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Aerobic fitness moderates girls' affective and working memory responses to social exclusion

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ABSTRACT

Because self-regulation skills are in development through adolescence, social exclusion can pose significant challenges to the well-being of young people. Thus, an understanding of factors that may ease the self-regulation demands of social exclusion is particularly important. One such factor is aerobic fitness. Using a quasi-experimental within-subject design in a sample of girls (N = 47, 10.4 ± 1.2 years), we examined whether affective and working memory changes following social exclusion differ by level of aerobic fitness. Overall, findings suggest that more aerobically fit girls may better regulate the demands of social exclusion than less aerobically fit girls. Specifically, girls with higher aerobic fitness evidenced smaller decreases in pleasant affect and larger increases in working memory performance following social exclusion than girls with lower aerobic fitness. This research extends understanding of how aerobic fitness may benefit well-being in young people.

Over the course of childhood is an increasing interest in peers, with relationships outside of the family and making new friends increasing in importance (Sullivan, 1953). However, not all social exchanges among children are positive and adverse experiences such as social exclusion are common. Social exclusion is the process where a person is put into a condition of being alone or is denied social contact (Blackhart et al., 2009). Social exclusion is associated with ill-being and poorer academic outcomes (Bowker et al., 2014; Buhs, Ladd, & Herald, 2006; Cacioppo & Cacioppo, 2014). With repeated exclusion the resources needed to enact goal-directed behavior (i.e., self-regulation; Hofmann, Schmeichel, & Baddeley, 2012) may be exhausted and depleted (Williams, 2007). Factors than can help a child reduce the self-regulatory burden of given experiences of exclusion can potentially offer protection from long-term maladaptive outcomes. We explored whether aerobic fitness could help explain different reactions of children to social exclusion.

The maladaptive outcomes of social exclusion have been extensively studied in developmental, educational, and relationship science (Riva & Eck, 2016). Maladaptive outcomes may arise through restricted access to instrumental activities in important contexts, a lack of meaningful peer relationships, and indications that the individual is not valued by others. These processes may coincide with reduced efforts to establish new friendships, withdrawal from group activities in contexts where exclusion is likely to occur, or aggressive behavior (Leary, 2001; Newcomb, Bukowski, & Pattee, 1993). Young people who are frequently socially excluded find themselves on a figurative "social perimeter" away from beneficial social experiences and deprived of activities that serve to enhance emotional, cognitive, and social functioning (Cacioppo & Cacioppo, 2014; Newcomb et al., 1993).

Social exclusion can also directly and immediately affect children's self-regulation. The temporal need threat model (Saylor et al., 2013; Williams, 2007, 2009) outlines the effects of social exclusion in its many forms (e.g., neglect, ostracism, rejection). This model specifies a progression of stages that includes affective, cognitive, and behavioral responses over time. These immediate effects are characterized by a reduction in pleasant affect and a diminished fulfillment of psychological needs (Blackhart et al., 2009; Williams, 2009). Studying social exclusion during late childhood and early adolescence is particularly important. Research shows these effects of social exclusion to be stronger in children than adults (Sebastian, Viding, Williams, & Blakemore, 2010) and that peer evaluation and relational aggression emerge as significant predictors of ill-being during this developmental period, especially for girls (Crick & Nelson, 2002). Children may be more sensitive to social exclusion than adults because of their heightened desire to affiliate with peers and their developing self-regulation skills (Sebastian et al., 2010).

Self-regulation is dependent on a higher-order cognitive system

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known as cognitive control (Gray, 2004; Hofmann et al., 2012). An important subcomponent process of cognitive control is working memory, which is the ability to hold information in memory and make use of that information when it is no longer perceptually present (Diamond, 2013). Working memory is critical to navigate complex problems posed by social exclusion like monitoring social cues and choosing appropriate behavioral responses. The interplay between working memory and social skills are important to children's development (Diamond, 2010). Indeed, working memory plays a crucial role in enabling children to forge positive social relationships with peers (de Wilde, Koot, & van Lier, 2016) and to respond to exclusion with behaviors offering the best chance to regain inclusion (Williams, 2009). This corresponds with parallel evidence showing social exclusion to activate neural networks associated with cognitive control and working memory processes (Bolling et al., 2011; Guyer, Choate, Pine, & Nelson, 2012; van Noordt, White, Wu, Mayes, & Crowley, 2015) and to impair working memory performance in eight-to 12-year old children (Hawes et al., 2012). Altogether, this system appears to be taxed when young people experience social exclusion.

Impairments to working memory can be understood from a limited capacity framework (Baumeister, Twenge, & Nuss, 2002). When social exclusion creates increased demands on cognitive resources, those resources are likely prioritized toward regulating the emotional and psychological effects of social exclusion and away from other important tasks (e.g., deciding on how to respond, deciding where attention should be directed). Because cognitive resources are limited, social exclusion can undermine performance on working memory processes (e.g., action planning, enacting prosocial behavior) and in turn hamper efforts to regulate behavior and regain inclusion. Of interest is if cognitive resources can be preserved in the face of social exclusion. Various individual characteristics may tie to working memory impairments. For example, social anxiety, rejection sensitivity and self-esteem have been identified as individual characteristics that lead to different responses to social exclusion (DeWall & Bushman, 2011). There is specific value in exploring individual characteristics that may reduce resource competition. Investigating characteristics that preserve working memory resources after social exclusion occurs offers potential to better understand resource competition and how to safeguard the well-being of young people.

