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Human Kinetics
ORIGINAL RESEARCH

A 5-Week Guided Active Play Program Modulates Skin Microvascular Reactivity in Healthy Children

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Purpose: Children's poor levels of physical activity (PA) participation and early-onset vascular aging are identified as global health challenges. Children's guided activity play (GAP)-based PA programs have emerged as effective strategies to improve cardiovascular risk factors and health-related fitness. This study proposes to investigate whether GAP improves children's cutaneous microvascular reactivity and health-related fitness. ***Methods:*** Children's (n = 18; 9.8 [1.5] y) PA during a 5-week (4 d/wk; 1 h/d) GAP program was assessed (accelerometry) with preassessments and postassessments for anthropometric, musculoskeletal fitness, blood pressure, estimated aerobic power, and cutaneous microvascular reactivity. ***Results:*** PA averaged 556 (132) kcal·week^{-1} at 34.7% (7.5%) time at moderate to vigorous intensity. Resting heart rate (−9.5%) and diastolic blood pressure (−7.8%) were reduced without changes in health-related fitness indices. Cutaneous microvascular reactivity to sodium nitroprusside iontophoresis increased the average perfusion (+36.8%), average cutaneous vascular conductance (+30%), the area under the curve (+28.8%), and a faster rise phase (+40%) of perfusion (quadratic modeling; $P \leq .05$). Chi-square and crosstabulation analysis revealed significant association between children's PA levels and sodium nitroprusside average perfusion levels, where children with PA levels ≥205.1 kcal·55 minute^{-1} were overrepresented in the medium/high levels of sodium nitroprusside perfusion. ***Conclusion:*** A 5-week GAP modified the microvascular reactivity in children without changes in body mass, musculoskeletal fitness, or estimated aerobic power.

Keywords: cooperative games, physical activity, microvascular perfusion, endothelial function, endothelial-independent function

Key Points

- After 5 weeks of guided active play, children achieve sufficient level of physical activity to reduce their diastolic blood pressure.
- This mode of physical activity that is based an interactive play led to a modulation of children's endothelial-independent microvascular function.
- Changes in children's microvascular reactivity were observed despite no changes in body mass and musculoskeletal fitness or VO_2max.

Over the last decade, children's vascular health has declined globally, and experts urge performing more studies on the determinant of children's vascular health (9,10). It is important to find interventions that can circumvent this trend, since early deterioration of vascular health during childhood considerably impacts the cardiovascular risk in adulthood (1,9,55). A primary focus of children's vascular health has been the microcirculation which is crucial to the regulation of blood pressure and blood flow (18). Findings support the notion that cardiovascular risk factors modify children's microvascular function. Children with cardiovascular comorbidities, such as hypertension, obesity, and type 1 and type 2 diabetes, present microvascular alterations ranging from adverse microvascular remodeling (ie, narrowing of arterioles) to a decrease in microvascular vasodilation due to an alteration in the endothelial function, smooth muscle function, or both (19,29,34,35,50).

To date, studies involving clinical or laboratory settings have investigated the impact of lifestyle interventions on the micro-

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vascular function in children with cardiovascular comorbidities (43,46). Clinical or laboratory training-based programs have a beneficial impact on children's cardiovascular health through improvement of vascular function and better control of blood pressure (11,25). Findings converge to show that the higher the intensity or the more vigorous the effort, the greater the improvement in vascular function for healthy children (13,20). Despite the benefits noted for clinical or laboratory physical activity (PA) programs, it has been proposed that their usefulness, practicality, feasibility, and relevance may be limited for improving children's PA participation during childhood (23,31,51). Studies targeting more familiar PA settings for children are needed to better characterize the microvascular function in healthy normal weight children with no cardiovascular comorbidity.

Recent evidence supports the notion that PA positively impacts children's retinal microvasculature in both healthy and obese children (35,36,52). Both school-based intervention and prospective studies have reported that children achieving greater level of PA have improvement in their retinal microvascular structure (ie, increase in arteriolar diameter) (52) and maintain lower blood pressure than less active children (35). While a sport-based PA program reported that time spent in moderate to vigorous intensity correlated positively with flow-mediated arterial vasodilation in healthy prepubertal school children (20), significantly less evidence exists regarding whether play-based PA programs could support changes in children's microvascular function. With this play-based format, children have a greater level of enjoyment while having an increased energy expenditure (EE), spending more time at moderate and vigorous intensities, while lowering sedentary time (5,21,39). It has been suggested that a play-based program may contribute to increasing children's PA participation (53) and subsequently improve tracking of cardiovascular and health-related fitness parameters (41).

Children's guided active play (GAP) is characterized by intermittent, short, and long bouts and activities that are fun, freely chosen, and self-paced (4,38,39,53). When performed over 2 to 3 months, the program can elicit improvements in cardiorespiratory fitness that are comparable to continuous or interval aerobic training delivered over 8 to 12 weeks (3,37,49). Although PA participation in GAP lowers children's systolic and diastolic blood pressure, the impact on microvascular function is unknown.

Hence, we proposed to assess whether GAP can induce changes in the cutaneous microvascular reactivity in normal weight children when engaged in a 5-week community-based summer day camp program. We assessed the endothelial and the smooth muscle reactivities and their kinetics by measuring the cutaneous vasodilation in response to acetylcholine (Ash; endothelial-dependent, ED) and sodium nitroprusside (SNP; endothelial-independent, EI) stimulations. We then tested whether PA (EE and moderate to vigorous intensity) levels were associated with a change in microvascular parameters.

