for predicting intensity measures developed and evaluated by Arvidsson et al,⁵⁰ whereas one reported transferred accelerometer (RT3) originated energy expenditure as intensity measure.³³

Similar physical activity levels were found between the patient group and the healthy controls in the majority of the included accelerometer-based studies.^{32–35,37,39,42,43} In contrast, White et al³⁸ reported that the CHD group spent significantly more time in light physical activity and less moderate-to-vigorous-physical-activity than the healthy controls, typically engaging in more sporadic bouts (<5 minutes), fewer short (5–10 minutes) and medium-to-long (>10 minutes) bouts of moderate-to-vigorous-physical-activity than the healthy controls. Similarly, Kao et al³³ observed significantly lower levels of total energy expenditure in boys with CHD compared to healthy controls, even if the reported moderate-to-vigorous-physical-activity was similar between the groups.

The majority of the accelerometer-based studies reported that the patients with CHD generally failed to meet the World Health Organisation recommendations of physical activity in children and adolescents.^{32,34,35,39,43} Banks et al⁴² recognised that the majority of the atrial septal defect patients met the recommendations of physical activity, but not the transposition of the great arteries, tetralogy of Fallot, or single ventricle patients; however, they did not state the proportions. Hedlund et al³⁷ studied the physical activity in Fontan circulation patients and observed an average moderate-to-vigorous-physical-activity of 148 minutes/day in the patient group, stating that they meet the World Health Organisation recommendations of physical activity.

Discussion

The main observation from all of the included studies was the contradicting finding of similar physical activity levels in children and adolescents with CHD compared to healthy controls, or due to the severity of CHD. These results are in line with the previous two review studies.^{17,18} Van Deutekom and Lewandowski¹⁸ raised the concern about the low level of physical activity in the general population, which could affect the possibility of detecting different physical activity behaviour in children and adolescents with CHD. Although this might be true, we argue for that the contradicting findings and absence of group difference in physical activity are largely explained by the methodological variations and limitations in the assessment of physical activity. In order to comply with the second objective of this study, and as it is recommended to use objective methods before subjective methods for obtaining more reliable assessment of physical activity,¹⁵ the discussion will mainly focus on the accelerometer-based studies included.

Subjectively assessed physical activity

As measurement errors in subjectively assessed physical activity have been stated by earlier research, demonstrating poor reliability and validity, especially in children,^{15,19,20} a potential misclassification and a variation among the results are seen as probable. Reports of both no significant differences towards healthy controls,⁴¹ significantly lower physical activity,^{37,40} and significantly higher physical activity in the patient group⁴³ were found. The inconsistent and widely divergent findings may be a result of all six articles using different questionnaires for the assessment of physical activity. Dissimilar properties of physical activity are thereby captured. Thus, stating general conclusions or even comparing the physical activity outcome is seen as inappropriate. A similar verdict was reported by Acosta-Dighero et al.¹⁷ and by Van Deutekom and Lewandowski.¹⁸

Accelerometer-assessed physical activity

Concerning the accelerometer-based studies, the overall results suggest that there are no differences in the physical activity levels between children and adolescents with CHD compared to healthy controls.^{32–35,37,39,42,43} Similar finding was reported by Acosta-Dighero et al¹⁷ and by Deutekom and Lewandowski.¹⁸ Two of the studies showed contradicting results. Kao et al.³³ reported lower total energy expenditure in boys with CHD, indicating that they move less than their healthy controls even if the reported moderate-to-vigorous-physical-activity was similar between the groups, whereas White et al.³⁸ reported the patient group as spending less time in moderate-to-vigorous-physical-activity and engaging in smaller bouts of moderate-to-vigorous-physical-activity than the healthy controls. As the physical activity outcome is highly dependent on the distinct settings made,^{28,30,51} a likely explanation of the many cases of the unexpected “no-difference in PA” between patients and healthy controls can be related to the irregularities in the methodologies used in and between the studies.

