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Individual heart rate assessment and bout analysis of vigorous physical activity in children

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Children should engage in 1 hr/day of moderate-to-vigorous physical activity (MVPA) that results in increased heart rates (HRs) (CDC, 2022). However, precise individualized HR criteria for MVPA are not provided, and it is unclear whether observed behaviors classified as MVPA are associated with elevated HRs indicative of MVPA. The current study replicated an individualized heart rate assessment (IHRA) for identifying MVPA HR zones in children (Van Camp et al., 2021). We then evaluated whether engaging in vigorous PA (VPA) for half of the session resulted in HRs indicative of VPA for at least half of the session when children engaged in running for 30, 60, 90, and 120 s bouts. Individual differences were observed during the IHRA. During the bout analysis, HRs were not within VPA zones for 50% of the session. However, HRs were within moderate PA (MPA) zones, with 30 s bouts producing the highest percentages of MPA.

Key words: bout analysis, heart rate, individualized assessments, MVPA, physical activity

The Centers for Disease Control and Prevention (CDC) has identified physical inactivity as a growing health concern world-wide (2022). Increased physical activity (PA) in childhood is associated with better physical and mental health, improved attention, memory, and grades in school (CDC, 2022), and long-term benefits such as decreased risk of developing chronic disease (Physical Activity Guidelines Advisory Committee [PAGAC], 2018). These health benefits are maximized when children engage in moderate PA (MPA) and are even more pronounced when children engage in vigorous PA (VPA; Janssen & LeBlanc, 2010). The CDC describes MPA as any activity during which an individual's heart rate (HR) is beating "faster than normal" (e.g., walking briskly). In contrast, VPA is described as activity during which an individual's HR is beating "much faster than normal" (e.g., running).

The current recommendation for children is that they engage in PA for 60 min (1 hr) or more of Moderate-to-Vigorous PA (MVPA) per day (CDC, 2022). Results from survey data suggest that only 21% of American children ages 6 to 17 years meet this recommendation daily (Child and Adolescent Health Measurement Initiative, 2021). A review of international studies using more objective measures of PA via accelerometers found that overall, only 9% of boys and 2% of girls (5 to 17 years)

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meet the recommendation (Cooper et al., 2015). A consistent finding across countries is that boys are more active than girls and that PA decreases as children age. In addition, American children were among the least active compared to some European countries (e.g., Norway and Australia). Unfortunately, children have been reported by their parents to have engaged in even less PA during the COVID-19 pandemic, both in America (Dunton et al., 2020) and globally (Okely et al., 2021). This is unsurprising as at times parks, recreation centers, and even schools were closed, and studies show children engage MPA most frequently outdoors away from home (Dunton et al., 2012).

An important consideration in the assessment of children's PA relates to the naturalistic distribution of activity. Often, these activities are done transiently. Both LPA and MPA last a median of 6 s and VPA lasts a median of 3 s. Intervals of VPAs remain relatively short, with 75% lasting less than 1 min (Bailey et al., 1995). Although bouts of high intensity activity may be shorter and less frequent, these bouts contributed a significant proportion of energy expenditure (Berman et al., 1998). One arrangement that approximates these short bouts of activity is high intensity interval training (HIIT), a short duration high-intensity activity that is alternated with rest periods (Cabral-Santos et al., 2017; Corte de Araujo et al., 2012; Dias et al., 2018; Gamelin et al., 2009; Rey et al., 2017). Compared to endurance training over the course of 12 weeks, children trained in HIIT demonstrated increased health benefits (Corte de Araujo et al., 2012), including reduced insulin resistance and increased aerobic fitness. Based on these benefits, it is advantageous to target bouts of VPA for interventions.

A consideration related to the assessment of PA is whether activities should be classified as MPA and VPA based on topography or physiological effects. Direct observation has been a common method to record children's PA behaviors in the behavioral literature (Van Camp & Hayes, 2012). The Observational System for Recording PA in Children ([OSRAC]; Brown et al., 2006; McIver et al., 2009) was developed based on the Children's Activity Rating Scale ([CARS]; Puhl et al., 1990). The CARS ranks different behaviors based on the expected energy expenditure from level 1 or stationary (less than 100 BPM [beats per min]) to level 5 or fast translocation (greater than 160 BPM). The OSRAC and CARS have demonstrated high interobserver agreement (Brown et al., 2006; McIver et al., 2009). However, Van Camp and Berth (2018) evaluated the concurrent validity of HR and OSRAC ratings and found individual variability in HR associated with MPA and VPA across participants; specifically, not all activities considered MPA and VPA resulted in HRs within expected HR ranges. Similar individual differences were observed in an earlier study by Larson et al. (2011). These studies suggest that direct observation may be a subjective and/or inconsistent measure across individuals. Also, training of observers on the coding systems used in direct observation is time consuming and resource intensive, and tests for observer drift and retraining need to be conducted frequently (Loprinzi & Cardinal, 2011; Pate et al., 2010).

A valid alternative to direct observation may be measurement of HR in BPM. Eckard et al. (2019) determined HRs associated with activities commonly classified as MPA (walking) and VPA (jogging) for individual participants via a Polar HR strap worn around the chest, and observers recorded HR every 20 s. Like Van Camp and Berth (2018), there was individual variability in HR for each activity. Eckard et al. then evaluated the HR associated with several less structured activities that would be classified by the OSRAC as VPA. While engaged with the elliptical, exercise bike, basketball, and boxing, no participants' mean HR reached the vigorous zone. Although these are categorized as VPAs by the OSRAC, they may not evoke the physiological effects expected of that level of exertion. Therefore, use of the OSRAC may lead to activities being misclassified as vigorous. An added complication is that individuals may engage in the same activity at different intensities (e.g., running versus sprinting), which may be difficult to quantify via direct observation. In contrast, HR is a more sensitive measure to individual differences.

