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In 6- to 8-year-old children, cardiorespiratory fitness moderates the relationship between severity of life events and health-related quality of life

Markus Gerber[1] · Katharina Endes[1] · Serge Brand[1,2] · Christian Herrmann[1] · Flora Colledge[1] · Lars Donath[1] · Oliver Faude[1] · Henner Hanssen[1] · Uwe Pühse[1] · Lukas Zahner[1]

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Abstract
Purpose In children, the pathways by which physical activity and fitness are associated with physical and psychological wellbeing are still not fully understood. The present study examines for the first time in young children whether high levels of cardiorespiratory fitness and physical activity moderate the relationship between severity of life events and health-related quality of life.
Methods Three hundred and seventy-eight children (188 girls, 190 boys, $M_{age} = 7.27$ years) participated in this cross-sectional study. Parental education, gender, age, severity of life events, health-related quality of life and physical activity were assessed via parental questionnaires. Cardiorespiratory fitness was assessed with the 20 m shuttle run test. Hierarchical regression analyses were used to test whether physical activity and fitness interacted with critical life events to explain health-related quality of life.
Results When exposed to critical life events, children with higher fitness levels experienced higher levels of psychological wellbeing, relative to their less fit peers. On the other hand, children with higher fitness levels experienced higher physical wellbeing and more positive friendship relationships when severity of life events was low. A similar moderation effect was found for physical activity with overall quality of life as outcome.
Conclusions Recent stressful experiences alone were not sufficient to explain negative health outcomes in young children. Children with low cardiorespiratory fitness levels experienced lower psychological wellbeing when they were exposed to critical life events. More research is needed to find out whether similar findings emerge with objective physical activity measurements and when critical life events are assessed over longer periods of time.

Keywords Everyday functioning at school · Family · Friends · Wellbeing · Self-esteem · Shuttle run test

Introduction

In children, regular physical activity and high fitness levels are associated with good physical and psychological wellbeing [1, 2]. To illustrate, a study with 502 Swiss primary school children showed that low physical activity levels were associated with poorer self-reported health, and increased fear of negative social evaluation [3]. Moreover, children reporting higher outdoor physical activity were more likely to self-report good health in a large cohort of Japanese youth [4]. Results from the Spanish National Health Surveys 2006 and 2011/2012 revealed that parents rated their children's health more highly when the children engaged in regular physical activity [5]. Additionally, increased school-based physical activity has the potential to positively impact on psychosocial quality of life in primary school children [6].

Despite this evidence, the pathways by which physical activity and fitness are associated with physical and psychological wellbeing are still not fully understood in young children, as defined as between 4 and 10 years of age. Four mechanisms have been posited. First, regular physical activity leads to favourable structural and functional neuronal adaptations [7]. Second, regular physical activity

✉ Markus Gerber
markus.gerber@unibas.ch

[1] Department of Sport, Exercise and Health, University of Basel, Birsstrasse 320B, 4052 Basel, Switzerland

[2] Psychiatric Clinics of the University of Basel, Center for Affective, Stress and Sleep Disorders, Basel, Switzerland

leads to increased fitness and thus to improved vascular and metabolic function [8]. Third, relative to children with low physical activity, children with high physical activity report higher self-esteem, stronger friendships with peers, and improved social resources [9]. Fourth, physical activity and cardiorespiratory fitness may have particularly positive health effects in children who are exposed to high levels of stress, which is also labelled as the stress-buffering hypothesis [10, 11]. While the stress-buffering hypothesis has largely been investigated in adults, fewer data are available for adolescents, and, surprisingly, no research has focused on young children. The first aim of the present study was therefore to examine whether physical activity and cardiorespiratory fitness moderate the relationship between severity of life events and health-related quality of life in 6- to 8-year old children.

While childhood stress can be defined as any situation that requires children to adapt or change, stressful experiences frequently refer to negative situations, and include acute traumatic events (e.g. natural and human disasters), chronic strain and adversity (e.g. poverty, personal or parental chronic illness), common, developmental stressors of daily life (e.g. being left out of the group, parents fighting), as well as the accumulation of stressful life events. Stressful life events comprise both normative (e.g. transition to a higher school level) and non-normative events (e.g. death of a loved person, parental divorce) [12]. In the present study, a special focus will be placed on non-normative critical life events. In young children, a definition of stress relying on cognitive appraisal processes was deemed less optimal due to children's limited capacity to perform cognitive appraisals of stressful life situations. This approach accords well with Grant et al.'s [12] claim that a definition of stress in young children should focus on external, environmental changes or conditions that "objectively threaten the physical and/or psychological health or wellbeing of individuals of a particular age in a particular society" (p. 449).

