Role of Childhood Aerobic Fitness in Successful Street Crossing

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ABSTRACT

CHADDOCK, L., M. B. NEIDER, A. LUTZ, C. H. HILLMAN, and A. F. KRAMER. Role of Childhood Aerobic Fitness in Successful Street Crossing. *Med. Sci. Sports Exerc.*, Vol. 44, No. 4, pp. 749–753, 2012. Increased aerobic fitness is associated with improved cognition, brain health, and academic achievement during preadolescence. **Purpose**: In this study, we extended these findings by examining the relationship between aerobic fitness and an everyday real-world task: street crossing. Because street crossing can be a dangerous multitask challenge and is a leading cause of injury in children, it is important to find ways to improve pedestrian safety. **Methods**: A street intersection was modeled in a virtual environment, and higher-fit (n = 13, 7 boys) and lower-fit (n = 13, 5 boys) 8- to 10-yr-old children, as determined by $\dot{V}O_{2max}$ testing, navigated trafficked roads by walking on a treadmill that was integrated with an immersive virtual world. Child pedestrians crossed the street while undistracted, listening to music, or conversing on a hands-free cellular phone. **Results**: Cell phones impaired street crossing success rates compared with the undistracted or music conditions for all participants (P = 0.004), a result that supports previous research. However, individual differences in aerobic fitness influenced these patterns (fitness × condition interaction, P = 0.003). Higher-fit children maintained street crossing success rates across all three conditions (paired t-tests, all P > 0.4), whereas lower-fit children showed decreased success rates when on the phone, relative to the undistracted (P = 0.018) and music (P = 0.019) conditions. **Conclusions**: The results suggest that higher levels of childhood aerobic fitness may attenuate the impairment typically associated with multitasking during street crossing. It is possible that superior cognitive abilities of higher-fit children play a role in the performance differences during complex real-world tasks. **Key Words:** CHILDREN, COGNITION, DEVELOPMENT, EXERCISE, MULTITASKING, PHYSICAL ACTIVITY

Street crossing can be hazardous and especially dangerous for children. Pedestrian accidents are the second leading cause of injury and mortality in children between the ages of 5 and 14 in motorized countries (22). Because children cross streets daily to attend school, participate in after-school activities, and visit friends, childhood street crossing safety is an important public health concern.

Pedestrian roadway navigation is a complex cognitive, perceptual, and motor challenge that involves the ability to multitask or perform more than one task concurrently. To successfully cross a street, pedestrians have to simultaneously attend to the flow of traffic, monitor and remember vehicle distances and speeds, and execute a crossing as a function of roadway distance and individual walking speed.

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In today's fast-paced society, the widespread and nearly constant use of technological devices has introduced additional competition for attentional resources during everyday tasks such as crossing a street. Mobile phone and portable music player ownership is rapidly growing among children between the ages of 8 and 18, with cellular phone use increasing from 39% to 66% and music player use from 18% to 76% during the past 5 yr (13). Research demonstrates that conversing on a cell phone interferes with driving performance (2,27), and recent evidence suggests that mobile phones also impair street crossing success rates across the lifespan (17,18,26). Of particular note, child pedestrians have been found to be involved in more collisions with automobiles while conversing on a cell phone compared with when undistracted (26). The street crossing findings provide converging evidence of performance decrements and response slowing using traditional laboratory-based multitask paradigms (e.g., dual-task, task switching) (7,8,10,20).

Because of the high injury risk associated with street crossing and the rising use of potentially distracting technologies, there is a growing research initiative to find strategies that improve child pedestrian safety. So far, the effectiveness of behavioral training interventions at street-side, on a computer, or in a nonimmersive virtual world is said to be limited (24). The present study uses a new approach to understanding childhood roadway safety by exploring the role of aerobic fitness in the relationship between street crossing and distraction. Increased physical activity and aerobic fitness during childhood are associated with superior cognitive and brain health. Children with higher aerobic fitness levels show improved academic achievement and cognitive abilities, coupled with larger brain structures and more efficient brain function (4–6,11,21). Specifically, higher-fit children show superior performance on tasks of cognitive control, which involve selective attention, interference suppression, response inhibition, and cognitive flexibility (6,11,21). The performance differences are associated with neural differences, such that higher-fit and lower-fit children show differences in the volume of the basal ganglia, a brain region involved in cognitive control (6), as well as in event-related brain potential indices (11,21). Higher-fit children have also shown larger bilateral hippocampal volumes, which have been associated with superior relational memory task performance (5).