Van Camp et al. (2021) replicated and expanded the individualized HR assessment of Eckard et al. (2019) by measuring HR every second and comparing the results to standardized formula-based HR criteria. To calculate children's maximum HR, age is multiplied by .7 and subtracted from 208 (Tanaka et al., 2001). Based on this criterion, the CDC (2022) suggests MPA and VPA target HR is 65% and 76% of the child's maximum HR, respectively. Multiple studies have found significant discrepancies in measured HR compared to these standards, perhaps because these formulas do not account for other factors that influence HR such as sex, race, or maturation (Nikolaidis, 2014). Van Camp et al. evaluated activities that would be considered light, moderate, and vigorous to determine HRs at each level of activity for each individual. Ten typically developing children wore heart monitors while they engaged in PA. Participants alternated completing four levels of activity: sit, walk slowly, walk briskly, and run. Participants engaged in 2 min of activity followed by 2 min of rest for a maximum total of 30 min per day. There were predictable differentiations in HR levels for each of the activities evaluated; however, individual differences were found. Based on the CARS HR criteria, four participants' average HR met criteria for LPA when engaged in walking slowly, seven participants' HR met criteria for MPA when engaged in walking briskly, and nine participants' HR met criteria for VPA when engaged in running. Finally, based on CDC recommendations, no participant's HR met criteria for LPA, eight participants' HR met criteria for moderate activity when engaged in walking briskly, and all 10 participants' HR met criteria for VPA when engaged in running. This indicates that the individualized HR assessments may be a valid alternative to inaccurate age-based formulas in identifying HR zones associated with MPA and VPA in children.

Physical activity research in behavior analysis has attempted to assess and increase durations of MVPA in children (e.g., Larson et al., 2014). However, it is unclear whether these increases would be associated with physiological benefits based on their short duration. For example, Larson et al. (2014) conducted a functional analysis of MVPA in preschool children. Researchers delivered reinforcement contingent on observations of initiation of MVPA and continued every 10 s as long as the participant's engagement in MVPA was maintained, according to OSRAC direct observation. Frequency and duration of bouts of MVPA were highest in the interactive play condition and lowest in the escape and control conditions. This methodology seems to support increased PA under certain reinforcement contingencies, but it is unclear if the duration of bouts of MVPA based on the OSRAC would be consistent with recommended HR levels for MVPA. Therefore, it is important to evaluate whether short bouts of activity will result in increases in HR to the MVPA zones that are considered beneficial by the CDC (2022).

The purpose of the current study was twofold. First, we replicated the IHRA with an additional 13 children. Second, with a subset of children, we evaluated whether engaging in VPA (running) for 50% of a 12 min session resulted in the same effects on HR regardless of whether intervals of running and resting varied across bout lengths of 30-s, 1-min, 1.5-min, or 2-min intervals. That is, would engaging in VPA for half of a session result in HRs indicative of VPA for half of the session regardless of distribution of run and rest intervals? If not, what might be an optimal bout length of running behavior that would increase HR to beneficial VPA or at least MPA levels?

Method

Participants

Participants were 13 typically developing children between the ages of 6 and 12 who attended a local after school care program (four males and nine females). Data were collected twice across the course of the study for one individual, once at the outset of the study and again approximately 2 years later. Their data will be reported as two separate participants according to the timepoints at which assessment occurred (Acadia and Acadia 2). Thus, the total number of datasets is 14. Participants were recruited via information packets that were distributed to caregivers. Specifically, information packets were either inserted into the children's school folders and sent home, or researchers delivered packets to caregivers by hand during pick-up times. Each caregiver provided permission via written signature. Each participant provided written assent after researchers explained details about the study and answered any questions. Participation was voluntary and participants were allowed to end participation at any time during or outside of sessions by indicating that they wanted to stop. HR was continuously monitored, and an experimenter would end the session if a participant's HR exceeded the recommended maximum ((208 − [0.7 × Age]); PAGAC, 2008). Participants were informed to report any injuries from participation. No injuries were reported during the course of the study. Caregivers also provided information about each participant's age, weight, height, and health status. See Table 1 for detailed demographic information.

Table 1

Participant Characteristics

Participant	Gender	Age	Height (cm)	Weight (kg)
Bea	Female	6	122	23
Acadia	Female	7	107	22
Tate	Male	8	122	29
Zahra	Female	8	130	20
Joslyn	Female	8	132	44
Leia	Female	9	142	25
Wesley	Male	9	137	41
Acadia 2	Female	9	133	38
Harry	Male	10	142	38
Lisa	Female	10	130	27
Atlas	Male	11	152	59
Cora	Female	11	150	36
Elsie	Female	12	147	36
Ember	Female	12	145	52

Setting and Materials

All sessions took place at the local afterschool program in a flat open field with an outdoor picnic table and bleachers. A Polar M400 (Polar Electro Inc, 2014) Bluetooth chest strap monitor was used to collect second-by-second HR measures (BPM) and stopwatches were used to time sessions. The Polar chest strap monitor was worn across the bare sternum and measured the heart's electrical signals via two electrodes embedded into the device. The device on the strap was positioned directly below the pectoral muscles when worn by participants. Participants fitted the chest strap to their sternum independently in a private restroom or researchers assisted with the fitting in a closed-off area. If participants fitted the chest strap independently, researchers asked them to point to the location of their shirt under which the device was positioned and asked if any adjustments were necessary for sizing. Polar chest straps were selected based on their use in previous studies (e.g., Eckard et al., 2019; Larson et al., 2011; Van Camp & Berth, 2018; Van Camp et al., 2021). Paper and pencil were used for additional data collection. Fruit gummies were provided at the end of each session for daily participation and leisure items were provided every three to five sessions as prizes for participation in the study (e.g., trading cards, temporary tattoos, stickers, pencils, stamps). Microsoft Excel (2020) and the Polar Flow application (Polar Electro Inc, 2014) were used for data collection and analysis. An Apple iPhone 7 (2016) was used to access the Polar Flow application.