Accumulating evidence shows higher levels of aerobic fitness to be associated with improved cognitive performance in children (Chaddock-Heyman et al., 2014; Kao, Westfall, Parks, Pontifex, & Hillman, 2017). Specifically, Kao et al. (2017) showed a positive association between aerobic fitness and working memory performance among nine-to 11-year-old children. In light of this finding, it is possible that young people with higher aerobic fitness may be able to more efficiently regulate the affective and cognitive effects of social exclusion, thereby reducing resource competition, and preserving working memory performance on a non-social task. Intact working memory performance after exclusion may reflect the presence of adequate self-regulation resources to protect from immediate and longer-term maladaptive outcomes of social exclusion.

The purpose of this study was to determine if aerobic fitness moderates the affective and cognitive impact of social exclusion in children. The study utilized a within-subject quasi-experimental design with two groups of participants. Participants in the experimental group were assigned to be included and then excluded by a computer game. For the experimental group, social exclusion was hypothesized to lower pleasant affect and working memory performance compared to social inclusion. The magnitudes of social exclusion effects were hypothesized to be dampened for participants with higher aerobic fitness compared to participants with lower fitness. A control group was added with the specific purpose to clarify change-over-time findings in the experimental group. Participants in the control group were assigned to consecutive social inclusion games to assess changes in affect and working memory over time independent of social exclusion effects.

1. Method

1.1. Participants

The final sample totaled forty-seven girls (aged 9–12 years). An initial sample of fifty-one participants was recruited from the local community through online advertisements, email listservs, and local recreational facilities, making specific reference to our interest in recruiting girls. The sample was delimited in this way because some research indicates that social exclusion is a more salient experience for female than male recipients (Beneson et al., 2013). This also simplified the design by removing a between-subjects factor. Two participants were excluded because they did not achieve any of the necessary criteria to quantify aerobic fitness and two participants were excluded for performance below 50% correct responses on the cognitive task.

Of participants in the final sample, self-description of race was 6.4% Asian, 4.3% Black or African American, 2.1% Native Hawaiian or other Pacific Islander, 66.0% White, 19.1% multiple races, and 2.1% other. Also, the sample was 6.4% Hispanic/Latina, 6.4% left-handed, and 34.0% requiring corrected vision (all participants had normal or corrected-to-normal vision). Most (87.2%) participants were currently participating in sport with an average of 5.0 ± 3.4 hours spent in sport per week. Additional characteristics are found in Table 1.

1.2. Design and procedure

The current study received approval from the university human subjects research protection program and used a within-subject quasi-experimental design. This design was chosen due to the infancy of the research area, delicate nature of lab-based social exclusion research, and sensitivity to ethical concerns with deceiving children. The design allows comparison of social exclusion effects within each experimental group. After obtaining informed consent/assent from the participants and their guardians, guardians were asked to complete a demographic questionnaire in a separate room. Meanwhile, in line with previous within-subject design research on social exclusion (e.g., Bolling et al., 2011; Sebastian et al., 2010), participants played the 'Cyberball' computer game with virtual partners that manipulates social inclusion/exclusion. Cyberball was preferred for simulating social exclusion in children because it involves a ball-tossing game that is engaging for children and involves less researcher burden than in-person paradigms (Zadro et al., 2013). Because manipulating exclusion in laboratory settings involves deception, the order in which participants progressed through conditions were fixed to capture natural responses and avoid negative spill-over effects.

After completing a questionnaire battery, 35 participants (henceforth referred to as the 'experimental' group) played the Cyberball game a total of three times (see Fig. 1). The experimental group first completed a social inclusion condition, then were socially excluded, and finally were socially included to mitigate potential extended negative

Table 1
Participant Characteristics.

	Experimental Group		Control Group	
Variable	*M ± SD*	*Range*	*M ± SD*	*Range*
N	35		12	
Age (years)	10.4 ± 1.2	9–12	10.2 ± 1.3	9–12
Grade	5.2 ± 1.0	3–7	5.1 ± 1.3	3–7
Tanner Stage	1.8 ± 0.9	1–3.5	2.1 ± 1.0	1–4[A]
BMI (kg/m^2)	18.9 ± 3.8	14.5–29.6	18.3 ± 3.0	14.2–22.3
BMI Percentile (%)	55.2 ± 28.4	1.6–99.2	54.4 ± 33.8	3.5–90.5
VO_2 Max (ml/kg/min)	40.8 ± 7.0	20.9–53.5	41.1 ± 8.3	29.4–55.5
VO_2 Percentile (%)	39.7 ± 32.0	3–93	34.7 ± 35.0	3–95

Note: BMI = body mass index; VO_2 Max = maximal oxygen consumption. BMI normative values provided by the Centers for Disease Control. VO_2 normative values provided by Shvartz and Reibold (1990). A = data from 10 participants.