Common variances in accelerometer-based studies regard matters such as device placement, raw data processing, epoch lengths, value calibrations, altered use of pre-calibrated cut-points, weekend-week-day-criteria, number of valid days/hours-a-day/week, and handling of sleep-time and non-wear time. The handling of these parameters is often poorly described or completely lacking, making comparisons between studies even more problematic. The lack of methodological consensus within accelerometry makes it difficult, or even impossible, to generalise and compare the results.^{28,30,51} In the following section, we will go through the methodological issues of the included studies and their consequences on the results. This will be performed by considering each issue separately.

Device placement

As the activities of the arm not necessarily reflect the movements of the rest of the body, the registered data differ between the hip- and wrist-worn placement sites.⁵² Hip-worn sensors typically capture movements that better reflect the whole-body energy consumption,²⁸ while wrist-worn sensors have been shown to be disposed for misclassifying seated behaviours that are involving high levels of upper body movement.⁵² One of the accelerometer-based studies used a wrist-worn accelerometer but applied physical activity intensity cut-points developed from a hip-worn accelerometer.³⁷ The use of wrist-worn accelerometers and the application of hip-worn accelerometer cut-points to wrist data reduce both study validity and comparability to the other studies included in this review.

Epochs

The epoch lengths are ranging from 3 to 60 seconds in the included studies, with two of the studies failing to report the epoch length used. The occurring epoch-length variances (and in many cases long epoch lengths) may result in different estimates of physical activity within the studied populations and thereby lead to distorted interpretations. Previous research has stated significant variation in physical activity volume and intensity using various epoch lengths, showing a progressive decrease in time spent in moderate-to-vigorous-physical-activity with longer epoch lengths.^{29,53–55} Also, with the movement pattern of children being highly intermittent, shorter epoch lengths have been recommended as longer epochs fail to capture the executed physical activity.^{29,56,57} To demonstrate, in the study by White et al³⁸ the results showed similar amount of *total physical activity* measured as ActiGraph counts per minute compared to the control group,

similar time in sedentary behaviour (SED), more time in light physical activity but somewhat less time in moderate-to-vigorous-physical-activity. An epoch length of 60 seconds was used in that study. Aadland et al²⁹ showed that with 60-second epochs, a large proportion of SED would be misclassified as light physical activity, and vigorous physical activity would be misclassified as light physical activity or moderate physical activity, but the total physical activity would not be affected. Hence, the 60-second epochs will not capture the variation in physical activity in children and would distort/reduce expected group differences.

Pre-calibrated cut-points

By calculating the relationship between accelerometer counts and the criterion value over a fixed time frame (epoch length), thresholds for the categorisation of physical activity (SED, light physical activity, moderate physical activity, vigorous physical activity, and moderate-to-vigorous-physical-activity) are generated. Numerous pre-calibrated cut-points exist, and there is no consensus in which one to use at what occasion, even if age-specific recommendations have been made²⁸ With the included articles using a variety of different cut-points, the classification of physical activity intensity categorisation varies largely between them. Banks et al⁴² used a moderate-to-vigorous-physical-activity threshold of >1600 counts per minute; Ewalt et al³² used age-specific calibrated cut-points for moderate-to-vigorous-physical-activity: 6–11 years = >1400 counts per minute, 12–15 years = 2221 counts per minute, and 16–19 years = 3001 counts per minute; Stone et al³⁴ used Pate⁴⁶ moderate-to-vigorous-physical-activity cut-points of >1680 counts per minute; Hedlund et al.³⁷ Voss et al.³⁹ White et al,³⁸ and Zaqout et al⁴³ used the Evenson cut-points⁴⁵ of >2296 counts per minute for the same physical activity intensity category. With different cut-points being applied, the easiness to accumulate moderate-to-vigorous-physical-activity differs between the studies, not displaying the same variations of physical activity within each physical activity intensity category even if results are presented in the same terminology. Pre-calibrated cut-points are population specific as body mass and age are important factors for the calculated mechanical energy used in accelerometry. Thus, when applying the cut-points, it is recommended to follow the same data gathering and processing criteria upon the same age group that was utilised in the original calibration study.

