



**Early Education and Development** 

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/heed20

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**To cite this article:** Amanda L. McGowan, Hope K. Gerde, Karin A. Pfeiffer & Matthew B. Pontifex (2023) Meeting 24-hour movement behavior guidelines in young children: Improved quantity estimation and self-regulation, Early Education and Development, 34:3, 762-789, DOI: 10.1080/10409289.2022.2056694

To link to this article: https://doi.org/10.1080/10409289.2022.2056694

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### Meeting 24-hour movement behavior guidelines in young children: Improved quantity estimation and self-regulation

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#### ABSTRACT

Research Findings: The present study examined the associations among meeting 24-hour movement behavior recommendations set by the World Health Organization (2019) and young children's self-regulation and quantity estimation skills in a sample of 123 children (n = 65 female;  $4.9 \pm 0.7$  years) in mid-Michigan. Meeting screen time recommendations alone, meeting physical activity recommendations in combination with either sleep or screen time recommendations, meeting more recommendations overall, and being active more days weekly were associated with superior quantity estimation. Meeting more guidelines and accruing more moderate-to-vigorous physical activity daily related to better self-regulation. Improvements in self-regulation partially mediated the relation between physical activity and quantity estimation. Practice or Policy: Our findings identify benefits for adopting specific physical activity guidelines for children (e.g., physical activity, screen time, and sleep duration) and integrating these into early learning standards so both families and schools can support children's capacity to meet 24-hr movement guidelines and thus support cognitive health. An active lifestyle in early childhood may support young children's self-regulation and early educational outcomes, with physical activity promotion efforts during early childhood serving as a viable means to address growing expulsion rates in preschool-aged children.

Children who exhibit challenging behaviors, including low self-regulation, inattention, and lackof inhibitory control, may miss out on learning opportunities (Cole et al., 2008; Montroy, Bowles, & Skibbe, 2016). For older children, evidence exists that physical activity enhances self-regulatory skills, including attention and inhibitory control (de Greeff et al., 2018), as well as academic achievement particularly in areas such as mathematics (Chaddock-Heyman et al., 2015; Correa-Burrows et al., 2014; Donnelly et al., 2009; Resaland et al., 2016). However, the relations between these skills with physical activity are underspecified for young children (Becker et al., 2014) who are rapidly developing early self-regulation and components of early numeracy, such as quantity estimation. Thus, there is a pressing need to understand what role physical activity plays in influencing young children's self-regulation and early academic achievement. Understanding such relations may help inform the design of classroom-based activity-promoting interventions to support teachers in addressing challenging behaviors – thereby enhancing educational and socio-emotional outcomes during the early years.

Supplemental data for this article can be accessed publisher's website.

### Movement across the Whole Day Matters

Physical activity is defined as all bodily movement requiring energy expenditure, including movement during leisure time (e.g., active play), for transport or getting to places (e.g., biking to school), or as part of a person's job (e.g., carrying blocks; Caspersen et al., 1985). Improving physical activity, however, could occur at the expense of another health behavior (e.g., getting enough sleep). Over the past decade, studies have indicated the independent contributions of greater levels of physical activity, sufficient sleep, and reduced sedentary behavior for physical health in school-age children (Cappuccio et al., 2008; Janssen & LeBlanc, 2010; Tremblay et al., 2011) and to a lesser extent young children (Kuzik et al., 2017). To this end, a new paradigm gaining momentum integrates guidelines for all movement behaviors (i.e., physical activity, sedentary behavior, and sleep) across the 24-hour day. In the same way that we would not examine the effects of diet on weight status by only considering what someone ate for breakfast, the impact of physical activity on physical and brain health is likely affected by the previous night's sleep and duration of extended sitting (i.e., sedentary behavior) throughout the day. Support for such an approach integrating physical activity, sleep, and sedentary behavior was strengthened when the World Health Organization (2019) released 24-hour movement behavior guidelines for children younger than 5 years old - a population previously underserved by physical activity guidelines. Highlighting that movement across the whole day matters, a growing body of evidence has begun to examine the health impacts of specific combinations of movement behaviors, which encompass sleep, sedentary screen time, and physical activity across a 24-hour period (Tremblay et al., 2017; World Health Organization, 2019).

Although the vast majority of evidence demonstrates greater physical activity participation relates to improved attention, inhibitory control, and academic achievement in older children, understanding the effects of physical activity, sleep, and sedentary behavior on brain health in young children remains in its infancy (Pate et al., 2019). At present, the notion that physical activity may facilitate cognitive development during early childhood is largely drawn from evidence in older children and adults. Drawing such conclusions are tenuous given that the physical activity behavior of young children differs considerably from that observed in older children and adults; young children are different anatomically and physiologically, and their psychological and cognitive capacities differ greatly from their youth and adult counterparts (Malina et al., 2004). In contrast to the physical activity behavior of older children and adults, which is typically planned, structured, repetitive, and often has the goal of improving fitness, young children engage in physical activity for shorter durations, with frequent changes in activity that are largely considered to be intrinsically motivated and freely chosen. Young children are more likely than adults and older children to engage in energetic play rather than planned exercise; they are still developing the complex motor, cognitive and social skills required for many organized sports. Relative to older children and adults, young children need more hours of sleep a pattern of behavior that is crucial for healthy development. Importantly, sleep is critical for executive functions and self-regulation especially in young children (Bernier et al., 2013; Williams et al., 2016). Exhibiting sleep problems or poor sleep patterns during early childhood is associated with lower selfregulation, greater hyperactivity, and greater risk of difficulties with emotion regulation - placing these children at higher risk for poor school adjustment and scholastic performance (Williams et al., 2016).

Sedentary behavior is characterized as any waking behavior with a low energy expenditure while sitting, reclining, or lying down (Gibbs et al., 2015), encompassing passive pursuits such as screen time (i.e., TV, tablet use) and educational pursuits such as reading. Reducing *sedentary screen time* – a novel inclusion to the 24-hour movement guidelines for the early years (Tremblay et al., 2017; World Health Organization, 2019) – is based on the findings that heavy screen exposure has been related to language delays (Chonchaiya & Pruksananonda, 2008), attentional difficulties (Zimmerman & Christakis, 2007), sleep problems (Garrison & Christakis, 2012), and excess adiposity (Jackson et al., 2009) in young children. Moreover, screen time exposure during the early years has the highest potential to become habit forming, placing children at greater risk of becoming sedentary or overweight later in life (Courage & Setliff, 2010; Jackson et al., 2009). While the ramifications of increased screen time on

pediatric populations remains underspecified (Radesky & Christakis, 2016), screen time is an important component of children's sedentary behavior largely overlooked by past research on the association between physical activity and self-regulation in young children.