Measures and Data Analysis

The Polar chest strap monitor transmitted HR (BPM) measures that were displayed in real-time on the Polar Flow application. Observers recorded time stamps for the onset and offset of each active or rest period using stop watches. Observers also recorded the activity type for each active period during the IHRA. Following each session, second-by-second HR measures (BPM) were synced and extracted for data analysis based on the primary observer's record sheet. The primary dependent measure for the IHRA was average HR. Each participant's HR criteria for MVPA in the bout analysis was determined by the results of the IHRA (described below). The primary dependent measures for the bout analysis were average HR and percentage of session spent in the HR zone for MPA and VPA.

A split-half analysis was used to evaluate within-session trends of HR (Perone & Hursh, 2013; Van Camp et al., 2021), which focused on the last 30 s for each 2 min session (Buchheit et al., 2012; Rabbani et al., 2018). For the last 30 s of each 2-min session, researchers calculated the difference between the average HR for the first 15 s and the last 15 s, which was then divided by the mean of the last 30 s and multiplied by 100 (Van Camp et al., 2021). The stability criterion was less than a 5% difference. The average percentage difference across all 204 trials was 1.5%, with 97% meeting the stability criterion. Per activity type, the average percentage difference was 2.2, 1.4, 1.7, and .8% for sit, walk slow, walk brisk, and jog, respectively. Six trials (across five participants and two activity types, including five sit trials) did not meet the 5% criterion; these ranged between 5.1% and 5.9% difference. Coefficient of covariation (CV) was used to evaluate the degree of change in HR when PA is repeated under similar conditions (Al Haddad et al., 2011). Researchers calculated the CV for each individual 2-min session by dividing the standard deviation for the last 30 s by the average of the last 30 s and multiplying by 100 (Van Camp et al., 2021). The stability criterion for CV was 10%, which is typical among previous research (Sandercock et al., 2005). The average CV for all session types was 1.6%, and per activity was 2.5%, 1.6%, 1.5%, and 0.6% across sit, walk slow, walk brisk, and jog, respectively.

Given the stability of the last 30 s within-session data, we considered these data representative of the maximum HR associated with that activity. To evaluate the stability of HR measures across consecutive sessions (per activity type), we calculated the CV by dividing the average standard deviation across sessions, dividing by the average mean across sessions, then multiplying by 100. The average CV across all participants and activity types was 5.3%. Per activity type, CV was 8.2%, 5.4%, 4.6%, and 3.1% for sit, walk slow, walk brisk, and jog respectively, which was below the 10% criterion (Sandercock et al., 2005).

Finally, we extracted temperature and humidity data for each session day from Weather Underground (The Weather Company, 2022). Correlations were calculated using the temperature and humidity recorded on the hour closest to time sessions started each day. Correlations between the baseline resting HR (based on the last 30 s of the first rest period) and temperature and humidity were .15 and −.29 respectively; neither were statistically significant, suggesting that weather did not have a significant effect on HR during these sessions.

Interobserver agreement was assessed for at least 80% of all IHRA sessions by having two observers simultaneously, but independently, record data. An agreement for duration was coded if both observers recorded the same timestamp for the onset and offset of a given period plus or minus 3 s. An agreement for activity type was coded if both observers recorded the same activity or rest for a given period. Trial-by-trial agreement was assessed for active and rest periods by dividing the number of agreements by the total number of trials and multiplying by 100. Interobserver agreement was assessed separately for the duration of each period and the type of activity. Agreement coefficients were 99.59% and 99.80% for duration and activity type, respectively.

Individualized Heart Rate Assessment (IHRA)

We replicated the IHRA described by Van Camp et al. (2021). Each participant wore a HR monitor and a researcher provided general instructions. Specifically, researchers indicated that the participant would either be standing, walking slowly, walking briskly, or running for 2 min, and that each activity would be followed by a rest of at least 2 min. Researchers also indicated that the participant would be given a 5 s countdown prior to the start of each activity or rest period. Researchers provided model prompts for each activity and gave vocal prompts to differentiate the two walking activities (i.e., walking slowly and walking briskly). For walking slowly, participants were told "walk at your normal pace," and for walking briskly participants were told "walk fast or as if you were walking on a pool deck and you aren't allowed to run." Researchers vocally prompted participants to continue engaging in activity as necessary. If they did not continue after an initial prompt, the session would have been terminated for the day and the participant would have been told that they could no longer participate in the study (no participants were excluded from the study for this reason).

After the participants indicated they understood the instructions and were ready, the session began with a rest period of at least 2 min, or until a steady HR was obtained (+/- 10 BPM for 30 s), to establish a baseline HR for the day. Researchers then instructed participants to begin the scheduled activity. Four activities representative of the OSRAC classifications for sedentary, light, moderate, and vigorous activity were evaluated in a multielement design. The activities included standing still (sedentary), walking slowly (light), walking briskly (moderate), and running (vigorous). Participants engaged in each activity for 2 min followed by at least 2 min of rest, or until their HR was within 10 BPM of the recorded daily baseline. Active and rest periods alternated until 30 min elapsed or until the assessment was completed. Sessions always ended on a rest period. Activities were presented in a randomized order across participants and sessions, two to four times for each participant. MPA and VPA criteria were determined by averaging HR for the last 30 s, minus 1 standard deviation, of the walking briskly and running activities, respectively.