In many of the included studies using pre-calibrated cut-points, the age group is not compatible with the age group used in the original calibration study. Only one of the studies used the same age-criteria.³⁴ Instead, Banks et al⁴¹ applied cut-points calibrated for 7–18 year old on a population of 4–12 year old, and the Evenson⁴⁵ cut-points calibrated for 5–8 year old, were applied to populations of 8–20 year old,³⁷ 8–19 year old,³⁹ 8–18 year old,³⁸ and 6–14 year old.⁴³ Consequently, with children generally moving with a bigger effort and a higher energy cost at a given activity than older (and taller) individuals,⁵⁸ the calibrated cut-points used indistinguishably between the age groups will cause false estimates of physical activity categorisation.

Modifications, or scaling, of pre-calibrated cut-points to fit the chosen epoch length are frequently seen in accelerometer-based research. However, a modification of cut-points alters physical activity estimates.^{56,59} Only one of the accelerometer-based articles used the same epoch setting as in the original calibration study.³⁹ Banks et al⁴² applied 15-second epochs on a cut-point calibrated for

60-second epochs, Ewalt et al³² applied 30-second epochs on a cut-point equation calibrated for 60-second epochs, Stone et al³⁴ applied 3-second epochs on a cut-point calibrated for 15-second epochs, Hedlund et al³⁷ applied 60-second epochs on a cut-point calibrated for 15-second epochs, White et al³⁸ applied 60-second epochs on a cut-point calibrated for 15-second epochs, and Zaqout et al⁴³ did not report used epochs on a cut-point calibrated for 15-second epochs, leaving us only with speculations on the effect upon the result.

Taken the age, epoch length, and device placement criteria for the usage of pre-calibrated cut-points all together, the divergent settings will affect the between-study comparisons and decline the internal validity of the measure within each study.

Calibration of cut-points and inclusion of whole-spectrum physical activity

Metabolic equivalent of task (VO_{2total}/VO_{2rest}) is a frequently used criterion measure of absolute physical activity intensity and is a way of expressing the energy cost of task-specific physical activity relative to body mass. Two articles reported calibrating cut-points via energy expenditure equations of MPA corresponding to 3 metabolic equivalent of task³⁵ or 4 metabolic equivalent of task.³² Validating cut-points against indirect calorimetry can be problematic as metabolic equivalent of task-calibrated cut-points are not comparable between ages. Typically, a 3 metabolic equivalent of task value is set for calibration of moderate physical activity threshold in both children, adolescents, and adults. However, when children walk at a speed of 5.6 km/hour, a metabolic equivalent of task value of 4.3 is reached,⁶⁰ whereas adults typically reach a metabolic equivalent of task of 5.0 at the same speed.⁶¹ However, the internal effort and energy cost of a child are greater. A child will consume more O_2 per kg body weight,⁵⁸ moving with higher step frequencies than taller individuals at a given speed.^{62,63} Adding the fact that the resting energy expenditure decreases with age⁶⁴ and metabolic equivalent of task values for specific activities typically increase with age (even more distinct at higher intensities),^{60,65} the usage of metabolic equivalent of task as a measure of effort across age groups when calibrating cut-points can be distortive.

To enable direct comparison of age groups and achieve age-equivalent measures of physical activity intensity categories (e.g. light physical activity, moderate physical activity, vigorous physical activity, moderate-to-vigorous-physical-activity), the VO_{2net} ($VO_{2total} - VO_{2stand}$, ml/kg/minute) has been recommended to use as criterion measure for calibration of accelerometers.⁵⁸ When a child (shorter) and an adolescent (taller) attain the same VO_{2net} , they will move with the same metabolic effort, but with the child generating less acceleration (or less mechanical work) as moving at a slower speed than the adolescent. Hence, minutes spent in, for example, vigorous physical activity will be directly comparable between age groups from a metabolic effort perspective. In contrast, when a child and an adolescent move at the same speed, they will generate similar acceleration (or mechanical work) but with different metabolic efforts.