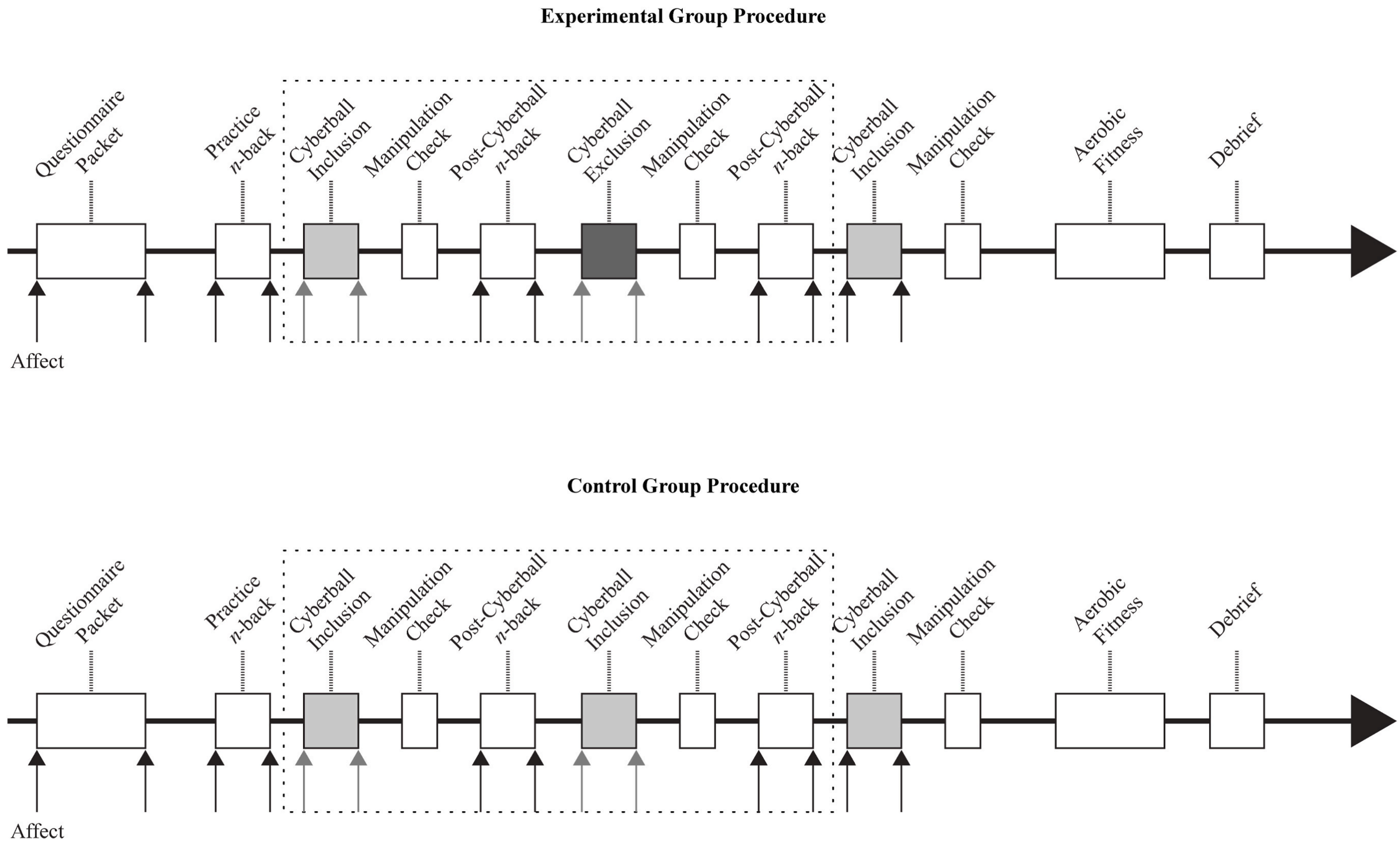

Fig. 1. Procedural timeline. Labels above rectangles indicate specific events. Inclusion manipulations indicated in light grey. Exclusion manipulation indicated in dark grey. Arrows indicate measures of affective valence with grey arrows indicating measures of interest. Dashed box includes measures of interest to the present study. Scale of events and spacing of time points are roughly consistent with time of an overall session.

feelings (Zadro et al., 2013). Following each condition of the Cyberball game, participants completed a three-item manipulation check derived from Zadro et al. (2013). Participants responded to items "I felt happy", "I felt sad" and "I felt ignored" on a 1 "*not at all*" to 5 "*very much so*" scale. Following completion of the manipulation checks, participants completed a working memory task to understand how the self-regulation demands of social exclusion impact working memory performance. Finally, during various phases of the experimental protocol (see Fig. 1), affective valence was assessed using the children's feeling scale (Hulley et al., 2008). This study was primarily focused on the measures starting at the first game of Cyberball and ending at the working memory task following the second game of Cyberball. A similar protocol was followed in a sample of 12 participants (henceforth referred to as the 'control' group) that replaced the social exclusion condition with an inclusion condition in order to provide insight into the extent to which practice effects inherent in the experimental protocol may have influenced the measures of interest.

Following the final Cyberball condition, all participants completed an aerobic fitness assessment, were given a small token (i.e., pencil, pen, eraser, stickers) and a $15 gift card for participating, were verbally debriefed along with their guardian to offer full disclosure of the study purposes, and were provided the opportunity to ask questions. Because the social exclusion component of the study was not disclosed prior to participation, a debriefing and consent to use data form was completed by guardians. No participants/guardians opted to withdraw data from the study.

1.3. Measures

Demographics. Guardians completed measures of the demographic characteristics, family environment, and activities of the participant. Additionally, guardians completed the Tanner Staging System (Tanner, 1962) to assess pubertal status for descriptive purposes.

Cyberball. Cyberball 4.0 (Williams, Yeager, Cheng, & Choi, 2012) is an open-source virtual ball-toss game that is used to invoke social exclusion via computer.[1] Cyberball involves three players, one of which is controlled by the participant and two that are computer-controlled confederates. It has been used in previous research to successfully elicit perceptions of social exclusion with children from seven to 12 years of age (Bolling et al., 2011; Hawes et al., 2012; Zadro et al., 2013). For purposes of this study, child participants were told a cover story that they will be playing a game of catch with two other children over the internet. In line with the recommendations of Zadro and colleagues, child participants were told to imagine they are tossing a ball with other children in real life. This was followed by questions from the research assistant to aid in imagining playing a game of catch in real life (e.g., "Tell me where you are playing?", "What kind of kids are you playing with?", "What color is the ball?"). The number of ball passes and direction were fixed in each condition. In the exclusion condition, participants received the ball only twice within the first 10 throws out of 20 total throws (i.e. 10%). In the inclusion condition participants received seven throws (i.e. 33%) evenly spaced throughout the 20 total throws. The two computer-controlled players were given sex-matched names. Names were chosen from publicly available data from the Social Security Administration for the most common names for girls in Michigan , USA in 2006 (around the participants' birth year).