It is possible that the performance benefits for higher-fit children in the laboratory and in school extend to a realistic multitask challenge such as street crossing. To explore this possibility, we used an immersive virtual reality environment to examine how childhood aerobic fitness relates to street crossing performance while undistracted, listening to music, and conversing on a hands-free cell phone. A street intersection was modeled in a virtual environment, and higher-fit and lower-fit children were asked to navigate trafficked roads by walking on a treadmill that was integrated with the virtual world. It was hypothesized that aerobic fitness would relate to street crossing and distraction, with higher-fit children outperforming lower-fit children.

METHODS

Participants. Thirteen higher-fit (seven boys and six girls) and 13 lower-fit (five boys and eight girls) preadolescents, ages 8–10 yr (mean ± SD = 9.1 ± 0.58 yr) from east-central Illinois were included in the analysis. Aerobic fitness was determined by measuring maximal oxygen con-

TABLE 1. Participant mean ± SD demographic and fitness data by aerobic fitness group.

Variable	Lower Fit	Higher Fit
N	13 (5 boys)	13 (7 boys)
Age (yr)	9.0 ± 0.5	9.2 ± 0.7
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	36.7 ± 5.1*	53.2 ± 1.2*
$\dot{V}O_{2max}$ (%)	11.8 ± 9.0*	84.9 ± 7.0*
BMI ($kg \cdot m^{-2}$)	19.2 ± 3.3*	15.3 ± 1.2*
K-BIT[a] composite score (IQ)	118.9 ± 16.3	125.0 ± 17.1
K-BIT[a] crystallized score (vocabulary)	113.5 ± 12.3	119.5 ± 12.5
K-BIT[a] fluid score (matrices)	119.9 ± 17.9	124.6 ± 19.9
Pubertal timing[b]	1.4 ± 0.5	1.1 ± 0.3
SES[c] (median)	2.3 ± 0.9	2.5 ± 0.5

[a] Kaufman Brief Intelligence Test (14).
[b] Pubertal timing assessed using a modified Tanner Staging System (28).
[c] SES was determined by the creation of a trichotomous index based on three variables: child participation in a free or reduced-price lunch program at school, the highest level of education obtained by the child's mother and father, and the number of parents who worked full-time (3).
* Significantly different at $P < 0.05$.

FIGURE 1—Photograph of the street crossing paradigm in the virtual reality environment.

sumption ($\dot{V}O_{2max}$) during a modified Balke protocol (1). Specifically, participants ran on a motor-driven treadmill at a constant speed with increases in grade increments of 2.5% every 2 min until volitional exhaustion. $\dot{V}O_{2max}$ was defined when oxygen consumption remained at a steady state despite an increase in workload (5,6). Only children whose $\dot{V}O_{2max}$ value fell above the 70th percentile or below the 30th percentile, based on normative data (25), were included. Higher-fit and lower-fit groups differed in $\dot{V}O_{2max}$ (t_{24} = 9.7, $P < 0.0001$) (Table 1). No significant group differences were found for age, gender, IQ (K-BIT) (14), pubertal timing (28), or socioeconomic status (SES) (3) (via independent *t*-tests [when the data were normally distributed, as determined by Kolmogorov–Smirnov tests, $P > 0.05$] or χ^2 tests [when the data were not normally distributed, as determined by Kolmogorov–Smirnov tests, $P < 0.05$]) (Table 1). Higher-fit and lower-fit groups also differed in body mass index (BMI) (t_{24} = 4.1, P = 0.001) (Table 1). Child participants and their legal guardians provided written informed consent in accordance with the Institutional Review Board of the University of Illinois at Urbana – Champaign. The study was also approved by the Institutional Review Board of the University of Illinois before the investigation.