Bout Analysis

Participants

Three participants were enrolled in the bout analysis following the IHRA (Zahra, Bea, and Acadia). Data were collected twice across the course of the study for Acadia—once at the outset of the study and again approximately two years later; thus, four datasets are reported. Recruitment, consent, and assent were conducted according to the procedures detailed above. HR was continuously monitored, and an experimenter would end the session if a participant's HR exceeded the recommended maximum ($(208 - [0.7 \times \text{Age}])$; PAGAC, 2008). Of the participants who participated in the bout analysis, body-mass indices (BMIs) based on age and weight suggested that one participant was of healthy weight, one was underweight, and two were overweight. See Table 1 for detailed demographic information.

Measures

The Polar chest strap monitor transmitted HR (BPM) in real time and was recorded by the researchers identically to the individualized HR assessment. Following each session, second-by-second HR measures (BPM) were synced and extracted for data analysis based on the primary observer's record sheet. The primary dependent measures for the bout analysis were average HR and percentage of sessions spent in the HR zone for moderate and vigorous activity.

Interobserver agreement was assessed for at least 60% of all bout analysis sessions by having two observers simultaneously, but independently, record data. Trial-by-trial IOA was assessed for active and rest periods by dividing the number of agreements by the total number of trials and multiplying by 100. Interobserver agreement was assessed separately for the duration of each period and the type of activity. An agreement for duration was coded if both observers recorded the same timestamp for the onset and offset of a given period plus or minus 3 s. An agreement for activity type was coded if both observers recorded the same activity or a rest for a given period. Agreement coefficients were 100% for both recording duration and activity type.

Procedure

Each participant wore an HR monitor and a researcher provided general instructions. Specifically, researchers indicated that the participant would start running for a set interval (i.e., 30s, 1 min, 1.5 min, 2 min) until the researcher told them to rest for that same interval. Researchers also indicated that the participant would be given a 5-s countdown prior to the start of each activity or rest period. Researchers vocally prompted participants to continue engaging in activity as necessary and if they did not continue after an initial prompt, the session would have been terminated for the day and the participant would have been told that they could no longer participate in the study (no participants were excluded from the study for this reason).

After the participants indicated they understood the instructions and were ready, the session began with running for the specified interval. Researchers then instructed participants to rest for the interval that followed. Activity (i.e., run) continued to alternate with rest for the specified intervals until 12 min elapsed. Sessions always ended on a rest period. Interval lengths were presented in a randomized order across participants and sessions, two to four times for each participant. MVPA criteria were determined based on the participant's individualized HR assessment described above.

Data Analysis

The Polar chest strap monitor transmitted HR (BPM) in real time. Following each session, second-by-second HR measures were synced and extracted for data analysis based on the primary observer's record sheet. The primary dependent measures for the bout analysis were average HR and percentage of the session spent in participants' individually determined moderate and vigorous HR zones. Average HR was calculated based on second-by-second HR for all active periods. Percentage of the session spent in moderate and vigorous HR zones was calculated by coding each second as a 0 if it did not reach the moderate or vigorous threshold and a 1 if it met moderate or vigorous criteria based on the IHRA. Percentage of session was then calculated by dividing the sum of seconds in moderate or vigorous zones by the total number of seconds for that session and multiplying by 100.

Participant error in adjusting the Polar chest strap sometimes resulted in zeros observed in the data stream, which would indicate no HR. Because it was impossible for participants to have no HR, we removed these instances from the data stream. To evaluate the effects of removing zeros from the data stream, we systematically removed 1%, 2%, 3%, and 4% of

HR measurements from a copy of one of our participant's data streams. There were no significant differences in average HRs when data were removed, even up to 4%. Specifically, differences in averages were only observed at the ten thousandths of a decimal point when 4% of the data were removed. During the IHRA, Acadia, Bea, Zahra, and Acadia 2 had a total of 0.16%, 0.56%, 0.75%, and 0.83% of zeros observed across all sessions, respectively. During the bout analysis, Zahra and Acadia 2 each had only three sessions with a total of 0.56% and 2.85% of zeros observed across those sessions, respectively. Acadia and Bea each had only two sessions with a total of 1.20% and 0.14% of zeros observed across those sessions, respectively.

Results

IHRA

Figure 1 displays the average HR for the last 30 s of each activity level across sessions of each activity. For most participants, there is clear differentiation between each activity level, with running producing the highest average HRs, followed by walking briskly, walking slowly, and standing. For Cora, Wesley, Acadia, and Leia, walking slowly and standing produced similar average HRs. Table 2 displays the average HR for each participant across activities minus 1 standard deviation (SD). These values served as the minimum HR criteria for sedentary, light, moderate, and vigorous activity for each participant (SD indicated in parentheses). For each participant, the lowest HR criterion is associated with walking, whereas the highest HR criterion is associated with running. Some individual differences were observed with respect to meeting the minimum expected HR for sedentary, light, moderate, and vigorous activities based on the CARS (Puhl et al., 1990) and the CDC (2022) recommendations.