As regards the stress-buffering hypothesis, the preventive role of physical activity and cardiorespiratory fitness has generally been supported in adult populations. A systematic review with more than 30 original studies supported the notion that regular physical activity or high fitness levels protect against the negative consequences of stress, as measured by a variety of health outcomes [10]. Stress-buffering effects of physical activity and cardiorespiratory fitness were also found in younger populations such as 11–18 years olds [13–20]. For instance, in a sample of 220 14-year-old female adolescents, Brown and Lawton [16] demonstrated that exposure to negative life events was associated with poorer self-reported health among those with infrequent exercise habits, but not among regular exercisers. These findings were supported in a 9-month longitudinal study with 344 adolescents, showing that the negative impact of stressful life events on health increased with decreasing exercise participation [17]. Further, in a sample of 1670 participants aged 11–16 years, Haugland et al. [19] demonstrated that high perceived school-related stress was associated with considerably more psychosomatic complaints among youngsters with low leisure time physical activity levels, compared to their more active peers. However, no support for this result was found in a sample of Swiss secondary students [21]. In spite of this, in a representative sample of 7232 Icelandic adolescents, Sigfusdottir et al. [20] showed that among girls who experienced high family conflict, those with high physical activity levels reported lower levels of depressive symptoms than their less active peers.

In summary, previous studies with older children, adolescents and adults generally supported the stress-buffering hypothesis [10], although no studies exist showing that the stress-buffering hypothesis can be generalized to children below the age of 10 years. This lack of research is surprising for a number of reasons. First, the prevalence of psychosomatic symptoms has increased among young children over the past decades [22]. This is critical because such symptoms are characterized by a high temporal stability [23]. Second, stress constitutes a recognized public health issue as early as in childhood [24]. For instance, Grant et al. [25] emphasized that stress plays a prominent role in most theories of child psychopathology [26]. Moreover, following Copeland et al. [27], at least two of three children will have experienced one or more potentially traumatic events by the age of 16 years. Third, because children have few experiences in dealing with stress and because childhood is a period of constant physical and psychological development [28], stressful life experiences pose a potential threat for children's physical and psychological wellbeing [12]. Thus, while mild stress can be beneficial and trigger learning experiences, too much stress can be dangerous and harmful [29]. Meanwhile, a plethora of studies have shown that children with higher total stress report more depressive and psychosomatic symptoms [30, 31]. Childhood stress was also negatively associated with health-related outcomes in later life [32], although the underlying mechanisms are not yet fully understood [33].

Given this background, the main purpose of the present study was to expand upon previous research and to explore whether in 6–8 year old schoolchildren, high levels of cardiorespiratory fitness and physical activity moderate the relationship between severity of life events and health-related quality of life. Based on the majority of existing studies with adolescents [15–17, 19, 20], we hypothesized that young children with higher cardiorespiratory fitness and physical activity levels would experience higher quality of life than their less fit or active peers if they are exposed to critical life events.

Methods

Study design

The current study was designed as a large scale, cross-sectional survey. All first-grade students of public primary schools in the canton Basel-Stadt, Switzerland who entered primary school in August 2013 were eligible for this study. The data assessment took place in February–May 2014 (approximately 7–10 months after school entry). The original goal of this study was to monitor cardiorespiratory fitness, body composition, back health and retinal microvascular health in first-grade primary schoolchildren (papers related to these variables have been published previously; briefly, these papers suggest that systolic and diastolic blood pressure are main determinants of retinal arteriolar diameters [34], that objectively measured endurance performance is related to improved retinal vessel health [35], and that socioeconomic background is associated with cardiorespiratory fitness levels and body composition in early childhood [36]). Ethical approval was obtained from the ethics committee of the University of Basel (EKNZ, Basel, No. 258/12), and all study participants and their families provided informed consent. Parents and legal guardians provided consent in written form, and children in verbal form.