Working Memory. A modified serial *n*-back task was administered that involves two consecutive blocks including 1-back and 2-back blocks (Pelegrina et al., 2015). Each block required participants to discriminate between 20 distinct consonant letter stimuli: B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, Y, and Z. Letter stimuli were presented one by one in the center of a computer screen. Participants completed a 1-back followed by a 2-back block containing a random order of matching and non-matching trials per block. Matching trials in the 1-back block were trials containing a letter that matched the letter immediately preceding it. Matching trials in the 2-back block were trials containing a letter that matched the letter two trials immediately preceding it. The 2-back block is more challenging in that it places greater demands on working memory than the 1-back block. Each *n*-back test block consisted of two sets of 40 (30 non-matching & 10 matching) trials. Each block used five random letter stimuli out of the 20 with a randomized order of trials within task blocks and equally probable presentation of stimuli (eight trials for each letter). All stimuli were approximately 3.4 cm tall presented one at a time on a black background on a computer screen for 500 ms with a fixed 3000 ms intertrial interval. Correct responses were recorded with a right button press for matching trials and a left button press for non-matching. This task was successfully used with children aged seven to 13 years in a large normative study (Pelegrina et al., 2015). Memory sensitivity (d') was used as the dependent measure of working memory performance because it accounts for overall accuracy of participants in discriminating among stimuli. The maximum d' score for this task is 3.8 using the Verde, MacMillan, and Rotello (2006) transformation.

Affective Valence. The children's feeling scale (CFS; Hulley et al., 2008) is designed to measure the affective states of children. The current study used a modified version with a 9-point bipolar rating scale from -4 "*bad*" to +4 "*good*" with a 0 "*OK*" midpoint. Modifications also included updating the faces to emoji-based faces to make the scale more contemporary than the original CFS. Affective valence is the degree of pleasantness of an affective state (i.e., good-bad; Russell & Barrett, 1999) and decrease in pleasant affect is a primary response to social exclusion (Baumeister & Leary, 1995). Dependent measures of affective valence were the pairs of reports immediately before and after the first two games of Cyberball. The remaining 10 measures of affective valence were used primarily to monitor participants' feelings and to mitigate potential participant suspicion of introducing an explicit report of affect tied to the Cyberball game.

Aerobic Fitness. Participants completed a test of maximal oxygen consumption (VO_2 max), considered the criterion measure of cardiorespiratory fitness (American College of Sports Medicine, 2010). Oxygen consumption was measured using a computerized indirect calorimetry system (ParvoMedics True Max 2400, Sandy, UT) while participants followed a modified Balke protocol (American College of Sports Medicine, 2010), that used a self-selected constant walking or running speed unique to each participant and increased the grade of a motor-driven treadmill by 2.5% every two minutes until volitional exhaustion. Averages for VO_2 and respiratory exchange ratio (RER) were assessed every 20 seconds and heart rate was assessed using a Polar heart rate monitor (Polar WearLink H7; Polar Electro, Finland). Ratings of perceived exertion were also collected every two minutes with the children's OMNI scale (Utter, Robertson, Nieman, & Kang, 2002).

Attainment of VO_2 max was evidenced by: (1) a peak heart rate > 185 bpm (American College of Sports Medicine, 2010) and a heart rate plateau (Freedson & Goodman, 1993), (2) RER greater than 1.0 (Bar-Or, 1983), (3) OMNI ratings of perceived exertion greater than seven (Utter et al., 2002), and/or (4) a plateau in oxygen consumption corresponding to an increase of less than 2 ml/kg/min despite an increase in workload. Participants' VO_2 max was then norm referenced to account for age and sex related differences in maximal oxygen consumption (Shvartz & Reibold, 1990).

1.4. Statistical analyses

Data were screened for normality, univariate outliers, and multivariate outliers (Tabachnick & Fidell, 2013), revealing no issues that affected the primary analyses. Descriptive analyses were conducted for all variables of interest. Because participants were not randomized, were tested for distinct purposes, and completed the study by group order,

[1] Cyberball has been updated to version 5.0: https://www1.psych.purdue.edu/~willia55/Announce/cyberball.htm.

analyses were conducted separately for experimental and control groups.

The manipulation check items in response to experimental conditions were evaluated with separate repeated measures analysis of variance models with Condition (experimental – inclusion, exclusion, inclusion; control – inclusion, inclusion, inclusion) as the within-subject variable. Planned post-hoc comparisons for the experimental group (that was exposed to the social exclusion condition) compared the first inclusion vs. exclusion and exclusion vs. the second inclusion condition whereas no post-hoc comparisons were planned for the control group.

Analyses focused on the segment of interest in the study, which consisted of the first two Cyberball administrations and associated measures (affective valence assessments, post-Cyberball manipulation check, post-Cyberball *n*-back task). For the experimental group, the role of aerobic fitness on affective valence and working memory performance in response to experimental conditions was evaluated by separate repeated measures analysis of covariance models with Condition (inclusion vs. exclusion) as the within-subject variable, Aerobic Fitness as the covariate, and the interaction of Condition × Aerobic Fitness as the interaction term. Shifts in affective valance (immediately before and after Conditions) were analyzed separately with dependent *t*-tests. To interpret interactions, change scores (exclusion – inclusion) were regressed onto Aerobic Fitness, after controlling for the influence of Age for cognitive developmental differences, and then plotted. Regression coefficients and their bootstrapped bias-corrected 95% confidence intervals are reported in brackets.