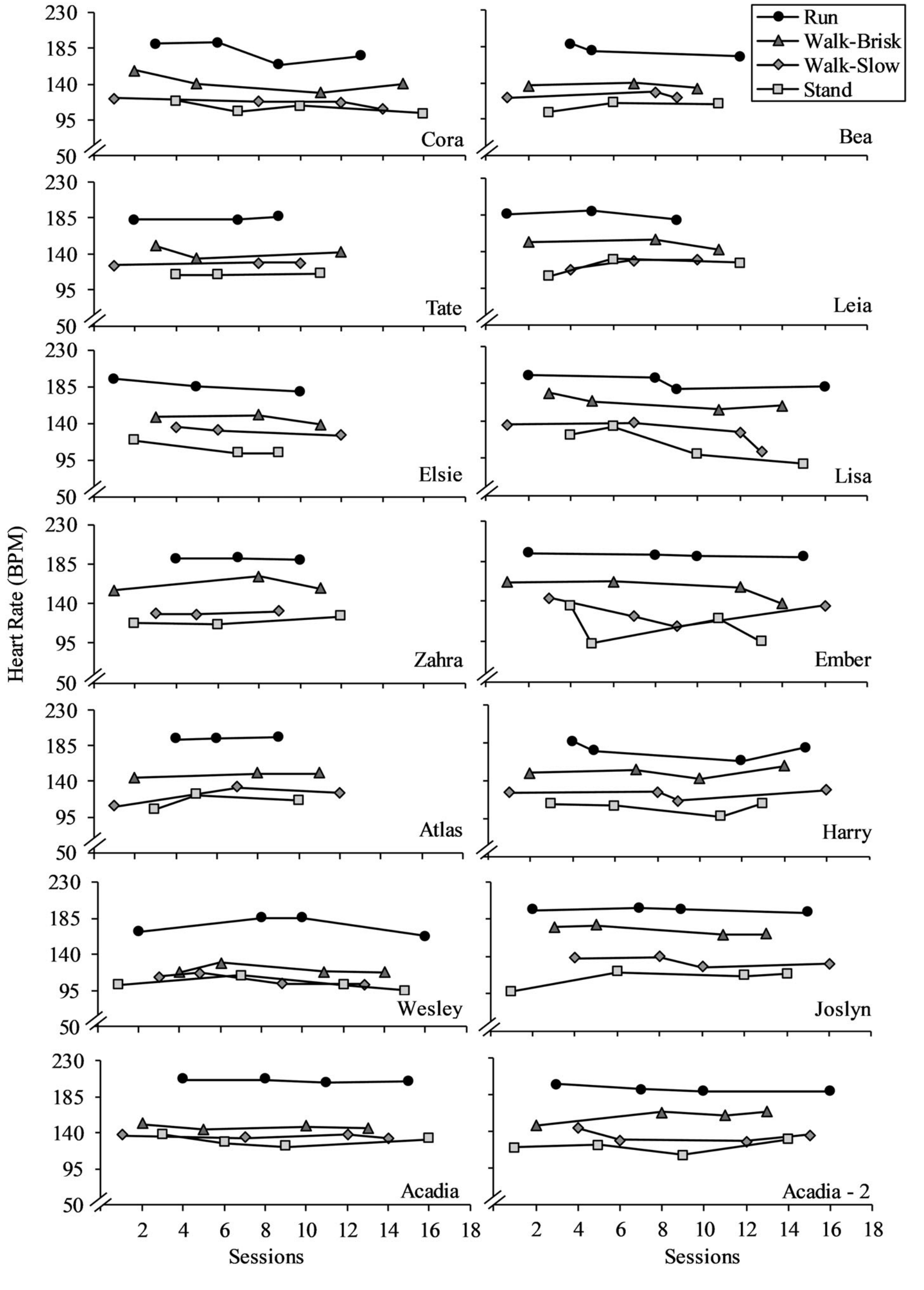
For walking slowly, HR minimums ranged from 109 BPM to 135 BPM, and 12 participants' minimum criteria met the minimum expected HR based on the CARS for LPA (120 BPM; Puhl et al., 1990). For the walking briskly, HR minimums ranged from 121 BPM to 171 BPM; 12 participants' minimum criteria met the minimum expected HR based on the CARS for MPA (140 BPM; Puhl et al., 1990), and 13 participants' minimum criteria met the minimum expected HR for MPA based on the CDC (2022) recommendation. Zahra, Joslyn, and Leia's minimum criteria for MPA also met the minimum expected HR for VPA based on the CARS (160 BPM; Puhl et al., 1990). Wesley's minimum criterion for MPA was close to falling within the expected HR for LPA based on the CARS (120 BPM; Puhl et al., 1990). For the running activity, HR minimums ranged from 175 BPM to 205 BPM, and all 14 participants' minimum criteria exceeded the minimum expected HR based on the CARS for VPA (160 BPM; Puhl et al., 1990) and the CDC recommendation.

Bout Analysis

Figure 2 displays second-by-second average HR, from top to bottom, for the 30 s, 60 s, 90 s, and 120 s bout lengths for each participant. Alternating white and shaded horizontal areas, from bottom to top, indicate participants' minimum HR criteria for LPA, MPA, and VPA. For the 30-s bout length, all participants' HRs met or exceeded MPA criteria during active periods. It is important to note, however, that HRs were not in the MPA zones for 100% of the active period. Specifically, it often took between 15-30 s for HRs to reach the criteria after onset of the active period when activity began. Bea's HR sometimes met the VPA criterion during 30-s active periods. For the 60-s bout length, all participants' HRs met or exceeded MPA criteria during the first active period. Zahra, Acadia, and Bea's HRs met the VPA criterion by the second or third active

Figure 1

Average Heart Rate (HR) of the Last 30 S Across Run, Walk-Briskly, Walk-Slowly, and Stand Sessions



period and HRs stayed within the VPA range for subsequent active periods, with the exception of a 15-30-s transition phase at the onset of the active period as noted above. Acadia 2's HR never met the VPA criterion during the 60-s bout length. For the 90-s and 120-s bout