### Self-regulation

Evidence generally supports the notion that self-regulation is a multidimensional construct (Diamond, Stuss, & Knight, 2002; McClelland & Cameron, 2012). Cognitive perspectives suggest the subcomponents of self-regulation include attention, cognitive flexibility, working memory, and inhibitory control (also considered executive functions). Personality perspectives characterize self-regulation as the capacity to handle emotions and behaviors in accordance with situational demands. Although researchers have operationalized self-regulation differently, with some measuring components of executive function (Becker & Nader, 2021; Bezerra et al., 2020; Willoughby et al., 2018) and others using on-task/off-task behavior (Mahar et al., 2006; McGowan et al., 2020, 2021; Webster et al., 2015), context is important for understanding how children self-regulate their behavior. Thus, it is important that self-regulation measures be relevant in the context in which the goal-directed behavior occurs. Although there remains great debate surrounding the precise definition of self-regulation and its relation to executive function (Allan & Lonigan, 2011; Eisenberg et al., 2010; Garon et al., 2008), we define self-regulation as the deliberate application of controlling and directing behavioral responses to achieve social, personal, or academic goals (Vohs & Baumeister, 2016). We operationalize selfregulation as the frequency of children's disruptive off-task behaviors observed during performance of a quantity estimation task, which is an educational context. In this way, we employ an ecologicallyvalid measure of behavioral self-regulation observable in a naturalistic context (e.g., while performing an early numeracy task) in line with McClelland and Cameron's (2012) definition of self-regulation. Self-regulation is the integration of executive functions, including the ability to pay attention, switch focus, remember directions, and execute self-control in support of behavioral responses, such as estimating quantities or waiting to be called upon before blurting out an answer (McClelland & Cameron, 2012). Indeed, this definition of self-regulation underlies off-task behavior - the assessment of self-regulation used in the present investigation - which relates to academic achievement (McClelland & Cameron, 2012) and is unrelated to executive functions (Blair et al., 2015), which are considered a unitary construct in young children (Wiebe et al., 2008). However, the physical activity literature has predominantly examined the relations between physical activity and components of executive function (Pontifex et al., 2019), thus we review relevant literature from both cognitive and personality perspectives of self-regulation.

### Early Self-regulation and Math are Important

Early self-regulatory skills (McClelland & Cameron, 2012; McClelland et al., 2007) are predictive of later life success, including greater self-esteem, superior professional attainment, and better health in childhood and adolescence (Bronson, 2000; Diamond et al., 2002; McClelland & Cameron, 2012; Moffitt et al., 2011). Moreover, acquiring strong self-regulation skills during the early years lays the foundation for developing positive classroom behaviors – such as paying attention, remembering instructions, and staying on task in the face of distractions – in addition to enhancing academic skills (McClelland et al., 2007). In preschool, self-regulation is associated with enhanced literacy, vocabulary, and math outcomes as well as gains in these educational outcomes during the school year (McClelland et al., 2007). Longitudinally, aspects of self-regulation measured at age four predict the likelihood of completing college (McClelland et al., 2013). Growing evidence indicates that children exhibit early, rapid gains in behavioral self-regulation during the preschool years (Montroy, Bowles, & Skibbe, 2016), with children who develop self-regulation earlier exhibiting greater gains in academic outcomes from preschool to second grade (Skibbe et al., 2019). Attention and inhibitory control are key components of self-regulation that are critical for positive classroom behavior and successful academic

learning (Carlson, 2005). For instance, attention in pre-kindergarten predicts reading and math achievement in elementary grades (Allhusen et al., 2003); preschoolers demonstrating difficulty paying attention and using inhibitory control to complete goal-directed tasks exhibited lower academic achievement (Bronson et al., 1995).

In addition to self-regulation, early quantitative knowledge is a key predictor of later overall academic achievement. The development of foundational mathematics knowledge includes numbering, number relations, and arithmetic operations (Jordan et al., 2007). These domains of early mathematical competence entail skills such as counting, quantity estimation, and demonstrating relationships between quantities on the mental number line (Purpura et al., 2011). Unfortunately, children who lag behind their peers on these skills upon school entry will exhibit slower gains in quantitative knowledge and experience enduring academic challenges (Duncan et al., 2007). Domainspecific factors, such as self-regulation appear to be particularly influential for aspects of early mathematics achievement (Geary & Hoard, 2005). For example, preschoolers' behavioral selfregulation was associated with and predicted growth in early math skills in first grade (Ng et al., 2015), and children exhibiting poor self-regulation during the early years exhibited lower math achievement scores across elementary school (Massetti et al., 2008). Thus, interventions that support young children's self-regulation, such as finding ways to increase children's physical activity, can support their early math achievement and thus have lasting impacts on their academic trajectories. For example, the benefits of physical activity also extend to classroom behavior, with children exhibiting greater on-task behavior - an index of behavioral self-regulation - when provided increased opportunities to engage in physical activity throughout the school day (Donnelly et al., 2009; Mahar et al., 2006; Szabo-Reed et al., 2017). In this context, physical activity may improve young children's math achievement by enabling gains in aspects of self-regulation that enable better learning of novel information (McGowan et al., 2020, 2021).

### 24-Hour Movement Guidelines for Young Children

Until recently, young children have been underserved by physical activity guidelines, perhaps due to the misconception that early childhood is a time when children are naturally active. In reality, approximately 60% of children spend 25-32 hours weekly in out-of-home childcare (Katzmarzyk et al., 2018), with more than 70% of their time spent sedentary (Hnatiuk et al., 2014). Additionally, children enrolled in center-based preschools and full-day kindergartens spend more time sedentary than their part-time or home-based child care counterparts (Tucker et al., 2015) – thus highlighting the sedentary nature of educational programming, even for young children, that may be contributing to challenging behaviors that impede children's participation in learning (Montroy, Bowles, & Skibbe, 2016). To address the growing trend of predominantly sedentary lifestyles - even among young children - in the United States, the Physical Activity Guidelines for Americans 2<sup>nd</sup> edition (U.S. Department of Health and Human Services, 2018) included guidance for preschool-aged children (3-5 years old) for the first time. These guidelines state that children should be physically active throughout the day to enhance growth and development and caregivers should encourage active play through a variety of activities. Although these guidelines remain vague due to a paucity of evidence during early childhood, the World Health Organization (2019) and other countries (e.g., Canada, Australia, United Kingdom, South African, and Hong Kong) have adopted 24-hour movement behavior guidelines for the early years, highlighting that movement across the whole day matters for optimal health and development (Capio et al., 2021; Draper et al., 2020; Okely et al., 2017; Reilly et al., 2020; Tremblay et al., 2017). For example, Canada has been at the forefront of developing specific 24-hour movement guidelines for the early years (Capio et al., 2021; Draper et al., 2020; Okely et al., 2017; Reilly et al., 2020; Tremblay et al., 2017). Within a 24-hour period, these guidelines recommend that preschoolers (3–4 years old) accumulate at least 180 minutes of energetic play, sleep 10–13 hours (including naps), and get no more than 1-hour of sedentary screen time; specific recommendations also included in the World Health Organization guidelines for the early years (Tremblay et al., 2017;

World Health Organization, 2019). No prior studies have examined the associations among adhering to these guidelines, self-regulation, and academic achievement in young children, which is the focus of the present study. Initial work by Bezerra et al. (2020) observed that greater amounts of physical activity related to inferior executive function in preschoolers, but when data were considered as a composition of 24-hour movement behaviors across the day, meeting more movement behavior recommendations was related to superior executive function – providing further support for research examining the continuum of movement behaviors.