Participants and procedures

Weight and height were assessed in 1255 children (96% of the eligible population, $N = 1302$ children) by a trained research assistant during a physical education lesson. The second author (KE) was responsible for the recruitment and instruction of the research assistants. Altogether, 15 assistants were involved in the medical tests and the assessment of physical fitness. All assistants had to pass a test (supervised by the second author) before they were allowed to take part in the data assessment. Body height was measured with a wall-mounted stadiometer, whereas body weight was assessed with an electronic scale, in light clothing and without shoes. The parents of 540 of these children (43%) gave permission for their children to participate in additional tests encompassing cardiorespiratory fitness, physical activity, psychosocial stress, blood pressure and retinal vessel diameters. A total of 149 children dropped out due to illness or other reasons at one of the two test dates. Therefore, the final sample of children participating in the fitness test measurements was $n = 391$. Teachers and parents were informed in advance about the study and its objectives. Parents provided information about children's critical life events and health-related quality of life by written questionnaire. Questionnaires for 12 children were not obtained. Thus, 378 children (188 girls, 190 boys, $M_{age} = 7.27$ years, $SD = 0.35$, range: 6–8 years) had complete data sets. None of the children included in the analysis took medication or supplementation.

Measures

Gender, age, critical life events, several dimensions of health-related quality of life, and parental education levels were assessed via a parental questionnaire. Parental educational level was operationalized with the highest completed school level resulting in an index ranging from 1 (low = only one parent with vocational training, but no tertiary education) to 3 (high = both parents with tertiary education). The parental questionnaire was completed in the same week as the assessment of cardiorespiratory fitness, blood pressure and retinal vessel diameters took place.

Critical life events

Parents filled in a 16-item adapted version of the Life Events Checklist (LEC) by Johnson and McCutcheon [37], to assess critical life events experienced by their children over the past three months. Examples of critical life events to self or significant others are: death of a loved one, illness or accident of a loved one, divorce/separation of parents, father/mother lost job. This list is not intended to be exhaustive, but rather to provide a sample of significant life events common during childhood [38]. Parents rated the impact of each event on their children's life, using a 4-point scale ranging from 0 (no impact) to 3 (large negative impact). The mean influence of all negative events was calculated as a severity indicator. Thus, children with few life events with a strong influence had higher scores compared to subjects with several but moderate life events. The LEC has been used previously in child stress research [39], and prior studies have shown that this instrument has adequate test–retest reliability over a two-week period ($r = .72$) [40].

Health-related quality of life

The 24-item KINDL-R questionnaire [41] was used to assess children's health-related quality of life. Parents were asked to respond on a 5-point Likert scale from 1 (never) to 5 (all the time). All items started with the anchor: "During the past week…" The resulting subscales are labelled: physical wellbeing (e.g., "my child felt strong and full of energy"), psychological wellbeing (e.g., "my child had fun and laughed a lot"), self-esteem (e.g., "my child was proud of himself"), family (e.g., "my child got on well with us as parents"), friends (e.g., "my child got along well with his friends"), and everyday functioning at school (e.g., "my child easily coped with schoolwork"). Each of the KINDL-R subscales consists of four items. Previous research has shown that all subscales have a high degree of reliability and satisfactory convergent validity. Moreover, the acceptance of the measure is high both among children and parents [41, 42]. Negatively poled items were recoded before computing the overall index and the subscale scores, so that higher scores reflected increased quality of life throughout all dimensions. To ensure comparability with norm values, items were converted into indices ranging from 1 to 100 [43]. The internal consistency of the KINDL-R was comparable to the German validation study [43], with an alpha of .77 for the overall index.

Cardiorespiratory fitness

The 20 m shuttle run test was used to assess children's fitness. The test was carried out during a physical education lesson, and was administered by a trained research assistant (with academic background in sport and exercise science). Since the children were not familiar with the protocol, the research assistant explained in detail how the test works and checked whether all children understood the protocol before the test started. A 5-min standardized warm-up was performed before the testing took place. The 20 m shuttle run test provides an estimate of children's endurance performance. Evidence for the reliability, validity, and sensitivity to change of this test has been shown in prior research [44]. During the test, the children run back and forth for 20 m, with initial running speed (8.0 km/h) being increased by 0.5 km/h every minute, paced by beeps on a stereo. If a child was unable to cross the 20 m line at the moment of the beep for two successive 20 m repetitions, the individual maximum was deemed to have been reached and the test ended. The number of stages, with one stage corresponding to 1 min, was counted with a precision of 0.5 stages.

Physical activity

To assess children's physical activity, a previously developed and established single-item proxy measure was used [45]. The parents were asked to interview their child in order to obtain information about vigorous physical activity (defined as time spent in vigorous activities and sport, except physical education lessons, measured in minutes per day). The reference period was the last 7 days. The exact wording of the interview question was: "Over the last 7 days, how many minutes per day did you spend in vigorous physical activities (e.g. sport) that made you out of breath (excluding school physical education)?" Similar proxy measures have been used in other studies with German-speaking samples to assess physical activity levels in young children [46, 47].

