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Does Taekwondo Improve Children's Self-Regulation? If so, How? A Randomized Field Experiment

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Emerging evidence suggests interventions can improve childhood self-regulation. One intervention approach that has shown promise is Taekwondo martial arts instruction, though little is known about its acceptability among stakeholders or its mechanisms of effect. We extend evidence on Taekwondo interventions in three ways: (a) testing the efficacy of a standard introductory course of Taekwondo, (b) assessing the acceptability of Taekwondo instruction among school children, and (c) investigating two self-regulatory mechanisms by which Taekwondo may operate (executive functions and motivation). This article reports findings from a randomized control trial implementing a standard 11-week beginners' course of Taekwondo. Participants were from a mixed-sex, nonselective U.K. primary school (N = 240, age range 7 to 11 years). Measures of self-regulation included teacher-rated effortful control, impulsivity, prosocial behavior, and conduct problems; computer-based assessments of executive functions; and child self-reported expectancies and values to use self-regulation. Postintervention, children in the Taekwondo condition were rated by teachers as having fewer symptoms of conduct problems and better effortful control (specifically attentional control), and they also had better executive attention assessed by a flanker task. Effects were not found for teacher-rated inhibitory control, activation control, impulsivity, and prosocial behavior or for assessments of response inhibition, verbal working memory, and switching. Taekwondo was rated very positively by children. Finally, there was evidence that children who completed Taekwondo classes reported higher expectancies and values to use self-regulation and that expectancies and values mediated intervention effects on self-regulation. We conclude that short standard Taekwondo courses are well received by pupils, improve attentional self-regulation, and reduce symptoms of conduct problems.

Keywords: self-regulation, self-control, Taekwondo, martial arts, executive functions

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Self-regulation is a psychological construct describing an individual's capacity to alter their own emotions, behavior, and cognition to enhance adaptation to a particular context (Nigg, 2017). The term self-regulation is often used synonymously with self-control in both popular and scientific literatures to refer to top-down or effortful regulation of the self. Thus, "good" self-regulation typically encompasses important competencies, including the ability to pay attention, work hard, and follow rules, as well as the

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capacity to control one's emotions, avoid inappropriate or aggressive actions, and interact positively with others (Nigg, 2017). Greater self-regulation is largely believed to be adaptive and beneficial, with empirical evidence suggesting there is no such thing as "too much" self-control (Wiese et al., 2018). Both executive function (EF) and motivational beliefs have an important role in explaining individual differences in self-regulation (Diamond, 2013; Gillebaart, 2018).

Good self-regulation is associated with higher school achievement and superior mental health in children (Duckworth & Seligman, 2005; Nigg, 2017; Robson et al., 2020), even in the early school years (Dignath et al., 2008). In fact, individuals with greater self-regulation generally live longer, healthier, happier, and more successful lives (Moffitt et al., 2011). Consequently, interventions that boost children's self-regulation could provide widespread public health benefits (Blair & Diamond, 2008; Moffitt et al., 2011) and are sought by policy makers (Hinds, 2019). Promisingly, a recent meta-analysis of 49 studies highlighted the malleability of self-regulation and showed that children's self-regulation can be enhanced with intervention programs including Taekwondo martial arts (Pandey et al., 2018). However, this meta-analysis lacks the detail required to translate these findings into practice. For example, there is little evidence of interventions' replicability and real-world effectiveness; thus, there are not yet any specific recommendations for practitioners based on strong evidence bases.

Taekwondo provides an interesting example of a self-regulation intervention because it explicitly promotes good self-regulation to students and combines many of the potentially important features present in other interventions such as mindfulness, physical exercise, and character training (Diamond & Ling, 2019; Lakes & Hoyt, 2004; Pandey et al., 2018). Taekwondo may be an especially helpful method to train self-regulation in young children who can have difficulties with explicit strategy training (Dignath & Büttner, 2008). The current study implemented a field experiment investigating the effectiveness of teaching primary-aged school children Taekwondo martial arts as a method of improving their self-regulation. Furthermore, we extend existing findings by assessing not only the efficacy of Taekwondo training but also the acceptability of Taekwondo in mainstream schools. We also examined possible mechanisms of effect for the first time, specifically focusing on how Taekwondo affects children's EFs and their motivational beliefs to exert self-regulation.