### **The Present Study**

This study provides a novel contribution to the literature by examining the extent to which physical activity relates to approximate number system acuity and behavioral self-regulation, which are important school readiness skills affecting children's academic trajectories. Further, we capture the mediating role of self-regulation in the association between physical activity and approximate number system acuity that is important for theory but has been overlooked by prior research and has been difficult to quantify. The present study captured associations among individual and combinations of physical activity, sleep, and sedentary screen time with young children's quantity estimation and selfregulation in a sample of 3-5 year old children in mid-Michigan, providing a more comprehensive examination of the relation of movement behaviors to cognition than previous research in this population. Four research questions were addressed. First, what are the patterns of adherence to 24hour movement behaviors in a sample of young children living in mid-Michigan? Second, what are the associations between meeting individual and specific combinations of movement behaviors to young children's behavioral indices (reaction time, response accuracy) of quantity estimation and behavioral self-regulation (as indexed by off-task behavior)? Third, what are the associations between doses of movement behaviors (active days weekly, daily moderate-to-vigorous physical activity, daily sleep duration, daily screen time) and children's quantity estimation and self-regulation? Four, does selfregulation mediate the relation between physical activity and quantity estimation? Based on current evidence in older children and existent findings in young children, we hypothesized that (1) more children would meet sleep recommendations over screen time and physical activity recommendations; (2) children adhering to more movement behavior guidelines, especially physical activity and screen time recommendations, would exhibit superior quantity estimation (shorter reaction time and greater response accuracy) and self-regulation; and (3) a higher frequency of physical activity, more hours of sleep, and reduced screen time would be related to better quantity estimation and self-regulation; and (4) self-regulation mediates the relationship between physical activity and quantity estimation.

### Methods

### **Participants**

Using a cross-sectional design, we use child performance on a quantity estimation task with parentreported physical activity, sleep, and screen time to test the associations among adherence patterns to 24-hour movement behaviors, quantity estimation, and self-regulation. Participants for this crosssectional study were preschool-aged children  $(4.9 \pm 0.7 \text{ years}; 65 \text{ females})$  recruited from mid-Michigan. Of the 127 eligible participants, four were excluded due to computer equipment failure during cognitive testing. Analyses were conducted on a final sample of 123 participants (see Table 1). The present study was approved by the Institutional Review Board at Michigan State University. Parents/guardians of all participants provided written informed consent. All parents/guardians reported participants being free of neurological disorders or physical disabilities and indicated normal or corrected-to-normal vision. The primary guardian's education spanned advanced degree (66.7%), bachelor's degree (25.9%), associate's degree (3.7%), some college (1.9%), and high school graduate (1.9%). The secondary guardian's education spanned advanced degree (42.6%), bachelor degree

Table 1. Participant demographic characteristics and differences by sex.

Measure	All Participants	Females	Males	р
Ν	123	65	58	
Age (years)	4.9 ± 0.7	$4.8 \pm 0.8$	4.9 ± 0.6	0.41
BMI z-score	$0.2 \pm 2.6$	0.3 ± 2.2	$-0.1 \pm 3.1$	0.42
Weekly Hours Spent in Childcare	25.7 ± 17.3	24.3 ± 17.5	27.2 ± 17.2	0.37
Attending Childcare (%)	78.9%	75.4%	82.8%	0.47
Months Attended Preschool	17.2 ± 18	16.5 ± 18.4	18.0 ± 17.8	0.70
Both parents with college education or above (%)	69.9%	66.2%	74.1%	0.43
Days Active (n)	4.3 ± 2.2	4.3 ± 2.2	4.4 ± 2.2	0.76
MVPA Daily (hours)	$2.5 \pm 2.4$	3.3 ± 3.1	$3.2 \pm 2.7$	0.72
Sleep duration (hours)	10.9 ± 1.9	11.1 ± 2.2	10.8 ± 1.5	0.39

Note: *p*-values denote differences between male and female participants. Findings unchanged when controlling for hours spent in childcare, attending childcare (0 = no; 1 = yes), months attended preschool, and parent education level.

(27.8%), associate's degree (3.7%), some college (11.1%), and high school graduate (7.4%). Parents identified their child as Hispanic (11.1%), non-Hispanic (81.5%), American Indian or Alaska Native (4.8%), Asian (9.7%), Black/African American (4.9%), Multiracial (1.6%), and white (78%).

### Procedures

Participants were recruited from local childcare centers, university-based parent email lists, and posters in the local community. After confirming children met inclusion criteria (i.e., 3–5 years old, English-speaking, and indicated normal or corrected-to-normal vision) through email, participants were scheduled for a laboratory visit. At the laboratory session, parents and children completed consent/assent, and parents completed the Physical Activity Readiness Questionnaire (PAR-Q; Thomas et al., 1992). The PAR-Q ensures children had no contraindications against participating in physical activity. Next, children's height and weight were measured followed by performance of the approximate number system task on a laptop during which frequency of off-task behaviors as an index of self-regulation were observed (see Measures). While children completed the computer task, parents completed a health history and demographics questionnaire on a tablet, reporting children's age, sex, childcare hours, months in childcare, physical activity, screen time, sleep, and parental education attainment. Parents reported on children's physical activity, screen time, and sleep based on the previous 7 days (see Measures).

#### Measures

### Approximate Number System Task

Acuity of the approximate number system was assessed using a nonsymbolic magnitude comparison paradigm (McGowan et al., 2020, 2021). The task was performed on a laptop using PsychoPy 1.83.4 (Peirce, 2008). For each trial, two schools of fish were presented side-by- side on the screen using a variable stimulus duration ranging from 1250 to 3000 ms and a fixed 1000 ms post- response interval on a grey background with button-response mappings appearing below the arrays to alleviate working memory demands. Children were instructed to respond as accurately as possible by pressing the button corresponding to the school of fish containing a greater number of fish without counting (see Figure S1). Task instructions introduced the buttons to children, asking them to select the colored button (left: red, right: green) below different shapes (e.g., square, pencil, circle) to ensure children understood the color and side each button corresponded to for the fish game. Prior to practice trials, the experimenter manually advanced through 4 examples of the schools of fish asking children to select the button for the side with more fish. Such an approach ensured children understood which color button corresponded to which school of fish and that children understood the goal of the game was "to catch more fish" prior to administering the faster practice trials and experimental trials.

Following 12 practice trials, children completed 72 experimental trials divided into 3 blocks of 24 trials each. Reaction time was quantified using median speed of responding following the onset of the stimuli only for correct trials, ensuring a more representative measure of reaction time in pediatric populations by reducing the effect of trials with outlying times (McGowan et al., 2020, 2021). Response accuracy was quantified as the proportion of correct responses relative to the number of trials administered (excluding practice trials). A number of task parameters and stimuli characteristics were controlled to maintain consistency with prior work using this task successfully with preschoolers, which are described in greater detail in McGowan et al. (2020), (2021). The number of fish in each school ranged from 2 to 20. The magnitude of the difference between schools of fish ranged from 0.19 to 0.89 (smaller school/bigger school) and were equally distributed across three levels of difficulty: very easy difference ratios ( $\leq 0.30$ ; i.e., 4 fish in one school vs 16 fish in the other school), easy difference ratios (0.33 to 0.5; i.e., 6 fish in one school vs 12 fish in the other school), and hard difference ratios ( $\geq$ 0.67; i.e., 10 fish in one school vs 11 fish in the other school). The side with the greater number of fish was counterbalanced across trials. This approach ensured that children engaged the approximate number system rather than responded to other characteristics of the stimulus presentation (i.e., luminance, individual fish size). Consistent with previous investigations using this task in preschoolaged children (Ansari, 2008; Libertus et al., 2013; McGowan et al., 2020, 2021), the size of the fish were equally distributed across small (39 pixels), medium (60 pixels), and large (81 pixels) fish and the surface density of the fish were counterbalanced such that all sizes of fish occurred with equal probability within arrays of greater or less magnitude and across congruent (greater surface density for the greater quantity), incongruent (greater surface density for the smaller quantity), and neutral (matching surface density between comparisons) trials. This approach ensures that children rely on acuity of their approximate number system rather than spatial perception cues to estimate quantities.