For the control group, separate repeated measures analysis of covariance models were conducted, with Condition (inclusion vs. inclusion) as the within-subject variable and Aerobic Fitness as the covariate. Because the goal of the control group was to gain insight into the extent to which practice effects inherent in the experimental protocol may have influenced the measures of interest, only the main effect of Condition was evaluated.

All post-hoc pairwise comparisons used *t*-tests with Cohen's d_{rm} effect sizes that adjust for the correlation of paired data (see Lakens, 2013) and 95% confidence intervals surrounding effect sizes are reported in brackets. Sensitivity analyses for the main effect of condition revealed that the experimental group sample size enabled detection of an effect size Cohen's $d = 0.33$, whereas the control group sample size enabled detection of an effect Cohen's $d = 0.6$ at 80% power and alpha at .05 (Faul et al., 2007). This leaves the experimental group sufficiently powered in light of previously published effect sizes of $\geq$ .86 with similar youth samples (i.e., Hawes et al., 2012; Sebastian et al., 2010) and the control group sufficiently powered to place the experimental findings in clearer relief.

2. Results

2.1. Manipulation checks

For the experimental group, results showed significant differences among Conditions in reports of feeling happy, $F(2,33) = 25.4$, $p < .001$, partial $\eta^2 = .61$, feeling sad, $F(2,33) = 14.0$, $p < .001$, partial $\eta^2 = .46$, and feeling ignored, $F(2,33) = 93.9$, $p < .001$, partial $\eta^2 = .85$. Participants in the experimental group reported feeling less happy, $t(34) = -6.9$, $p < .001$, $d_{rm} = -1.6$ [-2.2, -1.0], more sad, $t(34) = 5.4$, $p < .001$, $d_{rm} = 1.3$ [0.7, 1.8], and more ignored, $t(34) = 13.8$, $p < .001$, $d_{rm} = 3.1$ [2.3, 4.0], after being excluded compared to being included. After being included again, participants reported feeling happier, $t(34) = 7.1$, $p < .001$, $d_{rm} = 1.5$ [.9, 2.0], less sad, $t(34) = -5.3$, $p < .001$, $d_{rm} = -1.1$ [-1.6, -0.6], and less ignored, $t(34) = -13.3$, $p < .001$, $d_{rm} = -2.9$ [-3.6, -2.1], compared to being excluded. There was no evidence that responses to manipulation check items were related to aerobic fitness, r's = -.15 to .28, p's > .11.

For the control group, results showed no difference among Conditions in reports of feeling happy, $F(2,12) = 2.2$, $p = .14$, partial $\eta^2 = .17$, feeling sad, $F(2,12) = 1.6$, $p = .23$, partial $\eta^2 = .13$, and feeling ignored, $F(2,12) = 1.0$, $p = .38$, partial $\eta^2 = .08$. Descriptive statistics for manipulation check items are found in Table 2. Effect sizes observed in the experimental group were large whereas there was no evidence of significant effect sizes in the control group.

2.2. Working memory responses

Unexpectedly for participants in the experimental group, memory sensitivity was significantly different from inclusion to exclusion for both the 1-back task, $F(1,33) = 8.2$, $p = .007$, partial $\eta^2 = .20$, and the 2-back task, $F(1,33) = 17.8$, $p < .001$, partial $\eta^2 = .35$ (see Table 3). A higher d' score was observed for both 1-back performance, $t(34) = 2.8$, $p < .001$, $d_{rm} = 0.5$ [0.1, 0.8], and 2-back performance, $t(34) = 4.0$, $p < .001$, $d_{rm} = 0.4$ [0.2, 0.6], after exclusion compared to after inclusion.

For participants in the control group, no changes in memory sensitivity were evident in the 1-back task, $F(1,10) = 0.3$, $p = .63$, partial $\eta^2 = .03$, or the 2-back task, $F(1,10) = 0.03$, $p = .86$ partial $\eta^2 = .003$. Descriptive statistics for working memory performance are reported in Table 3.

2.3. Affective responses

For participants in the experimental group, affective valence was significantly different from inclusion to exclusion, $F(1,33) = 22.9$, $p < .001$, partial $\eta^2 = .41$. Affective valence was significantly lower after exclusion compared to inclusion, $t(34) = -4.4$, $p < .001$, $d_{rm} = -1.0$ [-1.5, -0.5]. After being included participants reported a mean of 3.9 ± 0.4 on the CFS, corresponding to a feeling state of good. After being excluded participants reported a mean of 2.3 ± 2.1, corresponding to a feeling state of just above fairly good. When analyzing shifts in affective valence, a significant positive shift in affective valence was found from before to after being included, $t(34) = 2.3$, $p = .027$, $d_{rm} = 0.4$ [0.1, 0.8], and a significant negative shift in affective valence from before to after being excluded, $t(34) = -3.6$, $p < .001$, $d_{rm} = -0.8$ [-1.3, -0.3].

For participants in the control group, there was no evidence that affective valence differed after each of the first two inclusion conditions, $F(1,10) = 1.0$, $p = .34$, partial $\eta^2 = .09$. Participants reported a mean of 3.2 ± 1.2 after the first instance of being included and a mean of 3.3 ± 1.2 on the CFS after the second instance. Both reports correspond to a feeling state between good and fairly good. When analyzing shifts in affective valence, there was no evidence that either of the first two inclusion manipulations produced shifts in affective valence, p's > .05.

2.4. Aerobic fitness and responses to social exclusion

There was no evidence that aerobic fitness moderated the effect of experimental condition on memory sensitivity from the 1-back task, $F(1, 33) = 2.7$, $p = .11$, partial $\eta^2 = .08$ (see Fig. 2, Panel A). Performance on the 1-back task after inclusion was significantly negatively related to changes in 1-back performance, $r = -.58$ [-.77, -.31]., $p < .001$.