Taekwondo is a traditional martial art comprising physical and mental training. Students of Taekwondo are taught self-defense and "forms" (choreographed patterns of movements, including blocking, kicking, and punching) and encouraged to increase their self-awareness and strive for self-improvement (Kim et al., 2011). Taekwondo explicitly promotes a set of character traits and values that epitomize good self-regulation: courtesy, integrity, perseverance, and self-control (Kurian et al., 1993). Such character training appears to be crucial to Taekwondo's effectiveness because teaching children combat/fighting sports outside the traditional martial arts context (i.e., without the associated character training) can actually reduce self-regulation (Trulson, 1986). Thus, it is unlikely that the positive effects of Taekwondo are due to physical exercise alone. Martial arts are popular extracurricular activities for children but are not commonly featured in the physical education (PE) curricula taught at schools. Studies have not yet explored whether school children want to be taught Taekwondo at school and how participating children rate the experience compared to typical PE lessons. Thus, there is a need to explore children's views of Taekwondo to assess its acceptability alongside further efficacy testing and understanding of the underlying mechanisms. It is anticipated that such evidence will be well received by teachers, school leaders, and policy makers responsible for children's physical and socioemotional development.

Framed from a developmental perspective, children in primary school undergo a notable period of plasticity that is typically characterized by increases in naturalistic measures of self-regulation as well as our hypothesized mediators: motivational beliefs and EFs (Best & Miller, 2010; Trautwein et al., 2006; Vazsonyi & Ksinan Jiskrova, 2018). By extension, we propose that the primary school years are an optimal developmental stage for administering self-regulation interventions as drops in naturalistic measures of self-regulation and motivational beliefs are typical after the transition to secondary school (Atherton et al., 2020; Ng-Knight et al., 2016). In contrast, EFs continue to improve throughout adolescence, indicating that self-regulatory capacities may not decline and that it is changes in motivation that explain lower scores on naturalistic measures of self-regulation during adolescence. Transactional exchanges between the child and their social partners are believed to be crucial drivers of children's self-regulation (Durbin, 2018). Of particular note is that adults (e.g., parents, teachers, instructors) are likely to have a central socializing influence on children before adolescence, after which peers take on a primary influence on self-regulatory outcomes (Blakemore, 2018). Thus, adult-led instruction such as Taekwondo may be particularly effective in primary school children.

Existing Evidence on the Effects of Taekwondo

Here, we briefly review previous studies linking Taekwondo to improved self-regulation, highlighting limitations and gaps in the evidence base. Observational studies indicate affective, cognitive, social, and behavioral benefits to concentration and respect for others (Finkenberg, 1990; Trulson, 1986; Weiss & Miller, 2019). Of course, observational studies do not account for selection biases, and randomized trials are needed to make stronger claims about causality. To date, we are aware of only two published randomized control trials (RCTs; one of which was a small sample pilot study) testing Taekwondo's effects on children's self-regulation.

The first published study testing the efficacy of Taekwondo used a sample of 207 children (aged 5–10 years) attending a private school in the United States (Lakes & Hoyt, 2004). Twelve weeks of Taekwondo instruction (vs. normal PE) increased observer-rated (blinded to condition) self-regulation during a physical challenge (a novel obstacle course), improved attention, and increased teacher-rated prosocial behavior (*d*s = .28–.49). There was also some indication of sex and age differences, where behavioral/conduct problems were reduced in boys only and affective self-regulation was improved in older students only. However, because the study sample was exclusively privately schooled children, it is unclear whether these findings would translate to mainstream education settings. Only 6.5% of children attend private schools in the United Kingdom (U.K. Government, 2020b), making it imperative to test efficacy of interventions in mainstream (state-funded) schools.