Materials and Methods

Study Design, Participants, and Ethics

Children recruited to this study (n = 18; 11 boys and 7 girls; 8–12 y) were a convenient sample living in a large urban city and registered in a subsidized 7-week community summer camp program that incorporated a 5-week GAP program. Prior to starting a 7-week summer camp, an information session was organized to inform parents/guardians and children about the opportunity to participate in a 5-week (4 d/wk) GAP research program to be incorporated to the 7-week summer camp. Parents/guardians completed an informed consent form and a PA readiness questionnaire. Children also provided verbal assent to participate in the study before each of the health and fitness assessments and the GAP program. Pre- and postmeasurements were performed the first or second session attended by the child at the summer camp and the last week of the summer camp among the last 2 sessions the child attended, corresponding to the week preceding the first GAP session and the week following the last GAP session attended by the child, respectively.

As previously described (38–40), the GAP sessions were delivered with the support of experienced kinesiology undergraduate majors serving as positive role models and encouraging children to participate, at a ratio of 5 children per 1 kinesiology student (5:1). Briefly, 1-hour sessions were conducted in the afternoons (1–2 PM or 2–3 PM) on 4 days per week, for 5 weeks during July and August. The GAP sessions consisted of a warm-up (3 min), a water break (2 min), and 55 minutes of self-paced PA incorporating age-appropriate cooperative games (5–6 games per session) selected from a compendium of children's games (4,5,40) that are cooperative and exhibit intermittent patterns of movement at various levels of intensity such as Dr Dodgeball, Blob Tag, or Zombie Tag (4). To be included in the results, the children had to participate in at least 14 out of the 18 GAP session (ie, 75%). At no time were the children forced to participate. All children were able to participate without feelings of incompetency and were provided the opportunity to cooperate and socialize with peers while having fun and being active (4,40). All procedures were approved by York University's Human Participants Research Committee.

Measures of PA

Children's PA was quantified and characterized during each session (55 min) with accelerometers (ActiGraph GT3X+). Accelerometer vector (counts·10 s) outputs determined by ActiLife (version 6.1) software were used to estimate oxygen consumption (VO_2; in milliliters·per kilogram per minute) and calculate Energy expenditure (EE in kilocalories per week) with laboratory-derived equation $y = 0.0069\ (VM) + 18.924$ (40). For estimated VO_2, the explained variance (R^2) and standard error of estimate using specific laboratory-based equations were .95 and 1.07 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$, respectively. Metabolic equivalents (METs) were estimated from our laboratory-based equation with $y = 0.0045\ (V) + 0.9912$ (4) and used to classify PA intensity as sedentary (≤1.9 MET), very light (2.0–2.9 MET), light (3.0–3.9 MET), moderate (4.0–5.9 MET), and vigorous (≥6 MET). Intensity data are expressed in percentage of PA time (ie, %PA) for both sedentary time and time spent at moderate and vigorous PA (%MVPA; ≥4 MET).

Measures of Health-Related Fitness

Body mass (in kilograms), height (in centimeters), vertical jump height (in centimeters), combined grip strength (in kilograms), resting heart rate (rHR; (in beats per minute), resting systolic blood pressure (SBP; in millimeters of mercury), and resting diastolic blood pressure (DBP; in millimeters of mercury) were measured as previously described (5,40). The blood pressure and HR assessments were taken after a 15-minute acclimatization period in a reclined position prior to starting the microvascular function assessment using an automatic blood pressure monitor (5). Mean arterial pressure was calculated using a standard mathematical formula, SBP + [(2 × DBP)/3] (48,59). Pulse pressure was calculated by

subtracting the systolic by the diastolic blood pressure (SBP – DBP). In addition, the Leger 20-m shuttle run was used to estimate maximal oxygen uptake (VO_2max) in milliliter oxygen per kilogram per minute (28). All assessments were conducted by the investigators and/or kinesiology students experienced with the equipment and procedures to within a coefficient of variation of ±3% (31,55).

Microvascular Function

ED and EI cutaneous microvascular reactivity were assessed by laser Doppler perfusion imaging (LDPI) paired with iontophoresis using Ach (ED) and SNP (EI) performed by one investigator (Moghaddaszadeh) (22,47,48). Laser Doppler imaging using the PeriScan PIM3 (Perimed) was used to measure skin blood flow, and this imager allowed acquisition of reproducible data for assessing the skin microvascular function (22). The PeriScan PIM3 System is a blood perfusion imager 1 mW system utilizing a laser wavelength of 680 nm. This imager has a 0.7 to 1 mm depth of measure, detecting blood flow from capillaries as well as arterioles and venules from the upper microvascular plexus in the dermis (6). Iontophoresis (Periont, Perimed) was used to noninvasively deliver Ach and SNP locally without systemic effect and without perturbation of skin biology. The delivery protocol was similar to previous studies (43,57,58). Children arrived at the site of summer camp in a fasted state (5 h) and sat (rest) for a minimum of 15 minutes during which children and their parents (if present) were given an introduction and a familiarization with the LDPI equipment and the iontophoresis patches. Following the rest period, children were reclined on a bed for a measurement of resting skin temperature (using an automatic skin thermometer) and blood pressure of the nondominant hand. The ambience, room, and skin temperatures assessed during the microvascular assessments remained unchanged throughout the study. The ambient and indoor temperatures during the first and last week of the GAP program were 27.6 °C (1.9 °C) and 28.2 °C (1.6 °C), and 25.9 °C (0.3 °C) and 26.1 °C (1.5 °C), respectively. The forearm cutaneous skin temperatures during the first and last week of the GAP program were 36.1 °C (0.3 °C) and 36.2 °C (0.3 °C), respectively.