### Self-regulation

Consistent with prior investigations in this area, frequency of off-task behavior was used as an ecologically-valid index of children's behavioral self-regulation (McGowan et al., 2020, 2021). Off-task behavior defined as motor or verbal behavior that was not relevant to or interrupted the learning situation (e.g., pressing both buttons at the same time, diverting eye contact away from the laptop screen, talking to the experimenter, getting up and walking away from the computer task). In response to children exhibiting one of these easily observable behaviors, experimenters reminded children "to press the button for the side with more fish." attempting to redirect children as would be performed by a teacher in the classroom. Total number of off-task behaviors was recorded during performance of the approximate number system task. Off-task behavior was quantified by a trained observer separate from the experimenter. Such an approach was used to maintain external validity with classroom practices – in which children are frequently redirected by teachers for exhibiting behaviors that do not follow class rules, do not support the learning situation, or are disruptive – and to reduce the time and training burden associated with other direct observation techniques. Prior work using this approach has demonstrated the definition and coding system were consistently employed and the scale for off-task behavior had sufficient reliability (ICC = 0.65; McGowan et al., 2020, 2021).

*Physical activity.* Physical activity measures were obtained using the exercise questions from the Youth Risk Behavior Survey (Centers for Disease Control, 2019; Kann et al., 2016), which demonstrate acceptable reliability (Brener et al., 1995, 2002) (ICC's  $\ge 0.76$ ) and validity (p's  $\ge 0.39$ ) as a parent report of young children's behaviors (Sarker et al., 2015; Telford et al., 2004). Parents reported the number of days that their child was physically active for a total of at least 180 minutes per day (at moderate-to-vigorous intensity) in the past 7 days. Additionally, the total duration of moderate-to-vigorous physical activity (MVPA) was examined to gain an understanding of the association between outcome variables as a function of dose of physical activity. Parents reported the number of days the child was physically active for at least 180 minutes (at moderate-to-vigorous intensity) and the average duration of physical activity on these days. Daily MVPA was calculated as [(duration  $\times$  number of

days)/7] to align with testing associations of 24-hour movement behaviors. Children were considered to meet the physical activity recommendations of the 24-hour movement guidelines for the early years if parents reported children being active 7 days per week for 180 minutes each day. Internal reliability of the physical activity measure was acceptable (Cronbach's  $\alpha = 0.70$ ).

### Screen Time

Recreational screen time was measured using the Youth Screen Time Survey (Sharif et al., 2010), which asked parents to report the number of hours per typical weekday and weekend day children spent performing a variety of recreational screen-based activities (e.g., television, video games, computer/tablet use). These items demonstrate moderate reliability (Cohen's kappas  $\geq$  0.68) and related to objectively-measured time spent in sedentary screen-based activities in adolescents,  $p's \leq .05$  (Rey-López et al., 2012). Daily recreational screen time was calculated by taking a weighted average of weekday and weekend screen time: [(the sum of weekday screen time in decimal hours 5) + (the sum of weekend screen time in decimal hours  $\times$  2)]/7. Children were considered to meet the sedentary screen time recommendation of the 24-hour movement guidelines for the early years if parents reported children accumulating  $\leq$  1 hour of daily recreational screen time. Internal reliability of the screen time measure was acceptable (Cronbach's  $\alpha = 0.84$ ).

### **Sleep Duration**

Sleep duration was measured using the Brief Infant Sleep Questionnaire (Sadeh, 2004), which asked parents to report the average number of hours of sleep during the day and nights on a typical day. These items demonstrate strong reliability ( $r's \ge 0.82$ ) and were correlated ( $r's \ge 0.27$ ) to sleep measures derived from actigraphy and sleep diaries in young children (Sadeh, 2004). Daily sleep duration was calculated by summing the number of hours of sleep during the day and night in decimal hours. Children were considered to meet the sleep duration recommendation of the 24-hour movement guidelines for the early years if parents reported children accumulating sleeping  $\ge 10$  hours daily. Internal reliability of the sleep duration measure was acceptable (Cronbach's  $\alpha = 0.66$ ).

### Meeting Individual and Combinations of Movement Behaviors

Children were considered to meet the daily guidelines if their parent reported at least 180 minutes of physical activity, at least 10 hours of sleep, and no more than 1 hour of sedentary screen time. Children were classified as (0 = not meeting, 1 = meeting) for each individual guideline. Then, children were classified as (0 = not meeting, 1 = meeting) for each of the possible combinations of guidelines (i.e., physical activity/sleep, physical activity/screen time, screen time/sleep).

### **Dose of Movement Behaviors**

To consider the dose of movement behaviors, we used the following variables from the measures: total number of guidelines met as a continuous variable (ranging from none = 0 to all = 3), number of days active weekly (ranging from 0 to 7), daily moderate-to-vigorous physical activity, daily hours of sleep, daily screen time hours (see Physical Activity, Screen time, and Sleep duration above for how these were calculated).

### Statistical Analyses

Descriptive statistics were used to summarize the proportion of children meeting 24-hour movement behavior recommendations for the early years (Tremblay et al., 2017) and *t*-tests and chi-square analyses were used to examine differences between males and females for adherence to recommendations and demographic characteristics. We tested the extent to which meeting individual and combinations of physical activity, sleep, and screen time guidelines (0 =not meeting; 1 = meeting) as well as doses of physical activity (total guidelines met as continuous variable, days active weekly, daily MVPA, daily sleep hours, daily screen time hours) were associated with quantity estimation (reaction time and response accuracy) in separate multilevel models. All mixed models followed a formal model-fitting procedure for fixed effects, random effects, and covariates. We selected the best fitting models based Akaike Information Criterion values (AIC; Akaike, 1974) as well as Bayesian Information Criterion values (BIC; Schwarz, 1978). AIC and BIC are standardized model-fit metrics allowing for the comparison of models. Preferred models have lower AIC and BIC values. To formally compare whether models with AIC and BIC values were significantly better, we compared the models differing by one degree of freedom using a log likelihood ratio test. Following this procedure allowed us to select the best-fitting most parsimonious model. We included a random intercept for participant (and Ratio when model convergence permitted) and age, sex, and BMI (body mass index) were included as covariates. Models were fit with full information maximum likelihood estimates using the nlme package (Pinheiro, 2009) in R Version 4.0.2 (R Core Team, 2019). We tested the extent to which meeting individual and combinations of movement behavior guidelines as well as doses of movement behaviors were associated with self-regulation (as indexed by off-task behavior) using separate generalized linear mixed effects models specifying a Poisson function (due to the count nature of the dependent variable) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2017). We included age, sex, and BMI as covariates. We specified a random intercept for participant.

Statistical analyses were completed using a familywise alpha level of p = .05 and Benjamini and Hochberg (1995) false discovery rate control q = 0.05. Given a sample size of 123 participants and a beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect the effects of 24-hour movement behaviors on quantity estimation exceeding a small effect size of d = 0.25 as computed using G\*Power 3.1.2 (Faul et al., 2007). To examine the extent to which selfregulation mediated the relation between physical activity and quantity estimation, mediation analyses were performed by constructing a series of linear regression models using the stats package (R Core Team, 2019) and comparing these models using the mediation package in R (Tingley et al., 2014). Unstandardized indirect effects were computed using 1,000 bootstrapped samples (Baron & Kenny, 1986; Tingley et al., 2014). Given a sample size of 123 participants and a beta of 0.20 (i.e., 80% power), the present research theoretically had sufficient sensitivity to detect the mediating effects of selfregulation on the association between physical activity and quantity estimation including covariates of age and ratio exceeding small-to-moderate effect sizes of  $f^{2'}s = 0.06$ .