Statistical analyses

Sample size calculations were performed to find out how many children were needed to detect small bivariate correlations between cardiorespiratory fitness and health-related quality of life. Using G-Power software for t-tests (one-tailed, $r = .15$, power = .90, 5% alpha error probability), the estimated sample size was 375 children in total.

Descriptive statistics (*M*, *SD*) were calculated to describe baseline characteristics of the sample. Pearson product moment correlations were run to examine (a) how gender, age and parental education were related to the study variables, (b) how the predictor (critical life events), outcome (health-related quality of life), and moderator variables (fitness and physical activity) are correlated with each other. Hierarchical regression analyses were performed to determine whether severity of life events and fitness/physical activity interacted in the prediction of health-related quality of life. In sum, a separate regression model was calculated for each of the seven indicators of health-related quality of life (separately for fitness or physical activity). The variables were introduced in the regression order in the following order: (a) Parental education (only if bivariate correlations with a specific health outcome were significant; see [48, 49]), (b) critical life events, (c) fitness/physical activity, and (d) interaction term between critical life events and fitness/physical activity. Critical life events and fitness/physical activity were centred (by computing *z*-standardized scores) before calculating the interactions to avoid problems associated with multicollinearity [50]. Following the guidelines of the American Psychological Association [51], the following coefficients were displayed in the results section: (i) the multiple correlation coefficient squared R^2 for the whole model after the final step, (ii) stepwise changes in R^2 (ΔR^2), and (iii) the standardized regression weights (β) for each predictor variable (for the final model). In case of significant interaction terms, interaction effects were plotted using procedures as proposed by Dawson [52]. Alpha was set at $p < .05$ across all analyses. All statistical analyses were carried out using SPSS® 23 (IBM Corporation, Armonk, NY, USA) for Apple Mac®.

Results

Descriptive statistics and socio-demographic influences

A summary of the descriptive statistics is provided in Table 1. With regard to severity of life events, the mean score was low ($M = 1.51$, $SD = 2.53$), with values ranging from 0 to 17 (possible range: 0–48). By contrast, the means

Table 1 Descriptive statistics and bivariate correlations between study variables

	M	*SD*	1.	2.	3.	4.	5.	6.	7.	8.	9	10.
1. Critical life events	1.51	2.53	–									
2. Physical wellbeing	81.59	14.67	−.09	–								
3. Psychological wellbeing	84.96	12.54	−.28***	.45***	–							
4. Self-esteem	72.31	15.98	−.10*	.13**	.16**	–						
5. Family	81.34	12.34	−.23***	.13*	.32***	.21***	–					
6. Friends	75.49	13.92	−.13*	.16**	.32***	.30′***	.21***	–				
7. Everyday functioning at school	88.16	11.86	−.08	.16**	.25***	.27***	.07	.27***	–			
8. KINDL-R Overall Index	81.85	7.69	−.22***	.59***	.65***	.62***	.51***	.64***	.55***	–		
9. 20 m shuttle run test (stage)	4.49	1.64	−.05	.10	.09	.01	−.07	.08	.19***	.09	–	
10. Vigorous physical activity (min/day)	56.38	39.25	−.03	.12*	.01	.04	−.03	.02	.01	.04	.15*	–
Age (years)	7.27	0.35	.05	−.02	−.03	−.02	.02	−.03	.02	−.02	.13*	.06
Gender (male = 0, female = 1)	–	–	−.02	−.06	−.01	.06	−.05	.08	.04	.04	−.21***	−.13*
Parental education	2.29	0.78	−.03	.06	−.03	.11*	−.07	−.07	.29***	.06	.32***	−.02

* $p < .05$; ** $p < .01$; *** $p < .001$

for the different health-related quality of life indicators were higher, with mean scores ranging from $M = 72.31$ for self-esteem to $M = 84.96$ for everyday functioning at school (with a possible range of 1–100). On average, the children achieved between 4 and 5 stages in the shuttle run test, and parents reported approximately 60 min of vigorous physical activity per day.

The correlational analyses (Table 1) showed that age and male gender were positively associated with children's performance in the 20 m shuttle run test. Furthermore, male gender was positively associated with higher physical activity levels. Finally, high parental education was associated with children's positive self-esteem, everyday functioning at school and performance in the 20 m shuttle run test. All reported correlations were weak to moderate, though statistically significant.