Two sets of 1 dispersive electrode and 1 drug delivery electrode were placed on 2 separate sites on the forearm midpoint between the wrist and elbow with the arm extended and resting on a cushion. Perfusion analysis was performed from scanned images recorded with a distance of 12 to 14 cm to the forearm at frequency of 0.1 Hz and a resolution ranging from 1.2 to 1.4 mm. Drug delivery electrodes were then filled with 200 µL of either Ach (1%) or SNP (1%) to measure ED or EI microvascular function (47,48). Cutaneous blood perfusion was recorded throughout the protocol. After 60 seconds of baseline perfusion recording, an anodal current was applied to start local drug delivery of Ach through iontophoresis. 20 µA current was applied for 210 seconds for the Ach protocol. Baseline recording (60 s) was then performed on the SNP electrode, and then, a cathodal current (20 µA) was applied for 400 seconds to deliver SNP (42). These protocols did not induce nonspecific vasodilatory effect when current was applied with the diluent in the absence of drugs, as previously reported (33). To test for the assumption of normality, skewness and Shapiro–Wilk statistics were performed on both the Ach and SNP protocols. For the Ach protocol, the skewness statistic was 0.407 (n = 16) and the Shapiro–Wilk statistic was 0.970 ($P > .05$). The intraclass correlation (n = 16) for the Ach protocol was .48 ($P \leq 0.1$), with a coefficient of variation of 5.8%. For the SNP protocol, the skewness statistic was −0.176 (n = 16) and the Shapiro–Wilk statistic was 0.938 ($P > .05$). The intraclass correlation (n = 16) for the SNP was 0.65 ($P \leq .05$), with a coefficient of variation of 7.2%.

The progression curves obtained showed blood perfusion in perfusion units (PUs) as a function of time allowing the determination of the peak perfusion (highest perfusion value observed in PU), the average perfusion (mean perfusion from start to end, in PU), and the area under the curve (AUC) as an estimate of the full perfusion. The relative cutaneous vascular conductance (CVC in PU per millimeter of mercury) was calculated as the flow in PU average perfusion divided by the mean arterial pressure. Percentages of changes from baseline were also calculated for the peak and average perfusion values (PU%).

To determine whether the GAP alters the kinetics of ED- and EI-driven cutaneous vasodilation, the perfusion curves were fitted with quadratic models using data points from 18 children. The progression curves for ED and EI were modeled using quadratic ($y' = a(x^2) + b(x) + c$) equation, then used to estimate the rate of change in ED- and EI-induced vasodilation. The coefficient a (COFFa) represents the rate of blood flow rise in the early stage of vasodilation; b (COFFb) represents the rate of blood flow change in the later stage of vasodilation. The goodness of the curve fitting procedures is determined by the R^2 and standard error of estimate.

Statistical Analysis and Data Treatment

Descriptive statistics are expressed as mean (SD). Health-related fitness and vascular function parameters pre and post the GAP program were compared with paired *t* tests with a $P \leq .05$. Quadratic curve fitting models were performed using SPSS (version 24) to generate coefficients (COFFa and COFFb), and constants (c). The EI and ED curve fitting data (coefficients and constants) were compared before and after the GAP program using paired *t* tests. COFFa and COFFb were used to predict the average rate of perfusion (PU·10 s^{-1}, for Ach and SNP fitted curves). Two approaches were used to investigate the efficacy of the quadratic equation modeling on the time course of microvascular perfusion following a GAP program. The first approach referred here as interindividual analysis, aimed to assess the interindividual variation in the time course of microvascular perfusion by combining perfusion values from all children (n = 18). This approach generated average curves for pre-GAP and post-GAP ED and EI iontophoresis protocols. In a second approach, referred here as intraindividual analysis, quadratic curves were generated for pre-GAP and post-GAP perfusion values for each child to assess intraindividual variation in the time course of microvascular perfusion.

To compare the level of PA and the microvascular variables, studied children were divided on tertials based on their EE and the average perfusion measured post-GAP program. The first tertial was defined as "low," the second tertial as "medium," and the third tertial as "high." Cut-offs were for EE, low ≤151.5 kcal·55 min^{-1}, medium (151.6–205 kcal·55 min^{-1}), high ≥205.1; for EI perfusion expressed as percentage of baseline, low ≤147.2, medium 147.3–255.6, and high ≥255.7; and for ED perfusion expressed as percentage of baseline, low ≤161.6, medium 161.7–286.6, and high ≥286.7. The χ^2 statistic (chi-square – [Fisher exact test]) was performed on tertials for EEs and vascular variables to assess the association between PA and vascular function following a GAP program using $P \leq .05$. Cramer *V* was used to test the strength of the relationship between PA and vascular function variables. SPSS (version 24) software was used to perform these analyses, and *P* values (≤.05) were considered as significantly different.