Table 2

Heart Rate Minimums Across Intensity Levels

Participant	Sedentary	Light	Moderate	Vigorous
Bea	111 (5.3)	124* (3.3)	137+ (2.5)	180*+ (6.5)
Acadia	130 (5.6)	135* (2.1)	147*+ (2.7)	205*+ (1.8)
Tate	115 (0.6)	128* (1.5)	143*+ (6.6)	184*+ (1.8)
Zahra	120 (4.1)	129* (1.6)	161*+ (7.0)	191*+ (0.7)
Joslyn	114 (9.4)	134* (4.8)	171*+ (5.0)	196*+ (1.8)
Leia	111 (18.1)	126*(14.0)	162*+ (7.5)	187*+ (7.1)
Wesley	103 (6.8)	109 (5.9)	121 (4.9)	175*+ (10.2)
Acadia 2	121 (7.0)	134* (6.3)	159*+ (6.8)	192*+ (3.4)
Harry	108 (6.4)	125* (4.9)	150*+ (5.5)	176*+ (8.4)
Lisa	123 (9.0)	126* (5.1)	150*+ (5.2)	185*+ (4.6)
Atlas	114 (7.6)	122* (9.9)	148*+ (2.6)	194*+ (1.1)
Cora	110 (6.3)	117 (5.0)	142*+ (10.1)	181*+ (11.6)
Elsie	109 (7.4)	130* (3.9)	145*+ (4.8)	186*+ (6.3)
Ember	111(17.7)	128*(11.9)	154*+ (10.1)	192*+ (1.7)

Note. HR minimums, in BPM, are based on average of the last 30 s minus 1 standard deviation (SD indicated in parentheses) for each intensity level: sedentary, light (walking slowly), moderate (walking briskly), and vigorous (running).
* = meets the minimum expected HR for light activity (120 BPM), moderate (140 BPM), and vigorous (160 BPM) activities based on the CARS (Puhl et al., 1990).
+ = meets the minimum HR for moderate and vigorous activity based on the CDC recommendations (2020).

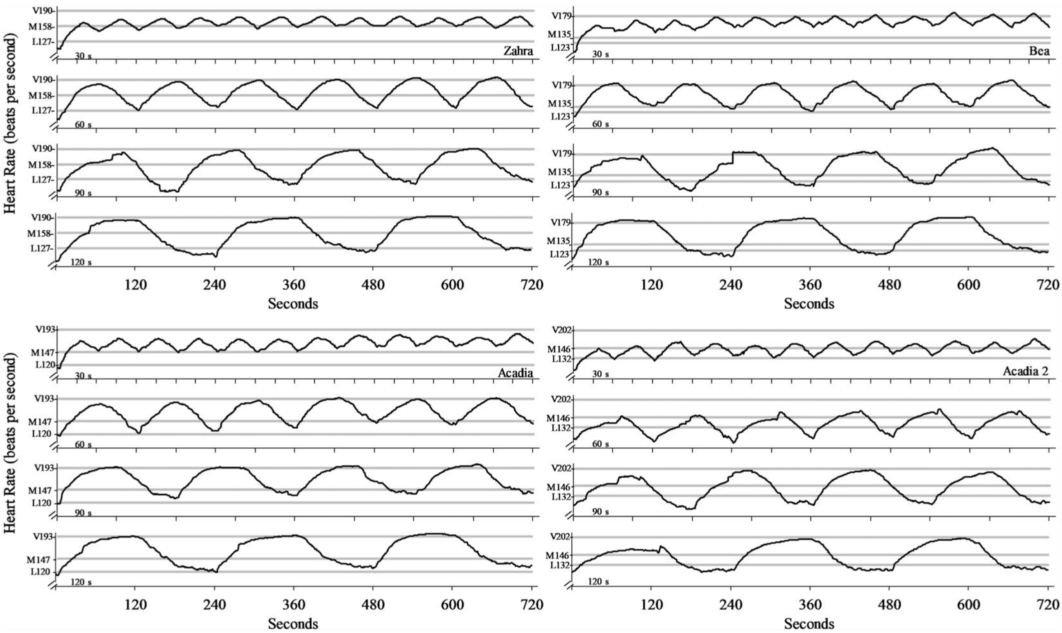
lengths, all participants' HRs met VPA criteria by the first or second active period and HRs stayed within the VPA range for subsequent active periods. During rest periods for the 60-s, 90-s, and 120-s bout lengths, all participants' HRs generally fell below MPA criteria, even sometimes falling below LPA criteria. During rest periods for the 30-s bout length, Zahra, Acadia, and Bea's HRs stayed at or above the MPA criterion. Thus, their HRs were at or above MPA criteria for most of the sessions (i.e., active and rest periods). Acadia 2's HR fell below the MPA criterion during all 30-s rest periods.

Figure 3 displays the percentage of each session spent in the moderate (middle column) and vigorous (right column) HR zones for each participant. Recall that for 50% of the session, all participants were engaged in the vigorous activity of running. Percentages of VPA tended to remain low and undifferentiated across participants. For only two data sets (Acadia and Acadia 2) did percentages of VPA reach 50% of the session spent engaged in VPA for any bout length. For all participants, the highest percentages of MPA occurred during the 30-s bout length, with most sessions nearing 100% spent in the moderate HR zone. The second highest percentages of MPA were generally observed during the 60-s bout length, though there was some overlap with 90-s and 120-s bout lengths. There was little differentiation in percentages of MPA between the 90-s and 120-s bout lengths. Only for two participants (Bea and Acadia) did percentages reach 50% of the session spent engaged in MPA during at least one of the two bout lengths.

Figure 4 displays the average percentage of each session spent in the moderate and vigorous HR zones across bout lengths for each participant. Average percentages of MPA were above 50% of the session across all bout lengths for all participants, and MPA was above 80% for the 30-s bout length for all participants. There was a general decreasing trend in average MPA as bout length increased. Average percentages of VPA were above 50% of the