Bivariate associations between the main study variables

Table 1 shows small but significant (positive) correlations linking critical life events with decreased psychological wellbeing, self-esteem, and the quality of life subscales family and friends. Correlations between the various indicators of health-related quality of life ranged between $r = .13$ and $r = .45$ ($ps < .05$). The statistically strongest correlation appeared between physical and psychological wellbeing. Correlations between the overall KINDL-R index and the six subscales varied between $r = .51$ and .65 ($ps < .001$). Higher performance in the 20 m shuttle run test was associated with better everyday functioning at school, whereas a significant positive correlation existed between vigorous physical activity and physical wellbeing. Interestingly, only a weak (but statistically significant) relationship was found between the performance in the 20 m shuttle run test and vigorous physical activity.

Cardiorespiratory fitness and physical activity as stress-buffers

Table 2 shows that cardiorespiratory fitness moderated the relationship between critical life events and three health-related quality of life indicators (physical wellbeing, psychological wellbeing, friends). For these variables, the interaction term explained between 1.0 and 1.3% of variance. However, Figs. 1, 2 and 3 suggest that the direction of the moderation effect varied between the three indicators. Figure 1 shows that in children with low stress exposure, their psychological wellbeing did not depend on their fitness level. However, among children with higher stress exposure, psychological wellbeing was significantly more impaired in those with lower fitness levels. By contrast, Figs. 2 and 3 show that children with higher fitness levels experienced higher levels of physical wellbeing and more positive friendships only if they experienced low stress levels. If exposed to high stress, the association with cardiorespiratory fitness disappeared. Finally, while severity of life events was a significant predictor of all health-related quality of life indicators, no significant interaction effects were found with regard to self-esteem, family and everyday functioning at school.

Table 2 Regression analyses with critical life events as independent variable and cardiorespiratory fitness as moderator variable

	ΔR^2	β
Physical wellbeing		
Step 1: critical life events	.008*	−.12*
Step 2: fitness	.006	.08
Step 3: critical life events × fitness	.010*	−.11*
Total R^2	.025*	
Psychological wellbeing		
Step 1: critical life events	.078***	−.24***
Step 2: fitness	.005	.07
Step 3: critical life events × fitness	.011*	.11*
Total R^2	.094***	
Self-esteem		
Step 1: parental education	.011*	.11*
Step 2: critical life events	.016	−.09
Step 3: fitness	.001	−.03
Step 4: critical life events × fitness	.000	.02
Total R^2	.022	
Family		
Step 1: critical life events	.051***	−.22***
Step 2: fitness	.007	−.08
Step 3: critical life events × fitness	.000	.02
Total R^2	.058***	
Friends		
Step 1: critical life events	.016**	−.17**
Step 2: fitness	.005	.07
Step 3: critical life events × fitness	.013*	−.12*
Total R^2	.034**	
Everyday functioning at school		
Step 1: parental education	.084***	.26***
Step 2: critical life events	.005	−.07
Step 3: fitness	.009	.10
Step 4: critical life events × fitness	.000	−.02
Total R^2	.098***	
Overall KINDL-R score		
Step 1: critical life events	.049***	−.25***
Step 2: fitness	.006	.08
Step 3: critical life events × fitness	.006	−.09
Total R^2	.061***	
n	378	

*** $p < .001$; ** $p < .01$; * $p < .05$

The interactions between critical life events and vigorous physical activity are displayed in Table 3. A significant two-way interaction between physical activity and critical life events indicated that children with higher physical activity reported better overall health-related quality of life, if experiencing low stress levels (Fig. 4). Two similar trends were found with regard to physical wellbeing and family. In addition, a significant main effect for vigorous physical activity was found for physical wellbeing, showing that children with higher physical activity levels had higher scores than their less active peers, even after controlling for critical life events.

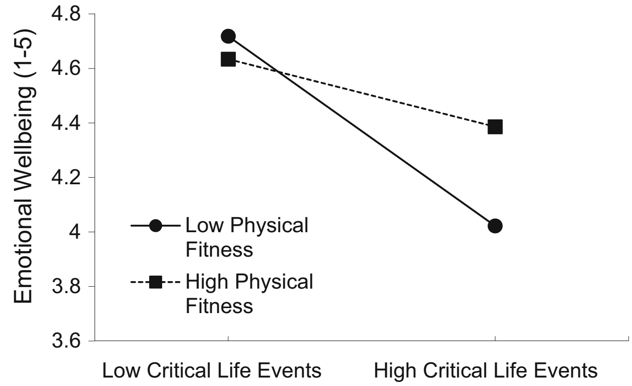

Fig. 1 Plot of the two-way interaction between critical life events and physical fitness on psychological wellbeing (see: http://www.jeremydawson.co.uk/slopes.htm)