Nevertheless, the crude classification of physical activity used in all studies included might cause a potential loss of information from the collected acceleration data. Aadland et al⁵⁷ showed how presenting physical activity as a high-resolution physical activity intensity spectrum provides more comprehensive information regarding the physical activity behaviour. By presenting physical activity as an intensity spectrum, the concern with studies using different cut-points is resolved.

Table 4. Detailed methodological considerations and guidelines for improving assessment of physical activity

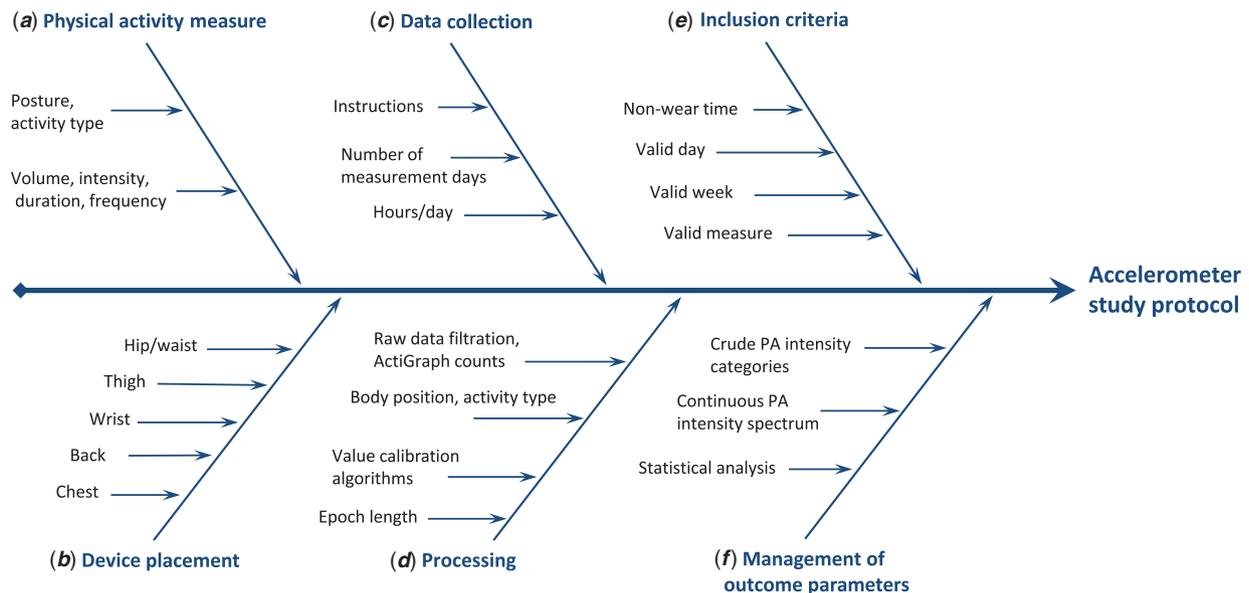
| Accelerometer aspect | Explication, suggested improvement and considerations |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical activity measure | <ul style="list-style-type: none"> Determine what type of physical activity measurement is of interest: <ul style="list-style-type: none"> Volume, frequency, duration, intensity Posture, activity type |
| Device placement | <ul style="list-style-type: none"> Device placements of both hip, wrist, and thigh occur (back and chest are also seen, but infrequently used). Thigh- and hip-worn sensors generally assess activities overall reflecting the energy consumption of the whole body and are seen as good at stating the physical activity dimensions volume, frequency, duration, and intensity. Thigh placement also enables the assessment of body position (e.g. sit, stand, lay down) and type of activity performed (e.g. biking, walk, run), but demands good tape solutions for attachment of the accelerometer as it has shown a tendency to be worn off during activity and change of clothes^{25,28} The wrist placement captures different movement patterns compared to the other placements, typically misclassifying seated behaviours involving high levels of upper body movement⁵² A concise instruction to wear the sensor 24 hours/day is seen to contribute to similar wear compliance between the placement sites²⁵ Comparisons should only be considered when using the same measurement location |
| Data collection | <ul style="list-style-type: none"> Clear instructions to patients with pictures displaying body attachment facilitate good wear compliance.²⁵ Registration period protocols at 24 hours/day show higher wear time compliance compared to waking-hour protocols⁷³ 7-day protocols are commonly used in physical activity research and are seen as sufficient for capturing normal variation in physical activity. If more accuracy on individual level is required, more days should be included.²⁵ Sampling frequencies should be sufficiently high to cover the movement frequencies, 30–100 Hz has been recommended.²⁸ A higher sampling frequency will limit the number of days to record physical activity as it requires more memory A sampling amplitude at 8 g covers most human activities²⁵ |
| Processing | |
| Epoch length | <ul style="list-style-type: none"> The epoch is the aggregation of the physical activity measure investigated over a chosen time interval, creating units of accelerometer measures (1–60 seconds) Significant variations in time spent in different physical activity intensity categories have been confirmed when using different epoch lengths^{29,55} Longer epochs will cause more reduced data, while shorter epoch lengths better capture the intensity distinctions within the performed activity, showing more time in the extreme intensity categories (e.g. SED and VPA/VVPA)^{29,55} Shorter epochs have been recommended in measurement of children to better capture their inherent physical activity movement pattern²⁹ |