The Taekwondo program used in Lakes and Hoyt (2004) was written specifically for children with a central focus on improving self-regulation. This tailored approached may be an important factor in its efficacy (we do not yet know as it has not been compared to other Taekwondo programs), but the bespoke nature of the intervention also leads to practical limitations. First, their program has not been formally manualized, making it difficult to replicate for both research and practice. Second, their results do not tell us about the real-world effectiveness of the existing Taekwondo programs that most schools have access to in their local areas.

The second published RCT was a pilot study that took place in a socioeconomically disadvantaged U.S. school ($N = 60$, $M_{age} = 12$ years), where the intervention group received 9 months of Taekwondo instruction and the control group took part in normal PE lessons (Lakes et al., 2013). The authors reported statistically significant improvements in parent-rated self-regulation (e.g., being able to sit still; $d = .95$) in the Taekwondo group versus controls but no significant effects on behavioral tests assessing children's EFs. Only half of the sample completed EF tests due to low rates of parental consent, so given the relatively small sample in this pilot study, the absence of statistically significant effects is likely due to the study being underpowered to find anything other than extremely large effects.

In sum, existing research suggesting a causal link between Taekwondo and improved self-regulation consists of a single adequately powered study. An evidence base comprised of a single study is too small to confidently recommend the implementation of Taekwondo in schools. More work is required that not only tests the generalizability of Taekwondo's effects in mainstream schools but also addresses practical questions about implementing Taekwondo in schools. Thus, the first aim of the current study was to test the acceptability of Taekwondo interventions from the child's perspective. Most children (both boys and girls) in Lakes et al.'s (2013) pilot study believed Taekwondo helped improve their self-regulation and physical fitness and agreed that classes were fun. However, no acceptability comparisons were made to a control group. In the current study, we assessed the acceptability of Taekwondo in mainstream classrooms using an RCT design that enables comparisons of attitudes toward PE between intervention and control groups.

The second aim of this study was to extend the generalizability of findings on Taekwondo's efficacy. This was done by testing the efficacy of Taekwondo in a mainstream (i.e., nonselective, publicly funded, socioeconomically diverse, mixed-sex) sample of schoolchildren. Furthermore, by adopting an adequately powered design, the study tested if there are more modest effect sizes of Taekwondo training on EFs, which hitherto has only been done in a small pilot study. Other methodological improvements over previous research include randomization at the child level (rather than at the class level, which introduces confounds when teachers are rating children's classroom behavior) and statistical models accounting for clustering of children within classes (Diamond & Ling, 2019).

The third aim of this study was to enhance our mechanistic understanding of the causal effects of Taekwondo training on self-regulation. We make a significant contribution to the literature by exploring, for the first time, changes to two putative mechanisms by which Taekwondo may exert effects on self-regulation. This is discussed further in the next section.

How Does Taekwondo Influence Self-Regulation?

The mechanisms of effect underlying Taekwondo's influence on children's self-regulation are not known. We tested two possible mechanistic explanations: (a) EFs and/or (b) children's motivation to exert self-regulation.

Our first hypothesis was that Taekwondo has positive effects on EF, which are often categorized into three basic facets: *working memory* functions that keep information in mind and shield it from distractions, *inhibition* functions that suppress automatic responses, and *mental shifting* that supports moving attention between tasks (Hofmann et al., 2012). EFs have clear implications for exercising self-regulation; for example, EFs allow us to pay attention and stay on task (working memory), stop ourselves from acting impulsively (inhibitory control), and consider alternative courses of action when faced with temptation (working memory and mental shifting). Good self-regulation has often been equated with the effortful inhibition of impulses (Diamond, 2013), though a key role for working memory processes has also been proposed (Hofmann et al., 2012). In an extremely thorough systematic review, Diamond and Ling (2019) concluded that the strongest evidence for benefits to EFs comes from practices like Taekwondo, that is, activities involving both mindfulness and body movement.

Working memory processes are in some respects an essential precursor to self-regulation. For self-driven behavior to occur, it is important to maintain a clear goal in mind; otherwise, self-regulation is likely to be directionless and ineffective (Hofmann et al., 2012). Furthermore, working memory capacity underlies the control of attention (i.e., executive attention) as it prevents goals from being crowded out by competing temptations, interests, or stimuli (Hofmann et al., 2012). The degree to which attention can be focused on a desired goal will increase the likelihood of that goal being achieved. Taekwondo instructors demand strict attention from their students, which may train executive attention. This provides opportunities for children to practice attentional focus in a highly motivated context. The effects of this may be similar to those of meditation but could potentially be more motivating to children than traditional meditation practices. Furthermore, students are required to learn and master complex forms, which may train attentional control and working memory capacity (Diamond & Ling, 2019).