Virtual reality street crossing paradigm. The task was administered in the Beckman Institute's virtual reality CAVE environment (http://www.isl.uiuc.edu/Labs/CAVE/CAVE.html), which allowed an immersive and interactive street crossing experience (Fig. 1). Participants walked on a nonmotorized, manual treadmill, which enabled them to move through the virtual world at their own walking speed. To create the virtual reality experience, participants wore a pair of wireless goggles, which rapidly alternated the viewing screen displays to each eye, resulting in the perception of depth.

We designed our paradigm to replicate many of the important aspects of street crossing, while also enabling the objective measurement of pedestrian behaviors in a safe situation, and with sufficient levels of difficulty to ensure the power to detect group differences. The high-quality graphics and high level of interaction and immersion, as reflected by participant movements controlling the virtual world, suggest that the paradigm provides a valid and realistic approximation of what might be encountered in the real world (23).

The task on each trial was for the child pedestrian to safely walk (not run) across an intersection while avoiding traffic. The two-way street consisted of two lanes that totaled 8 m in width, and moving cars traveled at 10 $m \cdot s^{-1}$ (~22 $miles \cdot h^{-1}$). The distance between cars remained constant at 75 m (~246 ft). Each participant performed the street crossing task under three conditions—no distraction, listening to self-selected music through headphones on an iPod Nano, or conversing on a hands-free cell phone with a confederate (about topics such as movies, television, sports, pets, books, hobbies, and restaurants). Simulated spoken feedback (i.e., "You made it!") was given if a pedestrian successfully crossed the street, and visual feedback was provided if a participant was hit by a car. The task conditions were blocked and counterbalanced across 60 experimental trials (two blocks of 10 trials for each condition, six total blocks per participant). Block order was counterbalanced such that each block and distraction type was presented an equal number of times in each presentation position across all participants. Each child also received four practice trials before the experiment to acclimate to the treadmill as well as to the virtual reality environment.

Furthermore, the virtual environment allowed not only the recording of street crossing success rates but also the measurement of specific behaviors during each crossing, including total trial duration, initiation and crossing durations, head turns, and distance between participants and vehicles. Total trial duration was defined as the time for a participant to walk from one gate at the start of the trial to another gate that ended the trial. This measure included initiation duration, the amount of time the pedestrian waited on the sidewalk before initiating a crossing, and crossing duration, the time spent by the pedestrian in the roadway. Head turns were counted during initiation, while the participant was on the sidewalk preparing to cross, as well as during crossing. The distance between the participant and the nearest vehicle at the time of roadway entry as well as at roadway exit were also recorded. Finally, we calculated "time to contact," which relates to a participant's judgment of whether a traffic gap is sufficient to safely cross a street based on the nearest vehicle's speed and distance (calculated by dividing the speed of the oncoming car (10 $m \cdot s^{-1}$) to the distance between the vehicle and pedestrian). Lower time to contact values indicate a closer vehicle while a pedestrian enters or exits the roadway and therefore a less safe crossing.

TABLE 2. Mean ± SD street crossing behaviors across all child pedestrians.

	Undistracted	Music	Phone
Crossing success rate (%)	80.4 ± 15.4	78.8 ± 17.6	69.4 ± 24.5*
Trial duration (s)	20.2 ± 7.6	20.4 ± 7.7	23.9 ± 9.5*
Initiation duration (s)	9.7 ± 6.2	10.3 ± 6.9	11.9 ± 8.7*
Crossing duration (s)	5.2 ± 1.1	5.1 ± 1.2	5.6 ± 1.3*
Initiation head turns (*n*)	3.1 ± 2.0	3.3 ± 2.2	2.6 ± 1.8
Crossing head turns (*n*)	1.2 ± 0.69	1.2 ± 0.7	1.5 ± 0.8*
Pedestrian–vehicle distance at enter (m)	54.7 ± 4.4	54.2 ± 4.7	53.5 ± 4.5
Pedestrian–vehicle distance at exit (m)	24.4 ± 6.1	24.9 ± 8.2	21.4 ± 5.6*
Time to contact at enter (s)	5.5 ± 0.4	5.5 ± 0.5	5.3 ± 0.5
Time to contact at exit (s)	2.4 ± 0.6	2.5 ± 0.8	2.1 ± 0.6*

* Significantly different at $P < 0.05$.