Results

Children recruited for the study participated to a summer camp organized by the Center for Spanish Speaking People who provide programs in an underserved health services community in a North American city. Children (n = 18) included in the study participated in 86% of the GAP sessions, with participation ranging from 78% to 100%. Children who engaged in the self-paced GAP program spent on average a total of 556 ± 132 kcal·week^{-1}, with no statistical differences reported among weekly values of 586 (37) kcal·week^{-1} (week 1), 649 (44) kcal·week^{-1} (week 2), 475 (99) kcal·week^{-1} (week 3), 483 (143) kcal·week^{-1} (week 4), and 588 (16) kcal·week^{-1} (week 5; $P > .05$). Throughout the entire GAP program, the PA intensity was 34.7 (7.5) %MVPA with weekly averages of 33.0 (4.1) %MVPA (week 1), 31.1 (8.2) % MVPA (week 2), 33.3 (6.3) %MVPA (week 3), 34.2 (9.8) % MVPA (week 4), and 41.7 (7.1) %MVPA (week 5; $P > .05$). Throughout the entire GAP program, sedentary (stationary) time averaged 12.7% (5.1%) ranging from 9.2 (1.8) %Sed (week 5) to 16.2 (7.8) %Sed (week 3; $P > .05$). GPA EE and percentage of MVPA between boys and girls (n = 11 for boys and n = 7 for girls) were not different ($P > .05$).

The 5-week GAP program led to significant decreases in DBP and rHR by 5 mm Hg and 8 beats per minute, respectively (Table 1, $P \leq .05$). The program did not alter the anthropometric and musculoskeletal fitness of children (Table 1). Height, body mass, body mass index, combined grip strength, and vertical jump height remained unchanged after the 5 weeks of GAP ($P > .05$, n = 18). Following the 5-week GAP program, SBP, mean arterial pressure, and estimated VO_2max also remained unchanged ($P > .05$, Table 1).

Baseline measures of cutaneous blood perfusion remained identical throughout the GAP for both our ED and EI protocols (Table 2, n = 18, $P > .05$). The GAP had no effect on ED microvascular function (Table 2, $P > .05$ for peak perfusion, average perfusion, and AUC). Data expressed as percentage of baseline remained unchanged for peak and average PU after GAP (Figures 1A and 1C).

In our EI protocol, the 5-week GAP increased the average perfusion and AUC by 36.8% and 28.8%, respectively (Table 2, $P \leq .05$). When data were expressed as percentage of baseline, average PU% was significantly greater by 59% post-GAP ($P \leq .05$), yet peak PU% was not impacted by the GAP (315.02% [206.4%] vs 394.7% [203.6%], pre-GAP and post-GAP, respectively, $P > .05$, Figures 1B and 1D).

For ED, the average CVCs remained identical (Table 2, pre-GAP and post-GAP, respectively, $P > .05$). For EI, the average CVC was increased by 30% (Table 2, pre-GAP and post-GAP, respectively, $P = .05$), showing a significant increase. Peak CVCs were unmodified by the GAP program for both ED and EI protocols (for ED, peak CVCs were 4.0 [1.3] PU·mm Hg^{-1} vs 4.0 [1.2] PU·mm Hg^{-1}; pre-GAP and post-GAP, respectively, $P > .05$). For EI, the peak CVCs were 3.7 (1.9) PU·mm Hg^{-1} and 4.6 (1.6) PU·mm Hg^{-1} (pre-GAP and post-GAP, respectively, $P > .05$).

The interindividual analysis of the perfusion curves represented in Figure 2 showed that a faster pace of rise during the early phase of EI vasodilation (+40%, 2.10 vs 1.25 PU 10 s^{-1}, pre-GAP vs post-GAP program, $P \leq .05$). At the plateau phase of vasodilation, the perfusion decreased at a faster pace after the GAP program (–1.18 PU 10 s^{-1}) compared to the start of the program (–0.27 PU 10 s^{-1}; $P \leq .05$). In contrast, ED vasodilation was slower in the early phase (1.41 PU 10 s^{-1}) after the GAP program compared to the start of the program (2.09 PU 10 s^{-1}; $P \leq .05$, Figure 2). In addition, the plateau phase for ED was slower after the GAP program compared to the start (–0.44 vs –1.17 PU·10 s^{-1}; $P \leq .05$, Figure 2).

The intraindividual analysis of EI perfusion curves revealed that COFFa (ie, early phase of vasodilation) and COFFb (ie, late phase of vasodilation) were significantly different for post-GAP

Table 1 Children's (n = 18) Anthropometric, Musculoskeletal Fitness, and Cardiovascular Responses to a 5-Week (4 d/wk; 1 h/d) GAP (n = 18)

	PRE	POST
Age, y	9.8 (1.5)	9.9 (1.4)
Height, cm	137.8 (10.5)	139.2 (10.6)
Body mass, kg	38.3 (10.2)	40.1 (10.2)
Body mass index, kg·m^{-2}	19.7 (4.3)	20.2 (4.4)
Combined grip strength, kg	30.6 (5.1)	33.5 (7.9)
Vertical jump height, cm	20.0 (5.4)	21.6 (4.8)
Mean arterial pressure, mm Hg	75 (7)	72 (4)
Systolic blood pressure, mm Hg	99 (10)	98 (8)
Diastolic blood pressure, mm Hg	64 (8)	59 (5)*
Pulse pressure, mm Hg	34 (12)	39 (10)
Resting heart rate, bpm	84 (17)	76 (12)*
Estimated VO_2max, mL·kg^{-1}·min^{-1}	46.8 (5)	47.8 (5)

Abbreviations: GAP, guided active play; POST, after; PRE, before; VO_2max, maximal oxygen consumption. Note: Measurements were obtained in the first (PRE) and last (POST) weeks. Anthropometric variables include age, height, body mass, and body mass index. Musculoskeletal fitness variables include combined grip strength and vertical jump height. Resting blood pressure and heart rate measurements were taken in a reclined position following 15 minutes of rest. Oxygen consumption levels were estimated from the Leger 20-m shuttle run test (estimated VO_2max). Data are presented as means (SDs).
*Significant differences compared to PRE, $P \leq .05$.