Inhibiting inappropriate behavioral impulses is often considered to be the hallmark of good self-regulation akin to lay concepts like willpower and exemplified by delay of gratification tasks like the marshmallow test. When faced with tempting options that conflict with our longer-term goals (i.e., self-regulation "dilemmas"), inhibitory processes can be used to control the impulses that would lead to self-regulation failures (Hofmann et al., 2012). Inhibition is often used synonymously with self-regulation, but it is a very specific type of self-regulation that predominantly takes place in close temporal proximity to situations posing self-regulation dilemmas (more on this below when we discuss motivational mechanisms). This is because inhibitory control has fairly small windows in which it can be deployed: after a behavioral impulse has been activated but before the impulse reaches a threshold of activation (Hofmann et al., 2012). However, it is possible to proactively prepare to exercise inhibitory control, and this skill increases with age (Chevalier et al., 2015; Doebel et al., 2017). We hypothesized that

Taekwondo improves inhibitory control. First, instructors demand high levels of behavioral and cognitive compliance, which trains students to control impulsive behavior. Second, inhibitory control is practiced during physical tasks such as punching and kicking drills where impulsive behavior can lead to injury.

Shifting is a useful skill helping us to adjust emotions and behaviors to different contexts. Effective self-regulation includes shifting from behavior and emotion that is appropriate in one setting (e.g., home) to meet the rules and requirements of another setting (e.g., school). At the task level, shifting may be important for managing competing goals and for swapping strategies to meet larger overarching goals (Hofmann et al., 2012). However, it is also possible that a greater ability to shift between tasks could lead to greater goal disengagement. Thus, we assessed shifting in the current study for completeness of covering EF facets, though we believe it is less likely that Taekwondo will effect mental shifting.

The role of EFs is most compelling in situations described as self-regulation dilemmas, situations where we are faced with temptations or distractions that need to be overcome. However, when faced with temptation, waiting until the last minute to assert control is generally the most difficult and least successful course of action (Gillebaart, 2018; Gillebaart & de Ridder, 2015). Interestingly, rather than relying on superior inhibitory control to deal with high-stakes situations, individuals with the highest levels of self-regulation can be distinguished by their use of "downstream" actions that actively structure their lives to avoid tempting situations (Galla & Duckworth, 2015; Gillebaart et al., 2017)—for example, packing a healthy lunch to avoid eating junk food or turning off a mobile phone to reduce distractions while studying. Such actions are strategic and include planning and initiating alternative behaviors; therefore, they do not require momentous displays of effort or rely heavily on inhibitory control (Gillebaart & de Ridder, 2015). These actions do, however, require significant levels of motivation. To date, the motivational basis of self-regulation in children has been relatively neglected (Galla et al., 2018).

Thus, our second hypothesis is that Taekwondo increases children's motivation to use self-regulation. To do this, we draw on expectancy-value theory (EVT), one of the most prominent motivation theories, which states that two kinds of motivational beliefs explain individuals' behaviors and choices. Applying EVT to children's self-regulation suggests that good self-regulation is more likely if a child has high expectancies of success (e.g., "I feel able to pay attention and finish this work") and perceives self-regulation to be valuable (e.g., "It is important that I finish this work"; Eccles & Wigfield, 2020; Wigfield & Eccles, 2000). EVT differentiates values into four types: (a) intrinsic value (self-regulation is intrinsically rewarding), (b) utility value (self-regulation is useful), (c) attainment value (placing importance on exercising self-regulation), and (d) cost (conversely, children may view self-regulation as unfavorable or having negative consequences). Recent research suggests that children who view schoolwork as high in intrinsic and utility value have higher self-regulation (Galla et al., 2018). Given that children's academic motivation, also with respect to their expectancies and values across domains, typically decreases over the school years (Wigfield et al., 2014), intervening on children's expectancies and values at an early stage might be important to promote positive academic development. Thus, because Taekwondo instruction (a) regularly exposes children to clear expectations of high levels of self-regulation and (b) provides structured opportunities for practicing self-regulation, we hypothesized that Taekwondo will increase children's perceived value of self-regulation and their self-efficacy (success expectancies) in using self-regulation.