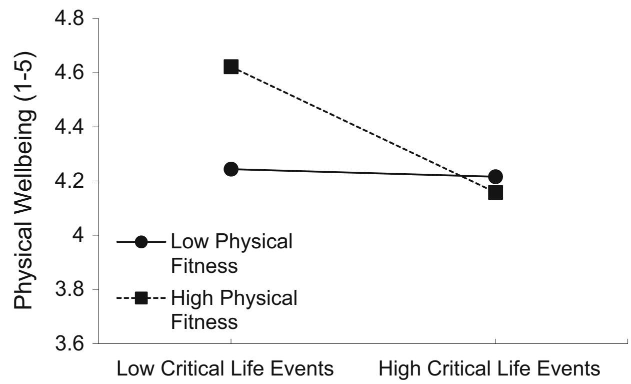

Fig. 2 Plot of the two-way interaction between critical life events and physical fitness on physical wellbeing (see: http://www.jeremydawson.co.uk/slopes.htm)

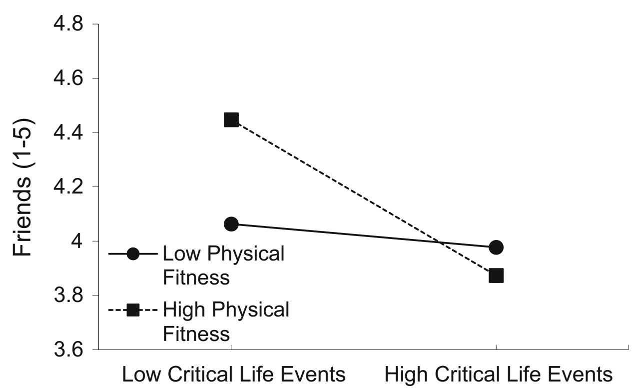

Fig. 3 Plot of the two-way interaction between critical life events and physical fitness on friends (see: http://www.jeremydawson.co.uk/slopes.htm)

Table 3 Regression analyses with critical life events as independent variable and vigorous physical activity as moderator variable

	ΔR^2	β
Physical wellbeing		
Step 1: critical life events	.008*	−.11*
Step 2: VPA	.013*	.12*
Step 3: Critical life events × VPA	.007$^+$	−.09$^+$
Total R^2	.028*	
Psychological wellbeing		
Step 1: critical life events	.078***	−.29***
Step 2: VPA	.000	.01
Step 3: critical life events × VPA	.002	−.05
Total R^2	.080***	
Self-esteem		
Step 1: parental education	.011$^+$	.10$^+$
Step 2: critical life events	.009*	−.11*
Step 3: VPA	.001	.03
Step 4: critical life events × fitness	.002	−.04
Total R^2	.024	
Family		
Step 1: critical life events	.051***	−.25***
Step 2: VPA	.002	.04
Step 3: critical life events × VPA	.008$^+$	−.10$^+$
Total R^2	.061***	
Friends		
Step 1: critical life events	.016**	−.14**
Step 2: VPA	.000	.02
Step 3: critical life events × VPA	.005	−.07
Total R^2	.021*	
Everyday functioning at school		
Step 1: parental education	.084***	.29***
Step 2: critical life events	.005	−.07
Step 3: VPA	.000	.00
Step 4: critical life events × fitness	.000	.02
Total R^2	.098***	
Overall KINDL-R		
Step 1: critical life events	.049***	−.25***
Step 2: VPA	.001	.06
Step 3: critical life events × VPA	.015*	−.13*
Total R^2	.065***	
n	378	

*** $p < .001$; ** $p < .01$; * $p < .05$; $^+$ $p < .10$

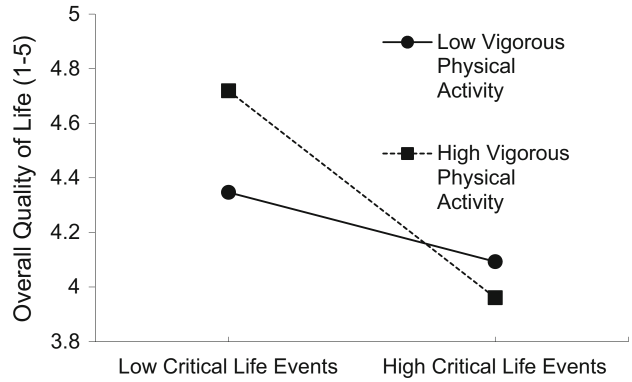

Fig. 4 Plot of the two-way interaction between critical life events and vigorous physical activity on overall quality of life (see: http://www.jeremydawson.co.uk/slopes.htm)