| Raw data filtration method | <ul style="list-style-type: none"> Frequency filters are commonly applied in order to reduce noise The narrow raw data filtration method used (ActiGraph counts) is seen to acquire misclassifications of >90% when compared to wider filters at the higher intensity spectra.⁷⁰ Interpretation of ActiGraph counts filtered acceleration is therefore highly deceptive A wider filter is recommended to better capture the physical activity performed, for example, frequency extended method (FEM)^{69,70} |
| Value calibration and calibration of cut-points | <ul style="list-style-type: none"> Value calibration against a reference method (e.g. indirect calorimetry (VO₂)) is performed in order to translate the accelerometer measure to more established measures of physical activity intensity (e.g. EE, MET). Cut-points are defined to create physical activity intensity categories. If measured VO₂ is used as reference, it is recommended to apply VO_{2net} (VO_{2gross}-VO_{2stand}, ml/kg/minute) as it provides an age-equivalent measure of metabolic intensity in order to compare physical activity between age groups⁵⁸ It is recommended to follow the same data collection protocol, sample characteristics, and processing criteria as used in the original calibration study when applying cut-points to a specific data set.²⁸ Scaling of pre-calibrated cut-points to fit the chosen epoch length is seen to alter physical activity estimates^{56,59} |
| Inclusion criteria | <ul style="list-style-type: none"> Including too few measurement days will decrease the chance of capturing the individual physical activity behaviour, differences between groups and relationships between physical activity behaviours and health aspects, as great within-individual variances in habitual physical activity exist^{25,76} Even if measured for several days, great variances typically occur in wear compliance, both in regard to whole days and in weekdays/weekend days. Studies should state inclusion criteria in regard to wear time (8–10 hours/day), valid day criteria (minimum of 4 days, >3 weekdays, and >1 weekend day) as well as non-wear definition to enable tracking of time that should not be involved in the activity analysis.⁷⁶ For higher precision, more days and hour/days should be included. Non-wear time (when the accelerometer is taken off) should be defined and sorted out to enable discrimination between sedentary behaviour and when the accelerometer is not in use. A non-wear time of at least 60 minutes of zero values is commonly used²⁸ |
| Management of outcome parameters | <ul style="list-style-type: none"> Outcome/results are often presented as time spent in crude physical activity intensity categories (SED, LPA, MPA, VPA, and VVPA)²⁸ It has been suggested to present and analyse the physical activity as a high-resolution physical activity intensity spectrum^{74,75,77,78} Even if higher intensities appear particularly beneficial to health,^{74,77,78} they only account for a fraction of time spent in physical activity when measured in minutes per day, even in very active individuals. The physical activity intensity spectrum allows more detailed inspection of the physical activity and may reveal physical activity patterns otherwise hidden when applying crude physical activity intensity categories With cut-points varying greatly among studies, and scaling of cut-points to fit the wanted epoch length being performed, the risk of confusion is assumed to be highly present when comparing and contrasting the results |