Table 2 Microvascular Characteristics of Children PRE and POST Participating in a 5-Week (4 d/wk; 1 h/d) GAP (n = 18)

ED (Ach)	PRE	POST
Baseline, PU	62.4 (22.5)	58.2 (27.1)
Peak, PU	309.5 (88.4)	286.8 (88.4)
AUC	40.521 (13,774)	37.599 (13,111)
Average, arbitrary unit	203.5 (70.3)	182.8 (64.0)
Average, % of baseline	250.7 (143.0)	268.6 (196.8)
Average CVC, PU·mm Hg^{-1}	2.3 (0.8)	2.3 (0.7)
EI (SNP)	**PRE**	**POST**
Baseline, PU	69.8 (25.3)	72.6 (29.0)
Peak, PU	274.4 (135.2)	271.2 (109.7)
AUC	63,896 (28,695)	82,305 (33,486)*
Average, arbitrary unit	154.7 (68.9)	211.2 (86.0)*
Average, % of baseline	134.9 (106.5)	214.4 (126.9)*
Average CVC, PU·mm Hg^{-1}	2.0 (1.1)	2.6 (1.0)*

Abbreviations: Ach, acetylcholine; AUC, area under the curve; CVC, cutaneous vascular conductance; ED, endothelial-dependent vasodilation; EI, endothelial-independent vasodilation; GAP, guided active play; POST, after; PRE, before; PU, perfusion units; SNP, sodium nitroprusside. Note: Perfusion parameters including baseline, peak, and average (raw and percentage of baseline) and total AUC were measured during Ach stimulation, that is, ED protocol, and SNP stimulation, that is, EI protocol. Data are presented as means (SDs) (n = 18).
*Significant differences compared to PRE, $P \leq .05$.

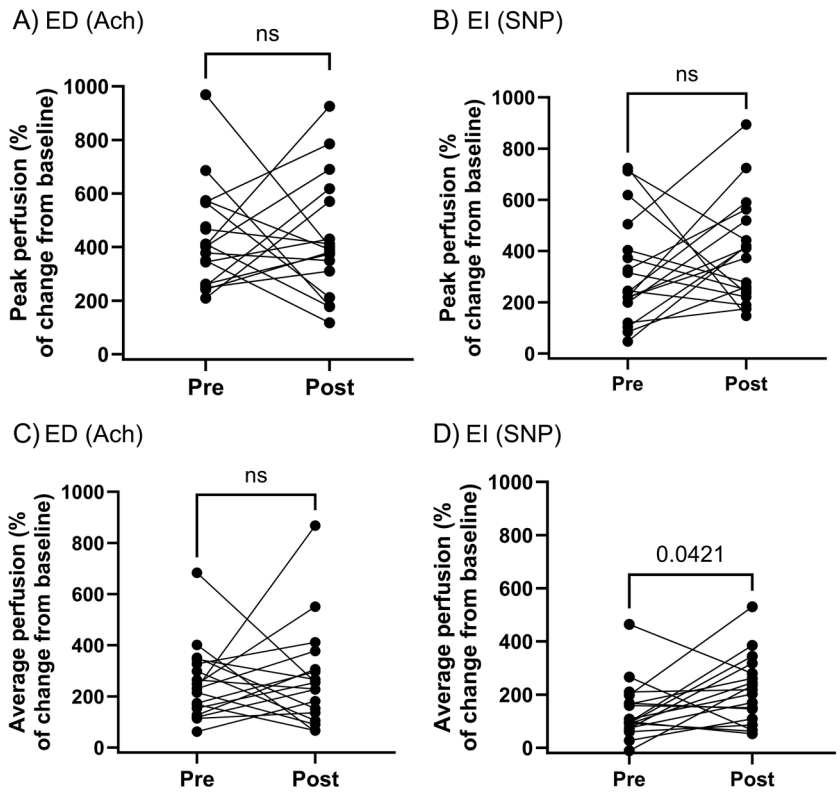

Figure 1 — Children cutaneous forearm perfusions PRE and POST a 5-week self-paced GAP program expressed as a percentage from baseline. A–B shows peak perfusion, and C–D shows average perfusion, measured during the Ach protocol testing ED (A and C) and during the SNP protocol testing EI (B and D). *Significant differences ($P \le .05$) between PRE and POST (n = 18). ns indicates nonsignificant difference ($P > .05$). Ach indicates acetylcholine; ED, endothelial-dependent vasodilation; EI, endothelial-independent vasodilation; GAP, guided active play; POST, after; PRE, before; SNP, sodium nitroprusside.

versus pre-GAP ($P \le .05$; Table 3), confirming GAP's impact on EI vasodilation. The analysis of intraindividual ED perfusion showed minimal differences for COFFa and COFFb between pre-GAP and post-GAP program (Table 3, $P > .05$).