Discussion

The key findings of the present study were that among a sample of 6- to 8-year-old children, cardiorespiratory fitness moderated the relationship between recent life events and health-related quality of life as follows: (a) when exposed to elevated stress levels, children with higher fitness levels experienced higher levels of psychological wellbeing, relative to their less fit peers; (b) children with higher fitness levels experienced higher levels of physical wellbeing and more positive friendship relationships when stress levels were low; (c) children with higher physical activity reported better overall health-related quality of life, but only if they experienced low stress.

Descriptively, the children of the present sample were comparable to other Swiss first graders with regard to the stages achieved in the 20 m shuttle run test [53, 54]. Moreover, according to the parental reports, the children were relatively active ($M = 56.66$ min/day of vigorous physical activity). Fifty-one per cent ($n = 166$) of the children engaged in more than 60 min per day of vigorous physical activity, whereas 49% ($n = 159$) did not meet this recommended standard [55]. Moreover, parents rated their children's quality of life relatively highly. The overall index ($M = 81.85$) was comparable to the German norm population ($M = 79.0$), which was also true for the six subscales (ranging between $M = 72.31$–88.16 in the present sample vs. $M = 70.80$–82.30 in the norm population).

The present data add to the current literature, as this study examined for the first time in young children whether cardiorespiratory fitness and physical activity are associated with higher health-related quality of life if children have been recently exposed to critical life events. Based on previous studies with adolescents [15–17, 19, 20], we hypothesized that both cardiorespiratory fitness and physical activity could buffer the relationships between recent life events and health-related quality of life in young children. Nevertheless, only limited support was found for this notion, as a "real" stress-buffering effect was only found for cardiorespiratory fitness on psychological wellbeing.

Next, the fact that cardiorespiratory fitness was associated with increased physical wellbeing and favourable friendships only among children with low stress levels was unexpected, which was also true for the two-way interaction between physical activity and critical life events on overall quality of life. Similar findings have been reported previously in an adult study, in which stress was operationalized via critical life events [56]. This finding clearly highlights the importance of adverse life events on children's health [57], as they seem to override the positive association between high cardiorespiratory fitness and physical activity and health.

The quality of the data does not allow a deeper interpretation of the underlying neurophysiological mechanisms responsible for this specific stress-buffering effect found in the present study. However, in the past, researchers have proposed several mechanisms to explain this finding. For instance, the human stress response is closely linked with the sympatho-adrenal medullary (SAM) system and the hypothalamic–pituitary–adrenal (HPA) axis [58]. Hence, recent life events can result in higher cortisol levels [59], which may negatively affect children's immune systems [24], and make them vulnerable to illness and psychological impairments [38]. In line with this notion, Huss et al. [60] reported that children suffering from migraine showed altered physiological arousal and longer recovery after exposure to emotional stressors when compared to healthy controls. Several studies revealed that people with high fitness levels show reduced cardiovascular, endocrine and negative emotional reactivity to experimental stressors [61, 62], a relationship which was recently corroborated in a study with young children [63]. Moreover, the stress-buffering effect might be attributable to higher mental toughness levels (that is, a tendency to see problems more as a challenge, to perceive them as controllable, and to stay committed to problem solving without losing confidence) among those who are physically fit [64]. This seems plausible because mental toughness has been shown to be associated with increased cardiorespiratory fitness levels [65] and better psychological functioning [64, 66].

Furthermore, several theories exist as to why cardiorespiratory fitness, but not vigorous physical activity, could buffer the relationship between recent life events and psychological wellbeing. First, although the present study supports previous research in the sense that a positive relationship was found between children's cardiorespiratory fitness and physical activity levels [67], both variables were only weakly correlated ($r = .15$, $p < .05$) in the present sample. Second, physical activity was assessed via parental reports, while fitness was assessed with a field-based test. When parental report is compared to objectively assessed physical activity via accelerometry, parents seem to overestimate the level of moderate-to-vigorous physical activity in their children [68]. Third, researchers have emphasized that fitness and physical activity are related, but different, constructs. According to Caspersen et al. [69], physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure, whereas fitness corresponds to a set of attributes (e.g. cardiorespiratory endurance) that people have or achieve, and that allows them to carry out daily tasks with vigour and alertness. In line with this notion, past research has shown that physical activity and cardiorespiratory fitness are independently associated with health outcomes in children [70]. Thus, while fitness includes a strong genetic component [71], physical activity is a purely behavioural variable. Therefore, patterns of physical activity might change more quickly after exposure to a critical life event than cardiorespiratory fitness.