As a sensitivity analysis, we estimated all models including other covariates (i.e., hours in childcare, months in preschool, parent education, and race). All results presented in the manuscript were robust to the inclusion of these other covariates and model fit criteria (AIC and BIC) suggested poor model fit and over-specification of the models. As such, we report the more parsimonious models in the main text.

### Results

### What are the Patterns of Adherence to 24-hour Movement Behaviors among Young Children?

#### **Descriptive Analyses**

To address the first aim, we sought to characterize the pattern of adherence to 24-hour movement behaviors for individual and specific combinations of behaviors (see Figure 4). On average, parents reported 4.3 days (SD = 2.2) per week of children being physically active for at least 180 minutes. Parents reported children being active daily at moderate-to-vigorous intensity for a median of 2.5 hours (SD = 2.4). The daily average recreational screen time was 8.9 hours (SD = 11.9) per day and average sleep duration was 10.9 hours (SD = 1.9) per day (including nighttime and daytime sleep hours). Overall, 20.3% of participants met the physical activity recommendation, 86.2% of children met the sleep recommendation, and 24.4% met the screen time recommendation. Approximately 7.3%

of children met no recommendations, 56.1% met one recommendation, 35% met two recommendations, and 1.6% met all three recommendations. For combinations of recommendations, 20.3% met physical activity and sleep recommendations, 20.3% met physical activity and screen time recommendations, and 24.4% met screen time and sleep recommendations. The proportion of children attending some form of out-of-home childcare in the current sample (77.8%) was higher than US national data (60%), yet hours spent in out-of-home childcare (25.5 ± 17.3) per week were similar to US national data (25–32 hours; Katzmarzyk et al., 2018). There were no differences in the proportion of males and females meeting individual or specific combinations of recommendations,  $X^{2'}$ s (1, 123)  $\leq$  0.3, p's  $\geq$  0.68.

### What are the relations between meeting individual and specific combinations of movement behaviors to young children's quantity estimation and self-regulation?

To address the second aim, we examined associations between meeting individual and specific combinations of movement behaviors to young children's behavioral indices (reaction time, response accuracy) of quantity estimation and self-regulation (off-task behavior) as outcomes in separate multilevel models. For all multilevel models discussed below, we present the significant fixed effects and refer readers to Tables S1-S3 for full model results.

### **Reaction Time**

Adherence to individual or specific combinations of movement behavior guidelines was unrelated to reaction time (p's  $\ge 0.10$ ).

### **Response Accuracy**

Meeting the screen time guideline was associated with greater quantity estimation accuracy (b = 6.55, p = 0.02, d = 0.55; see Table S1 and Figure 1A). Meeting a combination of the physical activity and sleep guidelines was related to superior quantity estimation (b = 5.54, p = 0.04, d = 0.32; see Table S1). Meeting a combination of the physical activity and screen time guidelines was related to superior quantity estimation (b = 5.55, p = 0.04, d = 32; see Table S1). No other individual or specific combinations were associated with quantity estimation ( $p's \ge 0.05$ ).

### Self-regulation

Older children exhibited higher self-regulation as indexed by lower frequency of off-task behavior than young children (b = -0.40, p = 0.003, d = -0.28). No associations between meeting individual or combinations of movement behavior guidelines emerged ( $p's \ge 0.09$ ).

### What are the associations between doses of movement behaviors and young children's quantity estimation and self-regulation?

To address the third aim, we investigated relations between doses of movement behaviors (total guidelines met, active weekly days, daily MVPA, daily hours of sleep, daily hours of sedentary screen time) and children's quantity estimation and self-regulation as outcomes in separate multilevel models.

### **Reaction Time**

No associations between doses of movement behaviors and reaction time were observed (p's  $\geq$  0.37).



Figure 1. Graphic representation of the multilevel models showing the association of (A) meeting screen time, (B) number of guidelines met, and (C) number of days active weekly with quantity estimation accuracy. 95% confidence intervals are presented in gray.

### **Response Accuracy**

Meeting more guidelines as a continuous variable related to superior quantity estimation (b = 3.42, p = 0.04, d = 0.31; see Table S2 and Figure 1B). Being active more days weekly related to superior quantity estimation (b = 1.12, p = 0.03, d = 0.34; see Table S2 and Figure 1C). No other associations were observed for doses of movement behaviors ( $p's \ge 0.62$ ).

### Self-regulation

Older children exhibited higher self-regulation as indexed by lower frequency of off-task behavior than young children (z = -2.79, p = 0.005, d = -0.47; see Table S3). Meeting more guidelines as a continuous variable related to higher self-regulation as indexed by fewer off-task behaviors (z = -1.96, p = 0.04; see Table S3 and Figure 2A). Accruing more moderate-to-vigorous physical activity daily related to higher self-regulation as indexed by reduced off-task behavior (z = -2.08, p = 0.04, d = -0.34; see Table S3 and Figure 2B). No other associations were observed for doses of movement behaviors ( $p's \ge 0.48$ ).

## Does Self-regulation Mediate the Relation between Physical Activity and Quantity Estimation?

In line with best practices suggested for conducting mediation analyses using observational cross-sectional data, the temporal ordering of the examined variables is correct in the tested mediation model and we control for confounding variables by using the pretest performance (i.e., removing error due to repeated measurement) and including covariates in the models (e.g., age, BMI, ratio; Baron & Kenny, 1986; Shrout, 2011). Parent-reported physical activity variables were reported for the week preceding the measurements of self-regulation and quantity estimation. Given that the data are observational and not experimental in nature, it is important to highlight to readers that the standardized coefficients from our mediation models presented below represent a series of correlation coefficients, and thus should be interpreted as correlational in nature.

We examined the extent to which self-regulation mediated the relation between dose of physical activity (days active weekly, daily MVPA, and total number of recommendations met as continuous variable) and quantity estimation (response accuracy). As a significant effect of the independent variable onto the mediator is a prerequisite for possible mediation, mediation analyses were conducted using Daily MVPA and total number of recommendations met since their association with self-regulation was significant ( $p's \le 0.05$ ). The effect of daily MVPA on quantity estimation accuracy was partially mediated via self-regulation (Proportion mediated = 58.7%; Average Causal Mediation Effect = 0.25 [95% CI: 0.07 to 0.45], p = 0.004; Average Direct Effect = 0.18 [95% CI: -0.32 to 0.69], p = 0.44 see Figure 3A), while accounting for the influence of age and BMI. The associations are in the expected direction, with greater daily MVPA associated with improved self-regulation (i.e., reduced off-task behavior), and lower self-regulation (more frequent off-task behavior) associated with inferior quantity estimation accuracy.

The effect of total number of guidelines met on quantity estimation accuracy was partially mediated via self-regulation (Proportion mediated = 25.6%; Average Causal Mediation Effect = 0.87 [95% CI: 0.16 to 1.72], p = 0.01; Average Direct Effect was 2.52 [95% CI: 0.38 to 4.62], p = 0.02; see Figure 3B), while accounting for the influence of age and BMI. The associations are in the expected direction, with meeting more guidelines associated with better self-regulation (reduced off-task behavior), and poorer self-regulation (greater off-task behavior) associated with decreased quantity estimation accuracy.



**Figure 2.** Graphic representation of the multilevel models showing the association of (A) number of guidelines met and (B) daily MVPA with self-regulation (as indexed using frequency of disruptive off-task behaviors). Higher scores represent lower self-regulation (i.e., higher frequency of disruptive off-task behaviors) whereas lower scores represent higher self-regulation. 95% confidence intervals are presented in gray. MVPA = daily moderate-to-vigorous physical activity (days  $\times$  minutes active per day/7).