Aerobic fitness moderated the effect of experimental condition on the more challenging 2-back task, $F(1, 33) = 5.2$, $p = .029$, partial $\eta^2 = .14$. This interaction revealed that there was a positive relationship between aerobic fitness and changes in memory sensitivity from inclusion to exclusion, $\beta = .37$ [.08, .61], $p = .03$, $\Delta R^2 = .14$ (see Fig. 2, Panel B). The interaction revealed that more aerobically fit participants showed greater change scores than less aerobically fit participants. That is, higher aerobic fitness was associated with greater increases in memory sensitivity. Performance after inclusion was not related to change in 2-back memory sensitivity from inclusion to exclusion, $r = -.07$ [-.36, .21].

Aerobic fitness significantly moderated the effect of experimental condition on affective valence, $F(1, 33) = 6.4$, $p = .016$, partial $\eta^2 = .16$. This interaction revealed that there was a significant positive relationship between aerobic fitness and changes in affective valence from inclusion to exclusion, $\beta = .40$ [.22, .58], $p = .016$, $\Delta R^2 = .16$ (see Fig. 2,

Table 2
Descriptive Statistics for Manipulation Checks.

	Experimental Group			Control Group		
	Included	Excluded	Included	Included	Included	Included
Variable	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*
Happy	4.5 ± 0.7	3.1 ± 1.1	4.6 ± 0.9	4.3 ± 1.1	4.4 ± 1.1	4.4 ± 1.1
Sad	1.0 ± 0.2	2.1 ± 1.2	1.1 ± 0.3	1.3 ± 0.6	1.3 ± 0.7	1.2 ± 0.6
Ignored	1.1 ± 0.4	3.9 ± 1.2	1.3 ± 0.5	1.0 ± 0	1.1 ± 0.3	1.2 ± 0.4

Note: Responses scale ranges from one "not at all" to five "very much so".

Table 3
Descriptive Statistics for Working Memory.

	Experimental Group				Control Group			
	1-back		2-back		1-back		2-back	
	Inclusion	Exclusion	Inclusion	Exclusion	Inclusion	Inclusion	Inclusion	Inclusion
Variable	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*
Hit %	86.9 ± 12.8	89.7 ± 12.5	66.3 ± 12.4	74.9 ± 15.4	82.3 ± 14.6	84.5 ± 12.6	68.0 ± 15.4	68.8 ± 17.8
False Alarm %	7.0 ± 6.9	3.5 ± 3.7	16.0 ± 12.4	14.1 ± 10.6	6.4 ± 4.4	5.6 ± 3.4	18.4 ± 14.4	20.4 ± 13.3
RT (ms)	812.8 ± 259.8	745.6 ± 216.4	965.7 ± 359.8	953.6 ± 378.5	977.1 ± 362.2	1007.3 ± 371.5	1165.5 ± 511.8	1147.9 ± 405.9
d'	2.6 ± 0.7	2.9 ± 0.7	1.5 ± 0.7	1.8 ± 0.8	2.7 ± 0.8	2.9 ± 0.7	1.5 ± 0.7	1.5 ± 0.9

Note: Hit % = percent of matching trials correctly identified as matching, False alarm % = percent of non-matching trials incorrectly identified as matching, RT = response time, *d*' = memory sensitivity.

Panel C). Less aerobically fit participants had greater decreases in affect from inclusion to exclusion than participants who were more aerobically fit. Affective valence after inclusion was not significantly related to changes in affect from inclusion to exclusion, r = -.10 [-.44, .33].

3. Discussion

The goal of the study was to determine if aerobic fitness moderates children's affective and working memory responses to social exclusion. Findings indicate that social exclusion affects the pleasant feelings and working memory performance of girls. Aerobic fitness appears to moderate these effects such that girls with higher aerobic fitness show a smaller decrease in pleasant affect and larger improvement in working memory performance. The collective results suggest that more aerobically fit girls better self-regulate in the face of social exclusion than less aerobically fit girls.

Manipulation check results showed that social exclusion made participants feel less happy, more sad, and more ignored compared to social inclusion. These findings are consistent with the use of Cyberball with children for producing mild social exclusion in a laboratory setting (Zadro et al., 2013). Manipulation check items returned to post-inclusion levels following the third game where participants were included, suggesting the impact of the experimental protocol can be reversed. Importantly, manipulation check results were not related to aerobic fitness, suggesting participants perceived social exclusion similarly regardless of fitness level.

The first hypothesis that social exclusion would decrease pleasant affect and working memory performance received partial support. Experimental group participants reported a negative shift in pleasant affect from feeling good to fairly good immediately before and after being excluded and also significantly lower than after being included. These results support previous meta-analytic findings that social exclusion can produce negative shifts in pleasant affect (Blackhart et al., 2009). This negative shift also aligns with adult literature, suggesting that laboratory manipulations of social exclusion reduce pleasant feelings, but are not unpleasant or make participants feel bad overall (Blackhart et al., 2009; Delli Paoli, Smith, & Pontifex, 2017).

Working memory performance results of the experimental group were opposite of hypotheses. Performance on both the 1-back and more challenging 2-back task was better after exclusion than inclusion. These findings conflict with previous research showing that social exclusion impairs working memory performance (e.g., Hawes et al., 2012). Social exclusion is hypothesized to place greater demands on cognitive control systems that are responsible for self-regulation (Baumeister et al., 2002). From the standpoint of limited cognitive capacity, this would be expected to impair performance on subsequent cognitive tasks. What, then, might explain the present finding? Given the repeated measures design, the finding may represent a practice effect. Examination of the control group findings is helpful in evaluating this possibility. These findings showed the working memory results under consecutive inclusion conditions to produce no change in performance. Thus, the findings of the present study do not appear to be explained by practice effects, and instead suggest that social exclusion may improve working memory performance in this laboratory context.