The association between PA (ie, weekly EE in kilocalories per 55 min) and microvascular functions (ie, average perfusion for ED and EI protocols) both classified into tertials (low/medium/high) was assessed. The EI microvascular function measured by average perfusion post-GAP program showed a strong association with the amount of PA assessed occurring throughout the program assessed by EE (in kilocalories per 55 min). The chi-squared analysis reported a χ^2 of 8.88 (4, n = 18; $P \le .05$) and a Cramer V of 0.64 between the EE (in kilocalories per 55 min) levels and EI average levels during the final week of the GAP program. Crosstabulation analysis revealed that children with high levels of PA (EE > 205.1 kcal 55 min^{-1}) were overrepresented (by 90%) in the medium EI group ($P \le .05$), whereas children classified as low PA (EE ≤ 151.5 kcal 55 min^{-1}) were overrepresented (by 60%) in the low EI group post-GAP ($P \le .05$). The chi-square and crosstabulation analyses of the associations between for PA and ED average perfusion levels classified as low, medium, and high during the final week of the GAP program were not significant ($P > .05$).

Discussion

The findings of this study demonstrate that a community-based 5-week self-paced GAP program increased the cutaneous microvascular function in children aged 8–12 years. During the GAP sessions, children achieved an average weekly EE of 556 kcal·$week^{-1}$ and spent 34% of their active time at a level of PA that was moderate or vigorous, which significantly reduced their rHR and DBP. After GAP, children's cutaneous EI microvascular functions appeared improved, as shown by the increases in peak and average perfusions in the SNP protocol. A close analysis of the microvascular perfusion curves confirmed that a faster pace of EI vasodilation after GAP. Children who had the greatest level of PA during the GAP had the greatest positive changes in EI vasodilation. Indeed, we reported here a significant association between PA participation estimated by EE and changes in EI vasodilation. In contrast, ED microvascular function assessed by Ach was not impacted by GAP with no change in peak and average perfusions. In summary, community-based GAP programming may be an effective strategy for improving diastolic blood pressure and increasing EI microvascular functions for normal weight children.

The EE achieved by children over the 5 weeks of the GAP program was sufficient to elicit improvement in cardiovascular parameters (ie, rHR and DBP). This is consistent with changes reported for children (11.1 y of age) after 5 weeks of structured endurance training at either moderate-intensity continuous training (at 66% maximal HR) and/or high-intensity interval training (at >80% maximal HR) (56). Yet, we did not report any significant improvement in estimated VO_2max and musculoskeletal fitness. While some PA programs of 4 to 7 weeks of duration that were based on either continuous endurance training or on high-intensity