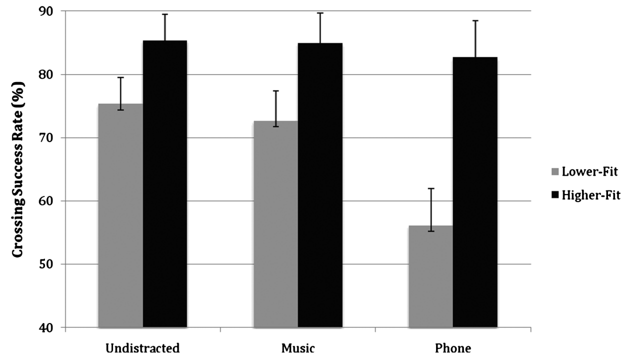

FIGURE 2—Children with higher aerobic fitness levels maintained street crossing success rates across all task conditions. Lower-fit children showed lower performance when conversing on a hands-free cell phone relative to crossing the street while undistracted or listening to music on an iPod. *Error bars*, SE.

Repeated-measures ANOVA were conducted to examine the association among street crossing, distraction, and aerobic fitness.

RESULTS

Street crossing and distraction. A main effect of task condition ($F_{2,48}$ = 6.3, P = 0.004) demonstrated that all children showed lower street crossing success rates when conversing on a cell phone (mean = 69.4%, SE = 4.1%) compared with when undistracted (mean = 80.4%, SE = 2.9%) (t_{25} = 2.6, P = 0.016, d = 0.54) or listening to music (mean = 78.8%, SE = 3.3%) (t_{25} = 2.6, P = 0.017, d = 0.44). Listening to music did not induce a performance cost relative to the undistracted condition (t_{25} = 0.67, P = 0.52, d = 0.097).

An examination of behavior during successful trials of the street crossing task demonstrated a longer trial duration ($F_{2,48}$ = 10.5, P < 0.001), a longer initiation duration ($F_{2,48}$ = 4.6, P = 0.015), a longer crossing duration ($F_{2,48}$ = 9.5, P < 0.001), more head turns during crossing ($F_{2,48}$ = 3.2, P = 0.05), and a shorter car distance between pedestrian and car at exit ($F_{2,48}$ = 7.4, P = 0.002) for the phone condition relative to the undistracted and music conditions, for all children (Table 2). In addition, a shorter time to contact for the phone condition was found when participants exited the roadway, relative to the undistracted and music conditions ($F_{2,48}$ = 7.4, P = 0.002) (Table 2).

Street crossing, distraction, and aerobic fitness. A main effect of aerobic fitness group ($F_{1,24}$ = 8.0, P = 0.009, d = 1.1) showed that higher-fit children (mean = 84.4%, SE = 4.1%) were more successful crossing the street than lower-fit children (mean = 68.1%, SE = 4.1%) across all distraction conditions. The effect remained significant when using BMI as a covariate in the analysis. Because weight (kg) is a factor

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in both the $\dot{V}O_{2max}$ and BMI formula, we do not report the covariate analysis as our main analysis because of the shared variance associated with the two measures.

The main effect was superseded by a fitness × task condition (undistracted, music, phone) interaction ($F_{2,48}$ = 3.6, P = 0.035), which demonstrated that higher-fit children maintained crossing success rates across all three task conditions (paired t-tests, all t < 0.7, all P > 0.4, all d between 0.03 and 0.16), whereas lower-fit children showed lower performance for the phone condition relative to the undistracted (t_{12} = 2.7, P = 0.018, d = 1.0) and music (t_{25} = 2.7, P = 0.019, d = 0.77) conditions (Fig. 2). In addition, independent t-tests showed that higher-fit children had significantly higher crossing success rates than lower-fit children for the phone condition (t_{24} = 3.3, P = 0.003, d = 1.3), with marginally significant group differences for the undistracted (t_{24} = 1.7, P = 0.097, d = 0.68) and music (t_{24} = 1.9, P = 0.074, d = 0.73) conditions.