Figure 2

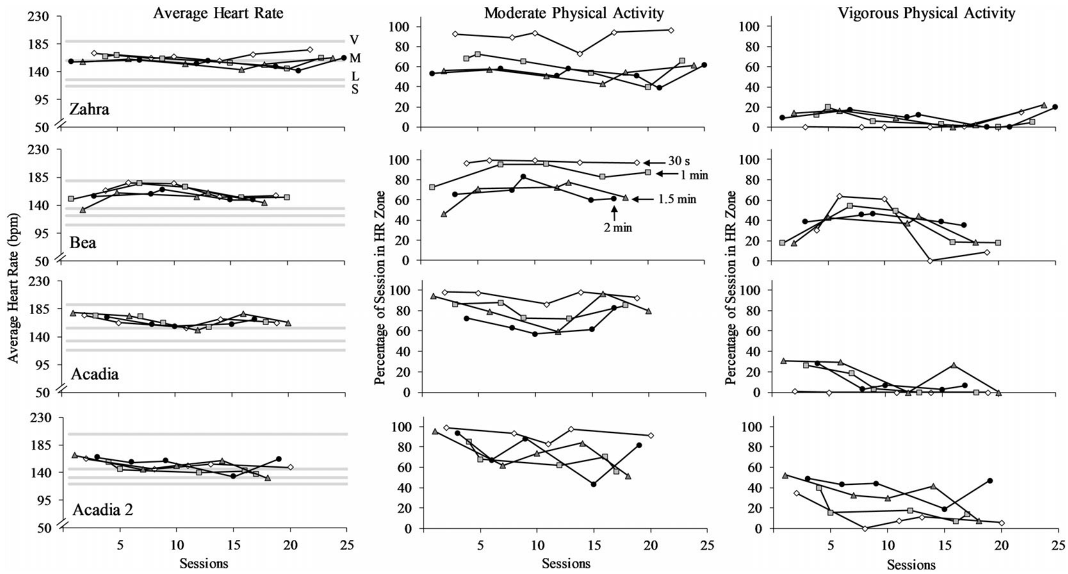
Second by Second Average Heart Rate (HR) across 30 s, 60 s, 90 s, and 120 s bouts



Note. Horizontal lines indicate each participant's minimum heart rate criteria for light (L#), moderate (M#), and vigorous (V#) physical activity.

Figure 3

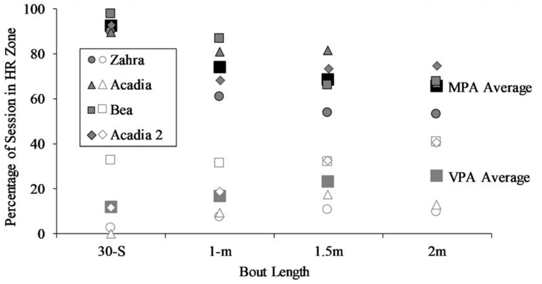
Heart Rate Averages and Percentages of Session Time in the Moderate and Vigorous Physical Activity Zones across Sessions for each Bout Length



Note. Horizontal lines on the left panels indicate each participant's minimum heart rate criteria for sedentary (S), light (L), moderate (M), and vigorous physical activity (V).

Figure 4

Average Percentage of Session in Moderate (MPA) and Vigorous (VPA) Heart Rate Zones



Note. The larger black (MPA) and grey (VPA) squares indicate the average percentage for all participants, across each bout length. Smaller grey (MPA) and white (VPA) symbols indicate the average percentage for individual participants.

session for Bea and Acadia only for the 120-s bout length. Average percentages of VPA were below 50% of the session across all bout lengths for Zahra and Acadia 2. Overall, there was a generally increasing trend in average VPA as bout length increased, though percentages remained below 50% in most cases.

Discussion

The present study replicated the IHRA with an additional 14 participant data sets and evaluated whether HR measures were indicative of VPA (or at least MPA) when subjects engaged in VPA (i.e., running) 50% of the session in various bout lengths of alternating activity and rest. There was differentiation of HR across the different activities measured, with the highest HR achieved during running and lowest HR achieved during standing, replicating Van Camp et al. (2021). Twelve out of 14 participants (86%) in the present study met minimum criteria for light activity based on the CARS (Puhl et al., 1990) when engaged in walking slowly, whereas only 40% of the participants in Van Camp et al. met this criterion. Twelve out of 14 participants (86%) in the present study also met minimum criteria for MPA based on the CARS (Puhl et al., 1990) when engaged in walking briskly, which is comparable to 70% in Van Camp et al. Thirteen out of 14 participants (93%) in the present study met minimum criteria for MPA according to the CDC (2022). Finally, participants who met criteria for VPA according to both the CARS (Puhl et al., 1990) and the CDC (2022) in the present study (100%) were similar to Van Camp et al. (90%). These data indicate that there are often individual differences in HR when children are engaged in similar activities, suggesting that HR is a more sensitive measure than direct observation.

In addition, if PA is to be measured via HR in research or clinical application, these data suggest MPA and VPA HR zones should be based on individualized assessments, rather than formulas based on age and gender. Although the procedure described in this study involved repeated measures and analyses of within- and across-session stability, these data, and those of Van Camp et al. (2021) suggest that the IHRA could be reduced in time and effort. Analyses of within-participant patterns indicated that HRs were stable within activity levels across repeated trials, suggesting that the identification of HR zones could be accomplished in one trial per activity. In addition, if a research or clinical goal were to increase PA to a specific level (just MPA for example) the IHRA could involve alternating only rest and walking briskly to determine MPA HR criteria. Future research could verify the predictive validity of shortened IHRAs. In addition, IHRAs could be conducted repeatedly, before, during, and after an intervention, to detect improvement in cardiovascular health. Finally, IHRAs could be conducted yearly to determine any changes in HR as children age.

The results of the bout analysis also have implications for how one should measure PA. Though children in the bout analysis ran for 50% of the session, HRs did not reach a vigorous threshold for 50% of the session for two of the four participants regardless of bout length. Only for Acadia and Bea did HRs remain close to the VPA zone 50% of the time for the 2-min condition, and Acadia 2 was the only participant with differentiation across bouts. Conversely, HRs were in the MPA zone for the most part across the different bout lengths. The highest percentages of HRs in the MPA zone were observed for the 30s bout and the lowest for the 2-min bout. Like findings of the IHRA (e.g., Van Camp et al., 2021), these findings differed across individuals. This individual variability is also consistent with Eckard et al. (2019) who found that engaging in activities classified as moderate or vigorous based on the OSRAC (Brown et al., 2006; McIver et al., 2009) and CARS (Puhl et al., 1990) may not result in HRs reaching expected levels for all individuals. Therefore, although both the OSRAC and CARS have demonstrated reliability, the inconsistency across individuals (e.g., Loprinzi & Cardinal, 2011; Pate et al., 2010) suggests HR is a more valid measure to set PA goals.