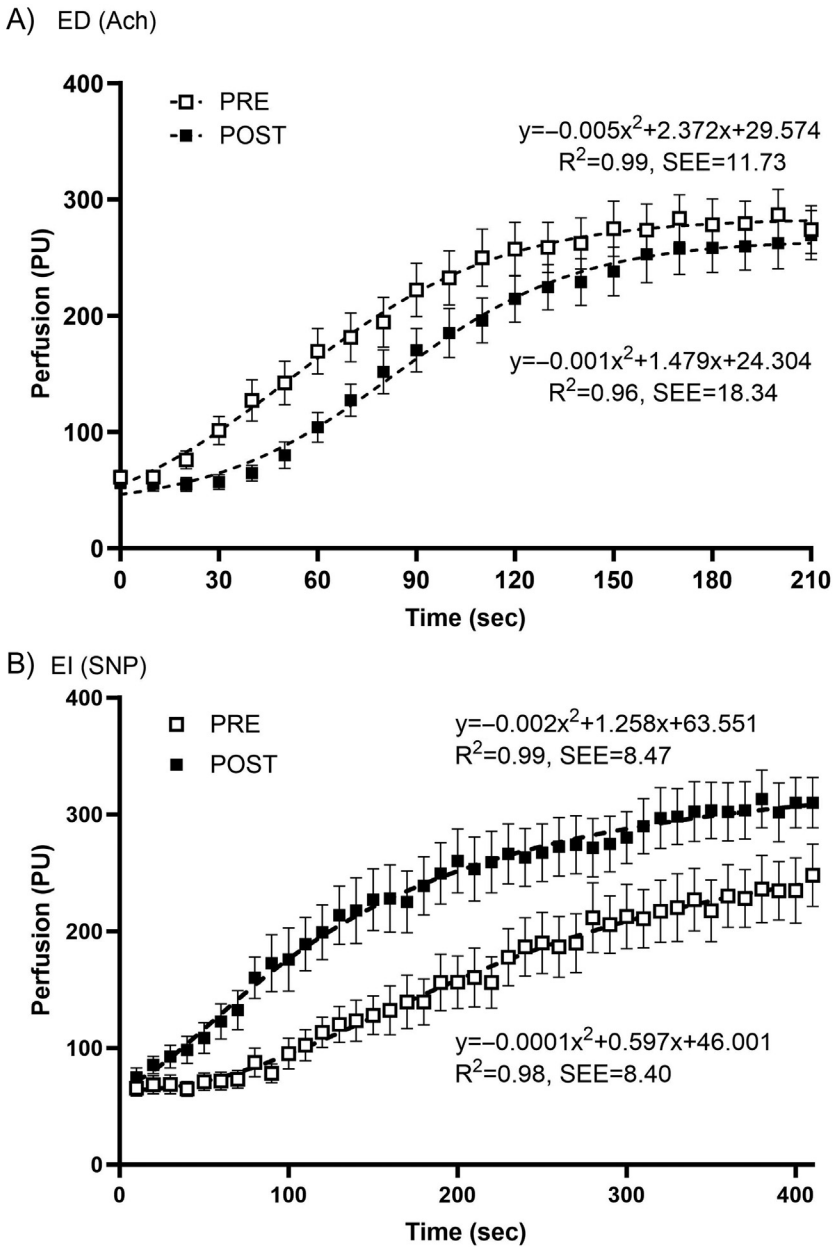

Figure 2 — Quadratic equations for the average perfusion curves for Ach protocol testing ED (A) and for SNP protocol testing EI (B) measured PRE (□) or POST (■) the 5-week guided active play program. Data show mean (SD), n = 18. Ach indicates acetylcholine; ED, endothelial-dependent vasodilation; EI, endothelial-independent vasodilation; POST, after; PRE, before; SNP, sodium nitroprusside.

interval aerobic training (>86% of maximal HR) reported increases in VO_2max by 4% to 7% and decreases in waist circumferences (3,8,27), shorter 4-week school-based aerobic training intervention led to no changes in body composition, grip strength, and leg power in healthy normal weight children (45,49). It is plausible that the short duration of the GAP program used in this study partly explains the lack of improvement in health-related fitness parameters.

The blood pressure (BP) reported is in the normal range for children aged 8 to 10 years, and the significant decrease in DBP observed corresponds to a change from the 60th percentile pre-GAP to the 45th percentile post-GAP (54), both still in the healthy range. This observation complements other studies that observed a period of 8 weeks of GAP significantly reduced both SBP and DBP (4). It is important to note in the current study that the children are normal weight. The mechanisms leading to hypertension in leaner children might be different than that of overweight and obese children (2). Indeed, studies consistently report that isolated elevation of DBP is more frequent in leaner children and thus potentially more likely to improve with an exercise intervention. While isolated systolic hypertension, where only SBP is high, is the most common form of hypertension in overweight and obese children (2,7,24), isolated elevation of DBP during childhood can have negative cardiovascular outcome later in life (30). Therefore, the lowering of DBP observed after this GAP program might help prevent isolated diastolic hypertension in normal weight children.

Here, we have shown that EI microvascular reactivity was modified at the end of our 5-week GAP program (see changes

Table 3 Assessing the Rate of Vasodilation for ED and EI Protocols Using Quadratic Curve Fitting Model [$y' = a(x^2) + b(x) + c$]

Variable	PRE	POST
ED (Ach)		
R^2	0.92 (0.04)	0.87 (0.12)*
SEE	23.7 (12.9)	28.1 (15.6)
COFFa (rise phase)	1.78 (1.02)	1.83 (0.61)
COFFb (plateau phase)	–0.91 (1.14)	–0.97 (0.69)
Constant	10.24 (37.57)	7.00 (35.87)
EI (SNP)		
R^2	0.89 (0.06)	0.92 (0.03)
SEE	21.2 (15.0)	23.2 (8.3)
COFFa (rise phase)	1.09 (0.78)	1.63 (0.9)*
COFFb (plateau phase)	–0.17 (0.81)	–0.74 (1.03)*
Constant	42.55 (32.34)	33.46 (36.28)

Abbreviations: Ach, acetylcholine; COFF, coefficient; ED, endothelial-dependent vasodilation; EI, endothelial-independent vasodilation; POST, after; PRE, before; SEE, standard error of estimate; SNP, sodium nitroprusside. Note: COFFa represents the early (rise) phase of vasodilation. COFFb the later (plateau) stage of vasodilation. Differences in children's (n = 18) coefficients (COFFa and b) and constants were compared before (PRE) and after (POST) a 5-week self-paced guided active play program. An assessment of the fit of the quadratic model, using the variability accounted for (R^2) and SEE, was included for both ED and EI conditions measured at PRE and POST of the guided active play program.
*Significant differences ($P \leq .05$).

reported in Table 2 and Figure 1). By modeling the perfusion curves using quadratic equations, we have shown that our self-paced GAP format promoted a faster cutaneous reactivity to SNP. While a significant gap of knowledge remains regarding whether regular PA modulates the cutaneous microvascular blood flow in prepubertal healthy normal weight children, previous studies led us to expect an improvement in the endothelial function. In young adults, clinical or laboratory exercise training has been reported to increase endothelial function (17), including cutaneous endothelial microvascular function without changing the EI function (60). Long-distance runners aged 26 years are a greater ED response but retained similar EI response than aged-matched healthy adults (26). And, studies performed on obese children who engaged in clinical or laboratory PA programs reported no change in microvascular EI function while reporting improved ED function in type 2 diabetic children (44,58). An improved and faster EI reactivity remains difficult to explain. Yet, a recent meta-analysis study has reported that exercise training could improve the EI function in adults, with vigorous aerobic exercise and mixed modality of exercise being most efficient in promoting this improvement (32). Play might be an efficient way to provide children with a mixed modality of PA, possibly sufficient to enhance their EI-cutaneous microvascular reactivity.