Lower-fit children also had more head turns while crossing the street compared with higher-fit children, across all three conditions ($F_{1,24}$ = 4.8, P = 0.038). No aerobic fitness group differences were found in terms of total trial duration, initiation or crossing durations, preparation head turns, pedestrian–vehicle distances, or time to contact (all t < 2, all P > 0.1). Finally, because the street crossing task was physically demanding, a split-half analysis was conducted to examine fitness group differences in crossing success rates for the first and second halves of the task (i.e., first 30 trials vs second 30 trials of the paradigm). This analysis helps to address the role of task fatigue. Within-group paired t-tests showed no decrease in street crossing success rates between the first and second halves of the task for any distraction condition, for either the higher-fit or lower-fit group.

DISCUSSION

Research suggests that higher-fit children outperform lower-fit children on cognitive tasks in the laboratory as well as on scholastic achievement tests (4–6,11,21). We demonstrate here, for the first time, that children with higher aerobic fitness levels also outperform their lower-fit peers on a simulated real-world task—street crossing.

The results support and extend previous research that cell phones impair performance such that child pedestrians were involved in more automobile collisions when conversing on a mobile phone compared with when undistracted (26) or listening to music. The reported longer initiation and crossing durations, more crossing head turns, less distance between pedestrians and traffic vehicles, and shorter time-to-contact judgments support the hypothesis that cell phone use compromises the multitasking abilities of children (26). Listening to music did not induce additional distraction in child pedestrians relative to the undistracted street crossing condition—a finding consistent with adult investigations (17,18). Nevertheless, the music findings should be interpreted cautiously, given the lack of ambient road noise (17,18).

We extended previous work by demonstrating that individual differences in aerobic fitness can affect these street crossing patterns. That is, only lower-fit children showed decreased crossing success rates when conversing on the phone, relative to the undistracted and music task conditions. Higher-fit children, on the other hand, maintained street crossing performance across all levels of distraction. Together, the results suggest that higher levels of aerobic fitness may play a role in attenuating the impairment typically associated with multitasking in challenging real-world tasks such as street crossing. Nevertheless, despite the possibility that childhood aerobic fitness may help to protect against the negative effects of cell phone distraction, neither higher-fit nor lower-fit children avoided all pedestrian–vehicle collisions. Thus, we suggest that crossing a street while concurrently conversing on a cell phone is still undesirable, as a single error can have severe consequences.

Researchers postulate that individuals cannot multitask, or "time share," without performance decrements on one of more of the constituent tasks. Multitasking costs are often attributed to several factors, including response competition (16), overlap in resource utilization (31), or a bottleneck that prevents response selection, decision making, and action from occurring simultaneously (20). However, recent evidence suggests the presence of a small percentage of "supertaskers"—extraordinary multitaskers who can perform two attention-demanding tasks without performance costs (30). Does aerobic fitness play a role in supertasking abilities? Although we cannot answer this question with the current data, our findings reinforce the need for the study of individual differences in the theoretical understanding of multitasking (30).

Although speculative, reported performance benefits for higher-fit children on cognitive tasks of attentional control, inhibition, and memory (5,6,11,21) may play a role in the performance differences during our cognitively challenging street crossing task. Interestingly, the striatum and hippocampus, brain regions found to be larger in higher-fit children compared with lower-fit children (5,6), are suggested to play a role in learning while multitasking under distraction (9). Further, the lack of fitness group differences in physical measures of crossing speed suggests that differences in cognitive abilities may play a greater role in street crossing multitask performance differences than treadmill coordination and walking speed. Additional research is needed to characterize the neurocognitive factors that play a role in multitask challenges such as street crossing.

In conclusion, we provide additional evidence of the importance of physical activity, which can lead to improvements in aerobic fitness, in a youth population. The results have important public health and educational implications, given the rise of childhood sedentary behaviors as well as the reduction of physical activity opportunities in schools (12,15,19). Our data suggest that childhood aerobic fitness not only relates to performance in the classroom and laboratory but also extends to childhood pedestrian–automobile accidents and, perhaps more generally, multitasking. With today's youth surrounded by media and technology, multitasking abilities are very important as children attempt to simultaneously complete homework assignments while browsing the Internet, listening to music, and watching television. Physical activity may be a promising low-cost, accessible, and fun strategy to improve multitasking and street crossing performance in children. The Walking School Bus (29), an initiative that organizes neighborhood children to walk to school under adult supervision, is a creative start to potentially increase the aerobic fitness levels of children as well as teach youth about roadway safety.

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