The Current Study

This article describes a randomized field experiment run in a U.K. primary school. We specifically aimed to answer the following questions: Is Taekwondo an acceptable activity among mainstream primary school children? Does Taekwondo instruction increase self-regulation in a mainstream school setting? Does Taekwondo instruction influence the hypothesized self-regulatory mechanisms of (a) EFs and (b) motivational beliefs? To aid comparability with previous research (Lakes & Hoyt, 2004), we also tested for gender differences and age differences in response to Taekwondo instruction.

Method

Design

A randomized field control trial tested the effects of Taekwondo instruction on self-regulation, from January to April 2019. Children were recruited from a single primary school (age range 7 to 11 years) in the South of England ($N = 240$). There were four year groups, with two classes per year group (eight classes in total). Half of the children within each class were randomly allocated to the Taekwondo trial group ($N = 122$) and half to the control group ($N = 118$). The experimental group received 11 weeks of Taekwondo classes, at the rate of two classes (45 min per class) per week. The control group received two PE classes (45 min each) per week (business as usual) during the trial period. PE lessons were completed within year groups, with four groups participating in Taekwondo classes (one per year group) and four groups participating in normal PE classes (all groups were of approximately 30 children).

Baseline data were collected from children the week before the intervention started, and postintervention data were collected in the final week of the intervention (11 weeks after baseline). Data collected were questionnaires from teachers and children and computer assessments of children's EF. Children completed questionnaires in class under the supervision of teachers. Computer assessments were carried out in groups of four to eight children supervised by researchers in the school library (at least one researcher per two participants). Researchers collecting the EF task data were blind to condition; however, teachers were not. Data are available from the first author upon request. This study was not preregistered.

Intervention Details

Taekwondo classes were led by an instructor in the International Taekwondo Federation style, who had taught Taekwondo full-time for approximately 20 years. The course was designed to mimic initial training given in regular Taekwondo club sessions. By the end of the course, children had progressed to the point where they could take their first test and gain their first grade on completion (i.e., a white belt, yellow tag, ninth kup); however, these tests did not take place. Classes were designed to be fun, but

they were also about discipline, with the aim of improving concentration and self-regulation. Sessions included a fitness activity to warm up. Each week, children assembled in straight lines (as a regular Taekwondo class would do) and recited the five tenets of Taekwondo: courtesy, integrity, perseverance, self-control, and indomitable spirit. The instructor spent a few minutes discussing the tenets with the class in the first session and throughout the course. After the warm up and class introduction, children were taught and practiced beginner techniques (punches, kicks, blocks). A summary of the curriculum can be seen in the online supplemental materials.

The control group took part in their typically scheduled PE classes. Activities differed across year groups: Year 3 took part in netball (learning the skills and rules of the game, such as passing, moving, and attacking), Year 4 took part in 5 weeks of fitness training (aerobic and skills-based circuits to improve stamina, speed, and games skills) followed by 6 weeks of netball, Year 5 completed 6 weeks of orienteering (map reading and navigation around the school, including "hide and seek" activities) followed by 5 weeks of netball, and Year 6 completed 11 weeks of jump rope (starting with single ropes and progressing to two ropes and designing a group routine).