Although laboratory research provides a controlled setting to observe social exclusion, manipulating artificial and new relationships in a laboratory setting is likely not as powerful as the experience of social exclusion outside of the lab. Effects may be stronger when being socially excluded by people who are physically present and valued by the targets of social exclusion (Blackhart et al., 2009). Social relationship difficulties with peers at school, for example, are likely more disturbing to a child than exclusion from a computer ball-toss game. Accordingly, the lab-based social exclusion protocol may not be sufficiently taxing to result in the cognitive interference expected within a limited capacity framework. A related consideration is that working memory tasks were completed after social exclusion ended rather than simultaneously with the social exclusion or within a series of social exchanges. Demands on cognitive resources may be higher in an ongoing social interaction outside of the lab where an individual must put forth effort to plan behaviors and process ongoing social information to help regain inclusion (Williams, 2009). This noted, our sequence of study tasks provided the participant with no opportunity for reparative behavior with the other virtual players and involved immediate performance of the task after answering questions about how the social exchange was perceived. This should enable acute demands imposed by social exclusion to be observed in the cognitive task. Also, we did not observe the absence of a social exclusion effect. We instead found working memory performance improvement for the experimental group after social exclusion.

These working memory findings introduce the possibility that the mild form of social exclusion studied here activates rather than

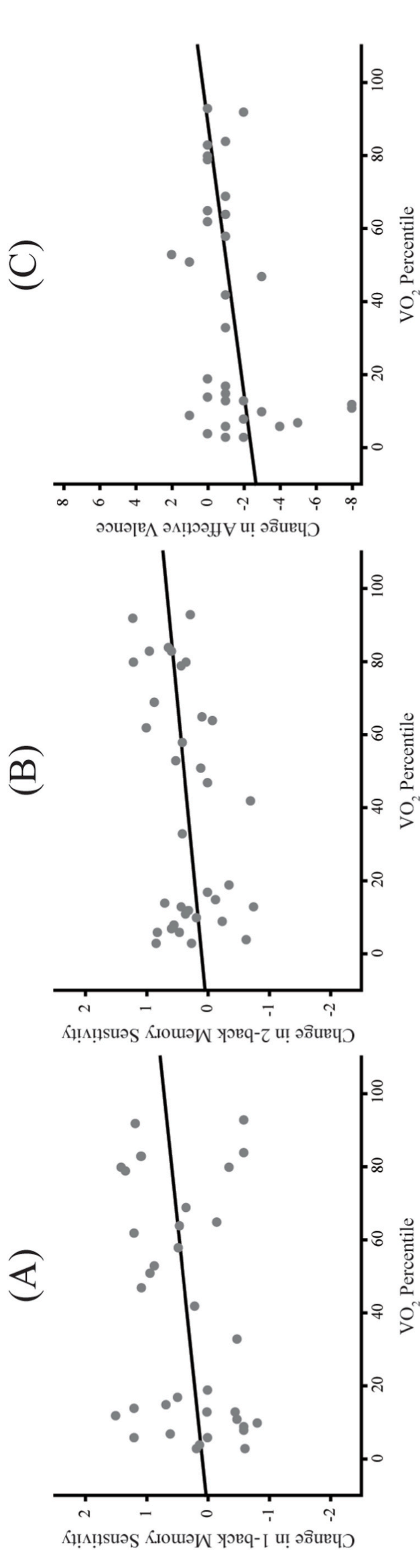

Fig. 2. Fitness with changes in affective valence and working memory. Positive values along the y-axis represent increases and negative values represent decreases from inclusion to exclusion for dependent variables. Panel (A) shows changes in 1-back task performance. Panel (B) shows changes in 2-back task performance. Panel (C) shows changes in affective valence.

interferes with cognitive control systems associated with self-regulation. Indeed, social exclusion may marshal cognitive resources in this self-regulatory process (Vijayakumar et al., 2017). This activation of resources may not rise to a level of cognitive interference when one is removed from the social interaction and does not have opportunity to engage in social monitoring or reparative behavior. In this context the elevated activation may serve as a resource that benefits working memory performance. Although extant neuroimaging research captures brain activity during on-going social exclusion (Vijayakumar et al., 2017), future research should consider capturing activation after exclusion ends to help gauge this hypothesis.

Of primary interest in the present study was the role of aerobic fitness in possibly moderating responses to social exclusion. The findings showed possessing higher levels of fitness to be associated with larger improvements in working memory performance as compared to those with lower levels of fitness. Also, possessing a higher level of fitness was associated with smaller decreases in affective valence than experienced by those possessing a lower level of fitness. Together these findings reveal that girls with greater aerobic fitness are more resilient in the face of social exclusion as administered in this laboratory study. They garner cognitive resources that benefit working memory performance and they better retain pre-exclusion positive affect. This potentially is explained by aerobic fitness being positively associated with improved neurophysiological function. Aerobic fitness is positively associated with neural network efficiency and connectivity (Chaddock et al., 2010; Chaddock-Heyman et al., 2014; Voss et al., 2011). More aerobically fit girls may be less cognitively taxed to regulate the effects of social exclusion because of a greater ability to adopt compensatory processing strategies and meet cognitive demands.