### Discussion

Findings of this study characterize patterns of meeting recommended 24-hour movement behaviors in predominantly white middle class young children and their relations to children's skills of quantity estimation and self-regulation. Children meeting the screen time recommendation alone or combinations of physical activity with sleep or screen time exhibited superior quantity estimation. Moreover, being active for more days per week and meeting more guidelines per week were related to increased quantity estimation. Meeting more guidelines and accruing more moderate-to-vigorous physical activity (MVPA) daily related to improved self-regulation (as indexed by reduced off-task behavior). Self-regulation partially mediated the influence of daily MVPA and number of guidelines met on



**Figure 3.** Standardized regression coefficients for the relationship between daily MVPA and quantity estimation accuracy as mediated by self-regulation. As the data are observational and not experimental, the coefficients should be interpreted as correlational in nature. Data did meet the temporal precedence set for the mediation analyses (i.e., parent-reported physical activity was reported for the week preceding the measurements of self-regulation and quantity estimation). The mediation analyses controlled for confounding variables (i.e., age, ratio, BMI). MVPA = daily moderate-to-vigorous physical activity (days  $\times$  minutes active per day/7). \* denotes p = 0.05, \*\*\* denotes p < 0.05.

quantity estimation. Such findings point towards the mediating effect of physical activity-induced alterations in self-regulation on academic outcomes, such as numeracy, in young children. In terms of policy and practice, the work highlights recommendations that efforts targeting the increase of young children's physical activity as one way to reduce inattention and off-task behavior in the classroom, challenging behaviors that have been implicated in minimizing children's access to learning experiences (Montroy, Bowles, & Skibbe, 2016) and the expulsion of young children from preschool and early care settings (Gilliam, 2005).

### **Physical Activity Is Important for Early Development**

The findings of this study expand our understanding of the value of physical activity on children's academic skills and self-regulation by demonstrating these relations for very young children. That is, even for children ages 3–5 years, who are developing self-regulation and numeracy skills (Montroy, Bowles, Skibbe, et al., 2016), moderate-to-vigorous physical activity accrued daily is related to better



Figure 4. Graphic representation of the frequencies of children meeting physical activity, screen time, and sleep guidelines. No significant group differences were observed between male and female participants.

self-regulation and numeracy. These findings are important in light of work demonstrating that early development of self-regulation, which includes children's attention skills (McClelland et al., 2000) and off-task behavior (Moffett & Morrison, 2019), has benefits for children's academic skill development (Blair et al., 2015; McClelland et al., 2007; Skibbe et al., 2019). Children with lower self-regulation may miss out on learning opportunities available to them in early educational settings (Montroy, Bowles, & Skibbe, 2016). Even more alarming, low self-regulation, inattention, and lack of inhibitory control contribute to the high levels of expulsion exhibited in preschool programs (Gilliam, 2005; Gilliam & Reyes, 2018). Our finding that children with more days of physical activity during the week have better self-regulation has important implications for understanding this developing skill and for practice in early learning environments.

Mediation analysis provides an even clearer understanding of the mechanisms contributing to the relation between physical activity and quantity estimation. The influence of physical activity on quantity estimation is mediated by children's self-regulation. Although more active days and meeting more guidelines directly predict quantity estimation, the mechanism through which physical activity relates to math is children's behavioral self-regulation. Importantly, children with more active days within a week and more MVPA daily have higher self-regulation. It is clear that physical activity, particularly daily MVPA, is important for young children's development. Such findings align with neuroimaging evidence in 8-9 year old children participating in 60+ minutes of moderate-to-vigorous physical activity, five days per week for 9 months demonstrating decreased activation in the prefrontal cortex – an area of the brain underlying higher-order cognitive functions including aspects of selfregulation - coupled with improved performance on tasks of attentional and impulse control relative to wait-list control group children (Chaddock-Heyman et al., 2013). These findings suggest that participating in more physical activity during childhood is associated with adult-like recruitment of neural networks underlying top-down cognitive and attentional control. In animal models, increased physical activity, such as swimming and treadmill exercise, improve attention and spatial learning and reduce impulsivity in hyperactive rats (Kim et al., 2011; Ko et al., 2013).

The current study provides new insight into the potential mechanism by which physical activity relates to academic achievement, especially in young children: improving self-regulation (in other words reducing off-task, challenging behaviors). Observing that self-regulation mediates the relation-ship between daily physical activity and number of movement behavior guidelines met with quantity estimation is unsurprising because young children (unlike adults) rely more on prefrontal cortex – also involved in self-regulatory processes – rather than specialized parietal areas during quantitative processing (i.e., precuneus, intraparietal sulcus) to discriminate between quantities (Ansari, 2012; Ansari et al., 2005). Moreover, the mediation analysis points towards the notion that physical activity improves educational achievement by enhancing self-regulation and reducing the frequency of challenging behaviors so children can take advantage of learning opportunities – a finding that aligns with animal models demonstrating that increased physical activity is associated with reduced challenging behaviors, such as hyperactivity, aggression, and impulsivity (Kim et al., 2011; Ko et al., 2013).

### 24-hour Movement Guidelines Matter

The findings of this study have important policy and practice-relevant implications providing evidence for the benefits of meeting the World Health Organizations (2019) 24-hour movement guidelines for children during early childhood. Our data support the 24-hour movement guidelines as behaving in line with these recommendations seems to matter for quantity estimation and self-regulatory skills in young children. In particular, meeting the screen time recommendation alone was related to superior quantity estimation. Meeting more guidelines, however, even combinations of two guidelines, resulted in better math outcomes for young children. The combination of meeting screen time and physical activity or meeting physical activity with sleep related to better acuity of the approximate number system. However, more daily physical activity was important for self-regulation and accruing more physical activity – through either increased moderate-to-vigorous physical activity daily or meeting more guidelines – related to better selfregulatory skills, which then mediated the relationship between physical activity and quantity estimation. These findings support the notion that greater levels of physical activity may enable young children to acquire foundational mathematical knowledge to a greater extent through enhancements in self-regulation derived from increased physical activity participation. In this context, then, differences in performance on academic achievement tests observed as a function of physical activity participation – be it spending a greater proportion of time during the week active (Booth et al., 2014) or participating in activity-promoting interventions – may be attributed to gains in behavioral self-regulation that lessen the likelihood of exhibiting challenging behaviors, thus preventing children from missing out on learning opportunities and supporting academic achievement.

Unfortunately, in this sample, very few children met all of these recommendations. In general, the majority of children met only one of the 24-hour movement recommendations. Findings revealed that a greater proportion of children met the sleep guideline over screen time or physical activity guidelines, with just 24% meeting the screen time and 20% meeting the physical activity weekly guideline. While it is clear families understand appropriate sleep guidelines for young children, meeting sleep guidelines alone did not support children's math skills or attention. Sleep is important; however, families who focused on increasing physical activity and limiting screen time in addition to meeting the sleep recommendations had children with better quantity estimation and self-regulation. A growing body of evidence has postulated that physical activity influences cognition via sleep (Wilckens et al., 2018). The present findings suggest that even though children may not be meeting physical activity guidelines, their sleep appears unaffected. Although not directly measured, further research is warranted to examine other aspects beyond sleep duration not captured in the present study, including onset, variability, and quality, which appear particularly important for young children's cognition (Vaughn et al., 2015).