Participants

Participants were 240 children (M_{age} = 9.37 years; SD_{age} = 1.09 years), 47% of which were female; 26.3% of children were eligible for free school meals (a proxy for socioeconomic disadvantage; national average was 23%) and were from a mix of both working-class and lower middle-class families. The school was located in a medium-sized town (mostly of White ethnicity, approximately 96%) surrounded by rural areas and other large towns. Pupils were largely from White British families and less ethnically diverse than the typical English school; for example, only 7.5% of children spoke English as a second language (vs. national average of 21.2%; U.K. Government, 2020b). Regarding special educational needs, 1.7% of children had a high level of needs (England average was 1.6%), and 21.3% had some level of special educational needs support (England average was also 21.3%; U.K. Government, 2020a). The percentage of pupils meeting the expected level of reading, writing, and math attainment (63%) was close to the national average (65%; U.K. Government, 2020b). This was a typical U.K. primary school in most respects. Six children in the control group and 13 children in the experimental group reported having prior experience of Taekwondo classes. These proportions were not significantly different, $\chi^2(1) = 2.30$, $p = .13$.

Ethics

All pupils at the school took part in Taekwondo classes as part of their PE curriculum. A waitlist design was implemented. Children in the control group participated in Taekwondo classes in the school term after the study was complete. Passive consent was obtained from parents who were given the opportunity to opt out their children from the study and data collection (two children were opted out of computer assessments by their parents). Children also completed a consent form indicating that their participation was voluntary and that they could withdraw at any time. The study was approved by the university ethics committee (University of Surrey, "Testing Taekwondo instruction as a method of increasing children's self-control," UEC/2018/110/FHMS).

Measures

Acceptability Measures

Children completed a paper-based questionnaire assessing their views of Taekwondo lessons. This measure was developed for this study. Preintervention, all children (control and intervention group) were asked how much they agree with the statement "I would like to do Taekwondo lessons." Postintervention, only children in the Taekwondo group were asked the following three questions: "Have you enjoyed Taekwondo lessons?", "Have you found taekwondo lessons interesting?", and "Would you like to do more Taekwondo lessons?" Both preintervention and postintervention, to enable comparisons between the intervention and control groups, all children were asked whether they agreed with two statements about PE lessons on the same 4-point scale: "I enjoy PE lessons" and "I find PE lessons boring." All acceptability questions used a 4-point response scale (1 = *NO!!*, 2 = *no*, 3 = *yes*, 4 = *YES!!*), which was recoded into binary format for logistic regression analyses (0 = *NO!!* or *no*, 1 = *yes* or *YES!!*). Acceptability items were analyzed individually.

Self-Regulation at School

Self-regulation was measured via teacher questionnaire reports of effortful control, impulsivity, behavioral problems, and prosocial behavior. Classroom teachers completed two subscales of the Strengths and Difficulties Questionnaire (Goodman et al., 2000) for every child in their class (N range = 28–32). The conduct problems subscale comprised five items assessing behavioral problems (α = .76). The prosocial behavior subscale comprised five items assessing positive social skills (α = .87). Teachers completed 17 items assessing three facets of effortful control and the impulsivity facet from the Temperament in Middle Childhood Questionnaire for every child in their class (Simonds et al., 2007). This included four items assessing attentional focusing (e.g., "pays attention," α = .94), five items assessing inhibitory control (e.g., "can stop him/herself from doing things too quickly," α = .84), three items assessing activation control (e.g., "can make him/herself do work, even when s/he wants to play," α = .86), and five items assessing impulsivity (e.g., "says the first thing that comes to mind," α = .87). Reponses were made on a 5-point scale with anchors 1 = *almost always untrue* and 5 = *almost always true*. Confirmatory factor analyses indicated the four-factor model had adequate fit to the data, $\chi^2(113) = 405.12$, $p < .001$; comparative fit index (CFI) = .91, root mean square error of approximation (RMSEA) = .11, standardized root mean square residual (SRMR) = .05, and fit better than a single-factor model, $\Delta\chi^2(6) = 204.05$, $p < .001$. Therefore, the four facets were examined separately rather than combining them into a single measure.