Our findings show that during GAP children with higher levels of PA (>205 kcal·55 min^{-1}) and spending at least 35% of their active time at MVPA showed improved microvascular function. Clinical and laboratory studies identified that the more time or energy expended performing PA at more vigorous effort, the greater the improvement in ED function for healthy children measured by flow-mediated dilation of the brachial artery (13,20). Our data show that fun-focused, self-paced GAP can elicit sufficient PA levels to enhance the EI function in the cutaneous microcirculation. Although the mechanism(s) underlying these results were not directly investigated, the improvement in EI function could be due to improved neural and myogenic controls of cutaneous blood flow (14). The status of children's health-related quality of life (ie, psychosocial functioning and mental well-being) impacts their microvascular retinal structure and, possibly, vascular function (15). Repeated bouts of increased psychosocial stress (over 8 d) are associated with increased microvascular constriction in response to sympathetic adrenergic stimulation in young adults (16). A previous study reported a reduction of children's psychosocial stress, improved psychosocial functions, and/or increased PA enjoyment for children participating in a GAP program (4). By providing self-paced and fun-focused play, GAP could reduce the level of stress during activity, resulting in better microvascular function (14). The findings in this study raise the importance of play-based PA, which is characteristic of children's movements and PA behaviors, in studying the influence of PA on microvascular smooth muscle function during childhood development. Ascertaining whether GAP impacts the EI microvascular function through increasing enjoyment and psychological well-being remains unknown and will require further investigation.

The current study has some limitations that may have influenced our results regarding the impact of PA participation on children's microvascular functions. First, there are limitations that are inerrant to the community-based setting. While children were familiarized with the research team, it was not possible to arrange a familiarization session before the first microvascular measures. The possibility that children's familiarity with the setting during the postmicrovascular measurements may have contributed to lowering psychological stress cannot be excluded. Our analyses could have benefited from a larger number of participants, for both boys and girls, and including a nonexercising control group. These limitations together with data collection only occurring before and after the 5-week GAP program did not allow us to follow the changes in ED and EI microvascular function on a weekly basis. Despite being unable to track children's PA outside of the summer camp, our experimental setting ensured that premeasurements preceded the attendance of the first GAP session for all children and postmeasurements were acquired at least 4 days after the last GAP session attended by the child ensure we could efficiently assess the chronic impact of GAP on children microvascular function. However, study designs used in "real-world" settings, such as community center summer day camps, are challenging and often associated without the benefits of a control group with the naturally emerging situations requiring use of quasi-experimental study designs. Although this approach may comprise the generalizability of our results, we view these results as exploratory and serve as a "proof-of-concept" for children's play-based studies.

Second, blood pressures were not recorded throughout the activity protocol, but rather at the start and end of the assessments. Our estimates of the CVCs are then based on the hypothesis that blood pressure remained constant throughout the protocol from baseline to plateau. This might have limited our capacity to detect changes in conductance induced at peak perfusion for both protocols (Ach and SNP) and with the average perfusion for the Ach protocol.

A third limitation is the use of a LDPI system that has different specifications than most commonly used Laser Speckle Contrast Imager. The depth of analysis of the LDPI used here is around 1 mm, collecting cutaneous blood flow more than twice as deep as in the dermis compared to what is most commonly used (22,44,57,58). Arterioles and venules become more abundant deeper in the dermis (6). Using this LDPI system, our analyses might collect blood flow from more arterioles and venules than Laser Speckle Contrast Imager-based studies. In our experimental conditions, we collected

10 images per minute which is about 60× less than Laser Speckle Contrast Imager system. Therefore, it might have impaired our capacity to accurately detect peak values. Despite these technical limitations, we were still able to detect a faster response to SNP, greater values of average perfusion, and AUC after GAP.

Finally, it is plausible that the most active children in the session were also active outside of the GAP. Active or fit children might have had greater microvascular functions than less active children at the start of the program, therefore having a smaller reserve for improvement of their endothelial microvascular function than less active children. Although the history of PA participation was not obtained, the relationships between aerobic capacity and microvascular function were not different at the start of the summer camp (data not shown). Furthermore, the length of the GAP program was 5 weeks compared to other studies performed on children that used longer training program and was combined with dietary interventions (12,44). Additionally, these clinical or laboratory studies were performed on children with comorbidities, obesity, and type 2 diabetes (12,44). In our study, children are healthy and normal weight children.

Conclusions

Our present work shows that a reduction in resting DBP and HR occurs in response to a 5-week GAP program with children, before any other cardiometabolic parameters become observable. These changes are associated with a faster increase in cutaneous microvascular blood flow and an increased average CVC after SNP stimulation, suggesting an enhanced smooth muscle vasoreactivity (EI). To date, most clinical or laboratory studies have investigated the impact of PA programs in children with comorbidities (ie, obesity and type 2 diabetes), showing an improvement of the endothelial function (ED) in response to lifestyle (PA and dietary) interventions. Our current work highlights the need to perform studies that are reflective of a child's more natural movement behaviors (fun, self-paced, and allowing for child autonomy) to better understand how microvascular blood flow is controlled and can be improved, in healthy and normal weight children. This might bring new insight into the mechanisms of physiological regulation of blood pressure in prepubertal children.

PA is a behavior, and in order to improve health it needs to be consistent, by providing children a fun interactive way to play they are more likely to participate because children are motivated through enjoyment. The GAP program using cooperative games is inclusive and provides an opportunity for children to be active, have fun, and be socially interactive. These attributes are especially important for children in underserved communities who may not be able to afford extracurricular sports and activities. Future directions should focus on the role and impact of GAP in a variety of environmental settings (ie, community, school, urban, and rural), psychological status (ie, depression and anxiety), and physical disabilities to determine the relevance and usefulness of GAP in supporting children's developmental trajectories for improving their health and fitness.

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