(Continued)

Table 4. (Continued)

| Accelerometer aspect | Explication, suggested improvement and considerations |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Notification – measure of absolute intensity | <ul style="list-style-type: none"> It is important to keep in mind that accelerometers primarily record mechanical, absolute work, translated to meaningful terms via value calibration. The relative intensity measured in individuals is thereby not accounted for Absolute intensity can be seen as especially problematic when used for specific groups who possess biological or physiological limitations, like the children and adolescents with CHDs. For example, running at a certain speed will potentially be of greater effort for individuals with reduced capacity in the cardiovascular system compared to healthy individuals, even if the same work is performed |

EE, energy expenditure; MET, metabolic equivalent of task ($EE_{\text{total}}/EE_{\text{rest}}$); crude intensity categories; SED, sedentary behaviour (<1.5 METs); LPA, light physical activity (1.5–2.9 METs); MPA, moderate physical activity (3.0–5.9 METs); VPA, vigorous physical activity (6.0–8.9 METs); VVPA, very vigorous physical activity (≥ 9.0 METs); MVPA, moderate, vigorous, and very vigorous all together

**Case scenario**

The objective is to explore the physical activity intensity in children (6–12 years) and adolescents (13–18 years) with various CHD towards age, gender and area-paired healthy controls. As the aim is to measure physical activity intensity and volume (a), a hip worn (b) sensor is chosen as the data collected will represent overall body movement. The participant will be given written instructions to wear the sensor 24hours/day for 7 consecutive days and to practice their everyday life as usual. Sampling settings will be at 8g and 50Hz in order to capture relevant acceleration signals (c). When the data have been gathered, raw data will be processed through Frequency Extended Method filtration with an epoch length of 3 seconds to reduce the information but still being able to assess the physical activity intensity variation in children (d). An inclusion criteria of 10 hours/day and at least 4 days of measurement (>3weekdays and >1 weekend day), with removed non-wear time (60 minutes of zero values) will be set for valid measure (e). The results will be presented both as a traditional crude physical activity classification (SED, LPA, MPA, VPA, VVPA and MVPA) categorization but preferably as a continuous physical activity intensity spectrum for more detailed physical activity patterns (f).

Please note, this scenario reflects one methodological angle of approach in how to design an ideal accelerometer-based study for the assessment of physical activity. Different designs may be required for different studies. Research design was not considered in this section.

Figure 2. Brief methodological considerations for tailoring a physical activity measure using accelerometers and a case scenario.**Raw data filtration**

Even if seen as more reliable than subjective measures, accelerometers have been shown to possess difficulties in capturing intermittent and high intensity physical activity, generating a decrease in counts even if activity is increasing (e.g. the “plateau” effect).^{66,67} The “plateau” occurs mainly as a result of the raw data frequency filtration in the original, most commonly used ActiGraph counts.⁶⁶ This is believed to be particularly applicable in the measurement of children as their general movement pattern is sporadic and highly intermittent,^{53,57,68} moving with a higher step frequency at a given speed,^{25,57,68} consequently reducing the acceleration signal ever further. Processing the acceleration through a wider filter improves the assessment of physical