The fact that most two-way interactions were non-significant may be explained as follows: children might not have been exposed to the assessed stressors for a sufficiently long time. Thus, it is possible that focusing on earlier (instead of recent) life events would have resulted in stronger association with children's health-related quality of life, and an increased likelihood for cardiorespiratory fitness and physical activity to act as stress-buffers. Another reason could be that parents/guardians may have a limited ability to reliably report their children's stress levels [38]. Thus, prior research has shown that parents tend to underestimate their offspring's stress levels [72]. However, few alternatives exist, as the suitability of objective stress biomarkers (e.g. hair cortisol) is still a matter of debate among stress researchers [73], especially as only weak relationships have been found between hair cortisol concentrations, life events and subjective stress perceptions [74, 75]. Finally, an alternative explanation could be that parents who "caused" a stressor did not want to admit that this stressor has a large negative impact on their child. Hence, the impact of some stressors might be systematically underreported.

The strengths of this study are that data were collected in a relatively homogeneous group of young children. This is important as sources of stress may vary with age and developmental level. Moreover, a standardized and well-accepted test was used to assess cardiorespiratory fitness. Finally, all analyses were controlled for age, gender and parental education because these factors can impact on children's stress levels and quality of life [76].

Nevertheless, several factors warn against an over-interpretation of the results. First, stress and health-related quality of life were assessed via parental reports. While prior research has shown that there was only limited concordance between reports of parents, teachers, and children on symptoms of maladjustment [77], studies have also revealed that stressors were more closely linked to parent-reported symptoms among younger children [25]. Second, negative life events were assessed over the period of the last three months. While—as noted by Grant et al. [38]—

"it makes intuitive sense that recent stressors would be more strongly associated than prior stressors with current symptoms", the narrowly set timeframe may have contributed to the fact that only a small number of children were exposed to critical life events. Third, the cross-sectional design of the study did not allow any conclusions about cause and effect to be drawn. Fourth, we do not have further information about participants who dropped out or parents who did not give written informed consent. Thus, since participation in the study was voluntary, a selection bias may have occurred (for instance, it is possible that there was a higher dropout rate among families with high stress levels). Fifth, we acknowledge that other factors, which were not assessed in the present study, might have influenced the relationship between stress and psychological wellbeing. For instance, research has shown that the relationship between high stress and psychological wellbeing might be exacerbated in people carrying a short allele in the serotonin transporter polymorphism [78]. Sixth, the present findings should be replicated with objective accelerometry and fitness tests that provide more precise estimates of children's physical activity and VO2-max. While researchers have questioned whether physical activity can be adequately assessed in younger children via self-report instruments [79], others have emphasized that physical activity and cardiorespiratory fitness can be independently associated with major cardiovascular risk markers [80] and mental health [81]. Given this background, we decided to test two-way interactions with stress separately for fitness and physical activity. Since we used a proxy measure to assess vigorous physical activity, we acknowledge that the data related to physical activity must be interpreted with caution (particularly as this was the only instrument which involved subject reports from the children). Finally, sample size calculations were based on bivariate correlation analysis. However, since analyses examining moderating influences of physical activity are more power limited [82], it is possible that some significant two-way interactions remained undetected in the multiple regression analyses due to limited sample size. For that reason, we also decided not to adjust our analyses for alpha error accumulation despite the fact that the same independent variables were used to predict multiple outcomes.

Conclusions

The present study revealed that children with low cardiorespiratory fitness levels were at increased risk for impaired psychological wellbeing when exposed to critical life events. Recent stressful experiences alone were not sufficient to explain negative health outcomes in young children. More research is needed to find out whether similar findings emerge with objective physical activity measurements, and when stress is assessed over longer periods of time. Moreover, there is a clear need for experimental studies in this field of research.

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Compliance with ethical standards

Conflict of interest None of the authors has any conflict of interest.

Ethical approval Ethical approval was obtained by the ethics committee of the University of Basel (EKNZ, Basel, No. 258/12). All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

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