It may be that families are unaware of movement guidelines. For example, research field notes indicated that many families were surprised by how much physical activity was recommended for young children by the standards (i.e., 180 min daily). Children accrued a median of 2.5 hours (SD = 2.35) daily of moderate-to-vigorous physical activity. Although this appears to be just shy of the recommendations for this age group, our findings suggest that policies should consider setting guidelines based on empirical evidence, which is insufficient in this population as identified by a recent systematic review (Pate et al., 2019). Our findings are preliminary evidence that the recommended daily physical activity for young children may need to be more than 180 minutes of MVPA. Instead, it may be that due to the different physical activity patterns of young children, largely of short duration and lower intensity, that recommendations may need to include accruing longer durations throughout the day and focus on reducing sedentary screen time by offering energetic play activities instead of passive sedentary pursuits.

Moreover, these guidelines reflect the World Health Organizations (2019) guidelines for young children, which are currently adopted by Canada, Australia, South Africa, and Hong Kong (Capio et al., 2021; Draper et al., 2020; Okely et al., 2017; Tremblay et al., 2017); the 2018 guidelines from the US, where these families reside, are far less clear regarding the amount of time children are to spend sleeping, being active, and using screens (U.S. Department of Health and Human Services, 2018). Perhaps if the US guidelines offered specific guidance, more families would meet more of these important criteria. For instance, recent estimates suggest that around 61.8% of Canadian young children (Chaput et al., 2017) and 93.1% of Australian young children (Cliff et al., 2017) are meeting the recent physical activity guidelines (i.e., 180 min of energetic play daily). Importantly, in Canada and Australia, guidelines were adopted and increased efforts have been paid towards disseminating the guidelines to families since 2016 and 2017, respectively. Other countries, such as South Africa and Hong Kong are now following suit (Capio et al., 2021; Draper et al., 2020). In the present study, the proportion of children (20%) meeting the physical activity recommendation appear more in line with other countries having not yet adopted such specific guidelines, such as Portugal where only 28.6% of

young children are meeting the physical activity guideline (Vale & Mota, 2020). Such findings highlight the primacy of providing clear, specific guidelines to families and effective health messaging for behavioral change to occur.

Additionally, families may struggle to meet these guidelines due to their busy schedules. Families juggle multiple responsibilities including work, shopping, cooking, cleaning, extracurricular experiences, travel, and more. Our data indicate that children meet physical activity guidelines 4.3 days of the week; it seems some families have active days but struggle to find time to be physically active every day. It is important to note that these families primarily lived in suburban neighborhoods with ample green space, hiking/biking trails, and community parks with play structures for young children. It may be even more difficult for families living in rural or urban locations without these resources to meet daily physical activity recommendations. In particular, young children living in metropolitan areas further from urban green space engage in physical activity less frequently and exhibit higher amounts of screen time (Akpinar, 2017). Living even just 20 minutes further from green/open spaces was related to 2 hours more screen time weekly (Aggio et al., 2015). Such findings highlight the need for considering interventions that increase physical activity despite not having easy access to activity-promoting environments.

Although families are an important aspect of young children's physical activity behaviors, children spend more than 25 hours outside the home in some form of child care or school from the ages of 3 to 18 (Katzmarzyk et al., 2018), making educational contexts important settings for promoting health behaviors. To this end, making teachers aware of specific guidelines during the 24-hour period may help them in balancing the selection of activities that are physically active, seated, and require screen time in the classroom. Teachers of young children tend to target more specific compared to less specific learning standards (Gerde et al., 2019), reiterating the importance of adopting specific guidelines in the US. In this context, incorporating the 24-hour movement behavior guidelines into specific learning standards is one means by which wide dissemination and implementation of these guidelines can be achieved. The school environment presents a viable conduit to increase children's access and exposure to green space; teachers should seize the opportunity to increase instructional time spent outdoors and being active. Increased time spent outdoors relates to greater levels of physical activity in young children (Gray et al., 2015), with benefits that may extend to classroom behavior as children attending kindergartens with higher levels of surrounding green space exhibited increased selfregulation and reduced challenging behaviors, including aggression, inattention, and hyperactivity (Liao et al., 2020). Where families may struggle to find time to spend outdoors with children, schools may compensate by incorporating specific learning standards that balance instruction time spent indoors versus outdoors and finding ways to incorporate physical activity into learning experiences including for numeracy (Mavilidi et al., 2018; McGowan et al., 2020) and literacy (Kirk et al., 2014; Mavilidi et al., 2015).

The finding that these young children spend nearly nine hours a day sedentary on screen-based activities may also reflect a busy family lifestyle. Note that these data were gathered prior to the COVID-19 pandemic when children were not engaged in school via remote learning approaches using a validated questionnaire that encompasses a variety of screen-based activities typically not captured by other measures. The comprehensive nature of this screen time questionnaire points towards how small amounts of tablet, phone, and television watching can add up to a large amount of screen time daily. Research demonstrates however, that even young children under age eight (98%) have access to smartphones with internet access (Rideout, 2017) and spend ample time daily engaged in e-games on screens for entertainment primarily (Silander et al., 2018). While parents do report children playing some educational e-games on phones/tablets and watching educational television programming (Gerde et al., 2021; Silander et al., 2018) parent interview data confirms that children's screen time was primarily "to occupy the child while the parent was busy" (Silander et al., 2018). Regardless of the content, the child engages with screens in a sedentary way, which does not support physical activity guidelines. Thus, families need to make choices about how children spend sedentary time and seek out opportunities that yield positive benefits in other ways. Although exergames have been found to

increase energy costs relative to seated video games, active gaming is no substitute for the cognitive and motor development derived from real sports and physical activities; in fact, a large proportion of exergaming activities do not engage children in moderate-to-vigorous intensity activity (Daley, 2009). While more needs to be learned about the benefits of screen-based learning opportunities and exergames promoting physical activity participation (Daley, 2009), the number of books in a child's home and shared book reading with young children remain consistent predictors of literacy outcomes and the number of years of education a child will achieve even when accounting for other family background characteristics (Evans et al., 2010). Focusing sedentary time on book reading, and particularly shared reading experiences, offers evidence-based learning opportunities while reducing screen time (Piasta et al., 2012; Wiecha et al., 2001). Indeed, time spent reading has been correlated with higher functional connectivity in areas of the brain underlying language, visual control, and selfregulation whereas screen time has been related to lower connectivity between these same regions (Horowitz-Kraus & Hutton, 2018).

### Small Steps Each Day Matter

While few children met all of the 24-Hour movement guidelines, findings indicate that meeting at least two guidelines can be beneficial for children's development. That is, just increasing physical activity or reducing screen time can be valuable for children's quantity estimation skills. In this sample, about 35% of children met two of the guidelines; about 20–24% of children met each combination of two guidelines with the most children meeting the sleep and screen time recommendations. Moreover, dosage matters. That is, children who were more physically active on more days had superior quantity estimation and decreased off-task behavior, even when they failed to meet the guidelines specifically. Thus, increasing physical activity across more days of the week can be beneficial for children's self-regulation and academic outcomes. While it is important to develop habits of being physically active every day as early as possible (Telama et al., 2005), families can consider physically active opportunities across the week – providing flexibility – so that the guidelines may be more attainable for busy modern families.

The whole day and the whole week matter for physical activity, screen time, and sleep in their relation to children's math and self-regulation. Children engaging in more physical activity across more days demonstrated higher math performance and better self-regulatory skills. One strength of the present study was capturing children's physical activity, screen time, and sleep across a typical week. Moving beyond cross-sectional, single time-point data that dominates previous work (Carson et al., 2019; Cliff et al., 2017; McNeill et al., 2020; Willoughby et al., 2018) is essential to understanding the dynamic nature of children's physically active behavior and cognitive development in naturalistic settings. Using intensive longitudinal methods combined with network science techniques will allow for disentangling the bidirectional and time-varying associations among movement behaviors and self-regulation in children in everyday life outside the laboratory. Future work employing such approaches will provide insights into how physical activity today influences self-regulation the following day as well as elucidate the complex interplay among these behaviors and a number of psychosocial outcomes in children and their families.