The present research also extends the HIIT research conducted with children (e.g., Cabral-Santos et al., 2017; Corte de Araujo et al., 2012). When engaged in bouts of running for 30-s intervals, HRs in the present study remained in the MPA zone for most of the session. During the first interval, HR consistently climbed to the MPA zone and did not dip below this zone during rest periods. Based on this study, HIIT should focus on shorter rest intervals of 30 s to retain the physiological benefits associated with sustained activity (i.e., increases in HR). These findings are crucial because children typically engage in short bursts of activity (Bailey et al., 1995; Berman et al., 1998).

The findings of the current study may have implications for interventions aimed at increasing PA in children as well. One line of research involves providing adult attention or interactive play contingent on engaging in 1 s of running, skipping, or jumping (Larson et al., 2014; Zerger et al., 2016) to identify which may be an effective reinforcer for MVPA. Subsequent treatment evaluations involve a similar contingency and have found that for some preschool children, contingent attention or interactive play may increase MVPA behavior; however, MVPA remained below 50% of the session in the majority of these cases (Larson et al., 2014; Zerger et al., 2016). Although an increase in MVPA from baseline is notable, it may be that requiring only 1 s of MVPA behavior may not be long enough to produce HR levels associated with physiological benefits. Results of the current study suggest that children may need to engage in MVPA for at least 30 s before HRs reach recommended levels. In addition, it is not clear whether similar results (i.e., increases in MVPA) would be found if the measure of interest was a sufficient increase in HR. Future evaluations could be conducted with both OSRAC- and HR-based measures of MVPA to assess this question directly. Future research should also evaluate minimum bout lengths necessary to reach and maintain beneficial HRs with implementation of behavioral assessments and intervention.

There are limitations to using HR as a measure of PA. HR may be affected by transient factors, such as an individual's emotional state, state of hydration, and climatic conditions such as temperature and humidity (Armstrong, 1998). In this study, weather was not found to be correlated with HR; however, we could not assess other factors such as hydration. That said, stress-induced influences on HR are of much lower magnitude compared to changes associated with physical activity (Epstein et al., 2001). These influences are less likely to affect HR at moderate or vigorous levels of activity (Armstrong, 1998). Genetic factors, such as gender, sex, and race also contribute to HR variation (Sarzynski et al., 2013); however, none of these factors affect HR as significantly as engaging in physical activity. Thus, despite these limitations, researchers have concluded that HR monitoring is a valid and reliable objective estimate of physical activity (Rowlands & Eston, 2007). Given that HR changes quickly and is sensitive to short bouts of activity typically observed in children (Epstein et al., 2001), HR may be used to provide thresholds equating to MPA and VPA (Armstrong & Welsman, 2006).

There may be some methodological and practical limitations associated with the Polar HR chest strap. Some of our participants reported that it was uncomfortable to have the device pressed to their chest while running and that they would loosen the strap to make it more comfortable. Relatedly, there were some zeros obtained in the second-by-second HR data stream that might suggest the chest strap was not making direct contact with the skin. Although this occurred rarely in this study, this is a potential limitation of chest-based HR measures. Wrist-based HR monitors may be a more comfortable alternative; however, some studies show that wrist HR measures are not as valid, especially during more intense activities (Muggeridge et al., 2021). Future research could be conducted comparing HR measures of two watch devices worn at the same time on each wrist (i.e., reliability), comparing those values to ones measured via a chest-strap. The IHRA may be a particularly useful preparation to use for such comparisons, as it involves engaging in behavior of varying intensity.

Another limitation of the current study is that the bout lengths evaluated may not reflect typical patterns of PA in children, or even typical activities that constitute MVPA for children. This preliminary bout analysis evaluated very structured bout lengths of sustained activity and rest periods. Our data established that engaging in behavior coded as VPA would not necessarily result in HRs indicative of VPA, and when such activities occurred for 50% of the time, the distribution (bout lengths) of activities differentially affected HR. Future research is needed to evaluate bouts of MVPA with a wider range of active and rest period durations. Additional research should also evaluate MVPA during bouts of activities other than running that might be observed during a typical day for children. For example, brisk walking is considered a moderate activity, and our IHRA data suggest HRs of many participants reached the CDC recommended level for MPA when engaged in brisk walking for 2 min. However, it is possible that shorter bouts may not result in similar increases.

The results of this study contribute to the literature in several ways. First, the IHRA was replicated with an additional 14 data sets. This assessment has identified individual differences in the HRs when engaged in structured activities indicative of MPA and VPA. These individual differences go beyond those accounted for in age and gender-based HR formulas. Researchers and practitioners utilizing HR as a measure of PA should consider using an IHRA to determine individualized HR zones. Second, the results of the bout analysis suggest that there are differences between observed measures of PA and measures of the physiological effects of PA. That is, engaging in VPA does not always result in HRs indicative of VPA. This preliminary evaluation suggests that more research is needed that measures both HR and observed behavior simultaneously to determine a) the extent to which reinforced behavior results in beneficial increases in HR in existing preparations (e.g., reinforcing 1s of MVPA behavior; e.g., Larson et al., 2014), and b) the optimal bout lengths of MVPA that should result in reinforcement such that increases in behavior results in concomitant increases in HR, as per the CDC recommendations.

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