There are theoretical and possible practical implications of this study. Williams's temporal need threat model (2007; 2009) indicates that the effects of social exclusion occur in a series of stages over time. The results of this study show that aerobic fitness moderates the effects during the reflective stage (i.e., on-going regulation of affect and working memory). Girls with higher aerobic fitness may be less negatively impacted because they are able to more efficiently regulate effects of social exclusion. Therefore, aerobic fitness may protect against maladaptive outcomes throughout development. Developing children's aerobic fitness may enable them to be more resilient when facing challenges in making new friends or being socially included, and perhaps may make them less likely to be on a "social perimeter" in important developmental settings (Bowker et al., 2014; Cacioppo & Cacioppo, 2014; Leary, 2001; Newcomb et al., 1993). Furthermore, aerobic fitness was positively associated with greater improvements in working memory performance, suggesting that improving a child's aerobic fitness may benefit academic (Raghubar et al., 2010) and social functioning (de Wilde et al., 2016). Therefore, there appears to be value to social functioning in engaging in moderate-to-vigorous intensity physical activity that can improve aerobic fitness. This can be accomplished in a host of physical activity settings (e.g., physical education, sport), and in itself can provide meaningful opportunities for positive social relationships with peers that contribute to positive social development, physical activity engagement, and well-being (Smith, 2019; Smith & Delli Paoli, 2018). This noted, any practical implications of results are necessarily tentative and preliminary. Replication and extension of key study findings will be required as will addressing limitations of the current work in future research efforts.

The sample of the present study was delimited to girls to remove assigned sex as an additional between-subjects factor. Moreover, some research indicates that social exclusion is a more salient experience for female than male recipients (Beneson et al., 2013). Future research should consider potential sex effects and the magnitude of these effects for different levels of aerobic fitness. Another concern related to the sample is that aerobically fit children may also possess psychological and other characteristics (e.g., good health, intelligence) as well as social skills that enable greater participation in physical activity and social resilience. The links among physical fitness, social relationships, and healthy functioning are dynamic and challenging to study. Children with poorer physical fitness may be more likely to face relationships difficulties and such difficulties are a common reason why young people discontinue physical activity participation (Balish, McLaren, Rainham, & Blanchard, 2014). A greater understanding of the links among fitness, social relationships, and healthy functioning may benefit from future research focused on how young people gain entry to and persist with activities that improve their fitness.

Despite the control group sample being closely matched on demographic characteristics of the experimental group, another limitation is that the study did not employ a true experimental design. When considering the resource demands of social exclusion research, securing child participants, and aerobic fitness testing, this study helps justify the pursuit of future research that uses true experimental designs of greater complexity. Relatedly, the sample size of the control group was only sufficiently powered to detect a moderate practice effect and it is possible that a smaller practice effect may exist (Schweizer and Furley, 2016). Of similar concern is that social inclusion may be an alternative manipulation and not a true control. Although inclusion is a typical experience for children, its use as a frame of reference for interpreting social exclusion findings must be acknowledged and considered in this research area. Finally, as with all research involving deception, there exist issues of believability. The protocol described in this study helped facilitate believability and rapport with participants. Although we did not directly measure believability, no participants in this study explicitly stated suspicions about the Cyberball protocol during debriefing. Assessment of the believability of this social exclusion paradigm with children could further affirm the effectiveness of the Cyberball protocol.

Beyond these matters pertaining to research design, future research should examine additional aspects of physical fitness. Physical fitness is a multidimensional construct comprising aerobic fitness, muscular endurance, muscular strength, flexibility, and body composition. This is an important consideration because research indicates that components of physical fitness other than aerobic fitness are associated with cognitive performance (Kao et al., 2017) and psychosocial well-being (LaVigne et al., 2016). As a primary context for children to achieve physical fitness, sport environments should also be considered with respect to their qualitative features in future developmental research on social exclusion. For example, sports vary in their cognitive complexity and degree of social interaction as well as physical exertion. Skill acquisition processes, which possess both physical and mental demands, may undergird cognitive performance benefits of engagement in sport and other physical activities (Tomporowski & Pesce, 2019).

Within the context of the limitations and directions for future research described above there remain several notable strengths of the present research. Results highlight that aerobic fitness may affect how children respond to social exclusion. Research exploring factors that can mitigate the potential negative effects of social exclusion are uncommon in the current literature base, especially for children. Second, the repeated measures design allowed for a richer understanding of shifts in affect and changes in cognition with social exclusion. Lab-based research on social exclusion more typically has employed between-subjects designs that cannot as powerfully address this (Blackhart et al., 2009). Lastly, social exclusion was manipulated in a controlled setting that allowed assessment of direct effects of social relationships, which offers an advantage over observational or correlational research. Considered together, this study enhances understanding of childhood social exclusion and provides a novel contribution to the developmental and exercise psychology literatures.

This research extends understanding of how aerobic fitness may benefit well-being, specifically showing that it holds potential to distinguish the magnitude of effects of social exclusion. Girls with higher aerobic fitness may be able to cope better after social exclusion than those with lower aerobic fitness. Importantly, aerobic fitness can be developed by participating in accessible exercise and sport activities. Though the findings reported here are preliminary and require replication, they suggest value in pursing future experimental research that addresses working memory performance and affect following social interactions, exploring other components of physical fitness, and considering other potential demographic and psychological characteristics that may help explain children's resilience (or not) in challenging social settings.

CRediT author statement

Anthony G. Delli Paoli: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing: original draft, Writing: review & editing. **Alan L. Smith:** Conceptualization, Funding acquisition, Formal Analysis, Methodology, Project administration, Resources, Supervision, Writing: original draft, Writing: review & editing. **Matthew B. Pontifex:** Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Resources, Software, Supervision, Writing: original draft, Writing: review & editing. **Jason S. Moser:** Conceptualization, Methodology, Writing: review & editing.

Declaration of competing interest

None.

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