### **Implications for Schools and Families**

The findings of this study provide important recommendations for families and schools, namely: increase physical activity and reduce sedentary screen time. More moderate-to-vigorous physical activity was an important predictor of self-regulation and math, and meeting screen time recommendations and sleep were important predictors of quantity estimation. Schools need to contribute to children's attainment of daily movement recommendations because young children spend a significant portion of their day in school or out-of-home childcare. The majority of children in this sample (77.8%) attended out-of-home child care/preschool where they spent an average of

25.5 hours ( $\pm$  17.3), which aligns with the US national average of 23–32 hours per week (Katzmarzyk et al., 2018). Unfortunately, the time pressure and anxiety caused by increased standards-based education often result in removal of experiences and subjects from the school day that are not directly assessed, such as physical education, which has been shown to increase children's self-regulation skills (Bailey et al., 2019). Instead, prioritizing extended opportunities for energetic play may help schools support children's self-regulation development and reduce challenging behaviors that may result in expulsion or suspension. One way is for schools to offer physically active learning opportunities to help children meet 24-hour movement behavior guidelines (McGowan et al., 2020, 2021). For example, activities mapped onto early learning standards for numeracy can be easily implemented by teachers such as having children run, jump, hop, or skip to numbers on a number line when learning about quantities or bouncing a ball corresponding to quantities (see McGowan et al., 2020, 2021) for detailed description of additional preschool activities).

Ensuring children have extended play opportunities both indoors and outdoors is a marker of quality programming in alignment with developmentally-appropriate practices and national guidelines (Copple & Bredekamp, 2009). Recent intervention work has found that for preschool-aged children, a brief 20-min physically active learning intervention results in immediate improvements in self-regulation and comparable academic performance to conventional sedentary lessons (McGowan et al., 2020, 2021), suggesting that getting children moving during lessons (instead of sitting) does not impair learning. Other research has identified innovative ways to integrate physical activity into children's preschool learning experiences including in literacy (Kirk et al., 2014; Mavilidi et al., 2015), numeracy (Mavilidi et al., 2018; McGowan et al., 2020, 2021), and science (Mavilidi et al., 2017). This work highlights the feasibility of early educators to play an important role in increasing physical activity throughout the school day and week by balancing seated and physically active learning experiences. Moreover, according to the results of this study, increasing physical activity of children can have added benefits of reducing children's off-task, often perceived as challenging, behavior.

While this study highlights the benefits of physical activity for minimizing children's off-task behaviors, it remains important for early educators to actively support children's development of self-regulatory skills through a range of early learning experiences in early educational settings. Physical activity is not meant to replace curricular supports for developing self-regulation. Self-regulation develops rapidly during the preschool years (McClelland & Cameron, 2012), though huge variation exists in children's skills during this time (Montroy, Bowles, Skibbe, et al., 2016). Self-regulation skills are malleable and there are multiple benefits to early development of these skills. That is, children who are more attentive can better take advantage of the learning opportunities available in their early care environments (Montroy, Bowles, & Skibbe, 2016; Skibbe et al., 2019). Thus, creating opportunities to facilitate development of self-regulation and increasing physical activity that yields increased attention can work in tandem to promote children's success in early learning environments.

It is important for schools and families to consider innovative ways to support children's attainment of behaviors across the 24-hour movement continuum (i.e., physical activity, sleep, and sedentary screen time). To this end, both teachers and families can consider ways to incorporate movement into daily activities that are traditionally sedentary. Include dance and movement into music time. Story time is one activity in which families and teachers alike can encourage students to find ways to move corresponding to the story. For example, popular children's stories use words that can be easily mapped onto movement (e.g., pop – jump up from a crouching position). Children can actively role play favorite stories, which promotes movement and language skills. To support sleep, schools may consider ways in which they can make sleep part of the curriculum by teaching children and parents about sleep habits and why sleep is important for health and well-being through workshops and even class projects that include sleep diaries and goal-setting for prioritizing healthy sleep habits for families. When offering opportunities for screen time, parents and teachers can track sedentary screen time habits and set goals for limiting screen time and increasing physical activity. Schools and families alike can suggest active fun instead of passive screen time pursuits, such as

playing board games or playing outside with friends in place of watching television. Limiting screen time during meal times and talking with children during family meals or meals at school are ways that parents and teachers can model healthy habits and promote social development for children.

### **Limitations and Future Research**

Some limitations of the current study should be noted. First, although efforts were made to reduce the potential for recall bias by using questionnaire-based measures asking parents to report typical physical activity, screen time, and sleep for the past week, the relations between physical activity, attention, and quantity estimation may be overestimated despite these measures demonstrating validity and reliability in prior work (Centers for Disease Control, 2019; Kann et al., 2016; Sadeh, 2004; Sharif et al., 2010; Walsh et al., 2018). Future research should combine objective measurements (e.g., accelerometry) with parents' reports across multiple time points to provide further analysis of the psychometrics of using such questionnaire measures in young children. Additionally, our measures were single- or two-item scales, which may not capture the full breadth of the movement behaviors measured (e.g., physical activity intensity outside MVPA, sleep quality and frequency of waking, and screen-based activities that are potentially active like exergaming). Despite this limitation, our scales demonstrated acceptable internal reliability (Cronbach's  $\alpha$ 's  $\geq$  0.66) and these scales have been widely implemented in similar population-based studies. These easy to administer instruments also reduce participant burden of completing longer scales. One strength of the work is the examination of a collection of movement behaviors across a full week; future studies should expand on this by including occasion-to-occasion and daily assessments of movement behaviors and self-regulation to better capture the dynamics between these behaviors and cognition throughout the day. Moreover, it is important to interpret the mediation analysis in light of its limitations. That is, this data provides preliminary evidence and should be tested by experimental studies directly testing the effects of an intervention aimed to increase self-regulation to confirm or refute the purported mediation of selfregulation on the relation between physical activity and quantity estimation. However, the mediation models provide preliminary evidence while controlling covariates (e.g., age, BMI, ratio) and suggest a correlation among the variables examined. The findings should be interpreted within the context of the sample characteristics. Although children were not excluded from participating in the study if their parent reported a neurological or physical disability, the sample consisted of predominantly Englishspeaking white (78%), middle class children (i.e., 70% of parents reported having college education or above) free from neurological or physical disabilities. Thus, the findings may not generalize beyond that population. Future research should examine a more diverse group of children to better understand the effects of socioeconomic status, race, ethnicity, and ability on the associations among movement behaviors, self-regulation, and early numeracy.

### Conclusions

This work identifies the benefits of adherence to 24-hour movement behavior guidelines and, in general, increasing the amount of physical activity children engage in daily and reducing screen time to help meet more guidelines, for young children's numeracy and self-regulatory skills. In terms of developmental mechanisms, the work highlights the mediating role of self-regulation on the relations between physical activity and early math skills. Our findings highlight the primacy of adopting specific physical activity guidelines for families (e.g., specific number of minutes for physical activity, screen time, and sleep) and perhaps integrating these into early learning standards for schools so both families and educators can support children's capacity to meet 24-hour movement behavior guidelines.

### **Disclosure Statement**

No potential conflict of interest was reported by the author(s).

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