activity and reduces the age variances in gait patterns.^{69,70} Notably, when compared towards broader filters, the ActiGraph counts showed a misclassification of >90% in the higher intensity spectra.⁷⁰ Consequently, the capture of physical activity intensities is considerably more accurate when processing the acceleration through a wider filter. With the previous raw data filtration being insufficient, it is likely that the included studies failed to capture the variance in physical activity at higher intensity levels as interpretations of ActiGraph filtrated moderate-to-vigorous-physical-activity are highly unreliable. Therefore, a possible larger difference in physical activity might be present between the studied groups than the included studies imply, as they rely on the narrow ActiGraph raw data filtration.

Fulfillment of World Health Organisation physical activity recommendation

When it comes to fulfilling the World Health Organisation recommendation of ≥ 60 minutes per day of moderate-to-vigorous-physical-activity,⁴⁴ the included articles point towards an agreement: children and adolescents with CHD generally fail to meet the recommended amount of physical activity, a result similar to that of Acosta-Dighero et al¹⁷ and by Van Deutekom and Lewandowski.¹⁸ However, the World Health Organisation guidelines are based upon subjective measures of physical activity. The results from the accelerometer-based studies regarding physical activity recommendations should therefore be interpreted with caution as they are based on different, incomparable methods. Further, the chosen cut-points and epoch lengths will affect the ratio of individuals reaching the physical activity recommendations as lower cut-points and shorter epochs will accumulate more moderate-to-vigorous-physical-activity; conversably, higher set cut-points and longer epochs will accumulate less moderate-to-vigorous-physical-activity.^{28,29,57} The fulfillment of the physical activity recommendation is also dependent on how strict the criteria are, that is, if attaining 60 minutes of moderate-to-vigorous-physical-activity on most days or as a daily average. For example, Voss et al³⁹ applied Evenson cut-points on 15-second epoch data and the stricter criteria of fulfilling the physical activity recommendation on most days; only 8% of the patients were sufficiently physically active.

Further, difficulties may arise when attempting to implement the World Health Organisation recommendations of physical activity for healthy individuals on children and adolescents with physical restrictions. The included articles contain a range of different types and severities of CHD, with various physician subscribed (former) recommendations for engagement in physical activity. Accelerometers measure absolute intensity, regardless of the intensity relative to fitness level. A moderate intensity level for an individual with a severe CHD might differ from the same physical activity level for a healthy individual. In addition, the cut-point for moderate intensity level might be set too low in general, corresponding to normal walking speed rather than to brisk walking speed in accordance with the original definition of moderate-intense physical activity.⁷¹

In summary, the methodological challenges, variances, and limitations might explain why we generally fail to see a difference between the groups even when a larger difference in physical activity is to be expected. We need to control for the discussed parameters and strive towards agreement between the methods used for enabling future comparisons and interpretation of the results. As long as there is no consensus concerning accelerometer protocols and settings, research protocols will be designed unequally, making between-study comparisons highly questionable. To enable further research on the effect of interventions, strategies, and models for promoting physical activity in CHD populations, valid and reliable baseline measures of physical activity patterns in CHD populations are needed. Interdisciplinary collaborations are advantageous when implementing accelerometry into clinical research for assessing valuable and accurate assessments of physical activity and thereby improve the quality of clinical physical activity research.

Figure 2 (a-f) presents a brief overview of methodological considerations for tailoring a physical activity measure using accelerometers together with a case scenario with implementation of the methodological steps of the accelerometer study protocol. More detailed information, concepts, and guidelines are provided in Table 4. Complementary information about existing methods may be provided in the work by Voss and Harris.⁷²

Conclusion

Previous research has been unable to establish whether the physical activity patterns in children with CHD differ to healthy controls, or due to the severity of CHD. These results are largely explained by methodological variation and limitations in the assessment of physical activity. This review provides methodological knowledge and guidelines for improved assessment of physical activity using accelerometers in clinical research.

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Ethical standards. None.

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