Measures of Potential Self-Regulatory Mechanisms

Child-Reported Expectancies and Values for Self-Regulation. Drawing on EVT (Wigfield & Eccles, 2000), self-report questionnaires were used to collect children's self-perceptions of their ability to exert self-regulation (success expectancies/self-efficacy) and their desire to do so (value placed on self-regulation). To assess the expectancy component of motivation, pupils

answered seven items about their success expectancies in relation to key self-regulatory tasks (α = .82). The measure was adapted from the motivation section of the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1993). Pupils responded on a 4-point scale to the following items prefixed with "Do you feel you can. . .": "pay attention in class?", "do things carefully?", "finish all your schoolwork?", "keep your things organized?", "follow rules?", "work really hard?", and "listen to your teachers?" To assess the value component of motivation, pupils answered 16 items about their values in relation to four key self-regulatory tasks (following rules, paying attention, being organized, working hard). This measure was designed for the current study. Four items were included for each of four value domains: intrinsic value (e.g., "I enjoy paying attention," α = .72), attainment value (e.g., "Being good at paying attention is important to me," α = .77), utility value (e.g., "Paying attention will help me at school," α = .71), and cost (e.g., "Paying attention makes me tired," α = .80). Confirmatory factor analyses indicated the four-factor model of value components had adequate fit, $\chi^2(74) = 152.68$, $p < .001$; CFI = .95, RMSEA = .07, SRMR = .04, and fit better than a single factor model, $\Delta\chi^2(6) = 256.81$, $p < .001$. Therefore, the four value components were examined separately, in line with their theoretical structure.

Executive Functions. Participants completed a task battery of EF measures assessing response inhibition (inhibitory control), executive attention, verbal working memory, and switching. All tasks were designed on and presented using Gorilla online testing software (www.gorilla.sc).

Response Inhibition. Response inhibition refers to the inhibitory control of behavior; it is akin to behavioral self-control, which refers to the inhibition of a dominant response in favor of a subdominant response. It was measured with the "Whack a Mole" game taken from Massonnié (2020), which was a child-friendly adaptation of a Sustained Attention to Response Test (Manly & Robertson, 2005). Participants were required to press the spacebar when they were presented with a picture of a mole (go trials) but not when they were presented with a picture of an eggplant/aubergine (no-go trials). Each trial was displayed for 1,300 ms. The task included 90 pseudorandomly presented trials split into three blocks (76% go trials, 24% no-go trials). There were never two or more no-go trials in a row, and the number of go trials before a no-go trial varied between one and five. Performance was measured as commission errors, the percentage of trials where nontargets were incorrectly hit.

Executive Attention. Executive attention refers to the inhibitory control of attention. It was assessed with a flanker task taken from Anwyl-Irvine et al. (2020), who adapted the task from Rueda et al. (2004). In each trial, participants were shown five fish in a horizontal line and were asked to determine whether the central fish was pointing left or right. Responses were made using the computer keyboard labeled with arrows pointing left and right ("Z" key to indicate left and "M" key to indicate right). For congruent trials, the flanking fish were facing the same direction as the central fish. For incongruent trials, the flanking fish were facing the opposite direction to the central fish. The task included 96 trials (equal numbers of congruent and incongruent trials). Each trial was presented until a key press. Trials were separated by a fixation cross displayed for 400, 600, 800, or 1,200 ms. Any response times that were less than 200 ms (too short to follow a conscious perception of the stimuli) or more than 3 standard deviations from the mean (outliers) were excluded. Performance was measured as reaction time (RT) costs, commonly referred to as the flanker effect, Flanker Effect = (M RT Incongruent Trials − M RT Congruent Trials)/M RT Congruent Trials. This indicates how much longer children's incongruent reactions were compared to congruent reactions.

Verbal Working Memory. A backward digit recall task was taken from Massonnié (2020). In each trial, a series of digits was displayed onscreen. Each digit was displayed for 1,500 ms, followed by a blank screen displayed for 500 ms. At the end of a given series, participants were asked to repeat the digits in reverse order by clicking on an onscreen keypad (Supplemental Figure S1). An incremental procedure was adopted. List length started at two digits, and only participants who successfully completed at least three trials (out of five) proceeded to the next level (e.g., three digits). Lists kept increasing in difficulty until participants reached the stopping criterion: If the children failed at two trials out of the five for a given list length, they did not progress to the next level and the task ended (see St Clair-Thompson, 2010, for a similar incremental procedure). There was no possibility to go down a list length and back up again. Performance was measured as the percentage of correct digits recalled from all possible trials (observed range 0% to 77%).

Switching. The switching task was adapted from Zelazo (2006). In each trial, participants were shown a target object and were asked to sort the object based on one of two criteria, color (blue or red) or shape (circle or triangle). This task included three blocks. In Block 1, participants were asked to sort objects based on their color. They were instructed to press the "M" key (labeled →) if the target object was the same color as the object on the right of the screen and the "Z" key (labeled ←) if the target object was the same color as the object on the left of the screen (Supplemental Figure S2). Participants were reminded to match by color via an audio prompt that was repeated for each trial (children wore headphones to hear the audio prompt). This block included 10 trials. Block 2 was identical except participants had to sort objects based on their shape.

In Block 3, the matching rule differed by trial (i.e., was mixed). For each trial, an audio prompt was used to inform participants whether they should match the target object by color (as in Block 1) or by shape (as in Block 2). This block included 20 trials. All trials were presented until the participant provided a response and was followed by a blank screen displayed for 800 ms. Performance accuracy on this task was measured as (a) "switching accuracy" calculated from seven trials in the mixed block where the matching rule switched (e.g., from color to shape) and (b) "switching costs" calculated by subtracting the accuracy at repeated trials (requiring no switch in dimension) from the accuracy at trials that require a switch. This reflects the cost to switch from one dimension to another (Frick et al., 2019) because children tend to slow down on all trials in the mixed block (Davidson et al., 2006). We also assessed (c) global switch costs (RT and accuracy), performance in the mixed condition compared to single-task blocks, and (d) mixing costs (RT and accuracy), performance on nonswitch trials in the mixed condition compared to performance in single-task blocks of nonswitch trials.

Analyses

The effects of the intervention were assessed in an analysis of covariance framework (i.e., a regression model with baseline equivalents of the outcome measure included as a covariate; Vickers & Altman, 2001)—for example, in the form of:

$$Y = m + \beta X1 + \beta X2 + \beta X3 \ldots + e$$

where *Y* is the outcome variable, *m* is the model constant, β*X1* is the effect size of the intervention, β*X2* is the baseline measure of the outcome variable, and β*X3* are additional covariates (these were gender and age in all models). In all models, standard errors were adjusted to account for the clustering of children within classes using relevant "cluster" commands in Mplus and Stata. Effect sizes, *p* values, and 95% confidence intervals are reported.

Analyses of observed scores (as opposed to latent variable scores) were performed in Stata Version 15. Distributions of observed outcome variables were examined prior to analysis to determine the most appropriate model. Linear regression was used to analyze continuous data that followed a relatively normal distribution. These variables were executive attention, verbal working memory, switching costs, global switch costs RT, and mixing costs. Unstandardized (*B*) and standardized (β) regression coefficients are reported for linear regression. Negative binomial regression was used to analyze discrete/count data (i.e., data consisting of nonnegative integers) and data that were overdispersed (i.e., where the mean is lower than the variance), which often occurs when the distribution is heavily skewed (positive skew) and includes a large proportion of zeros. These variables were conduct problem scores and response inhibition commission errors. Prosocial behavior, switching accuracy, and global switch accuracy scores had distributions that mirrored the binomial distribution (i.e., large proportion of maximum values and negative skew) so were reverse coded and analyzed using negative binomial regression. Unstandardized regression coefficients (*B*) and incidence rate ratios (IRR) are reported for negative binomial models. For IRRs, values lower than 1 indicate a lower incidence rate in the intervention group, values of 1 indicate equivalent rates in both groups, and values over 1 indicate a higher rate in the intervention group. Binary logistic regression was used to analyze binary categorical data. The only binary outcome variable was attitudes toward PE. Odds ratios are reported for logistic regression models.

Teacher-rated effortful control and self-reported expectancies and values (measured with multiitem ordinal scales) were modeled as latent variables and analyzed with the robust maximum likelihood estimator in Mplus Version 8. All variables satisfied assumptions of longitudinal factorial invariance to at least partial scalar invariance (see Supplemental Table S1); this means the measurement structure of the latent factors were stable across time and suitable for mean-level comparisons across groups (Van De Schoot et al., 2015). Follow-up mediation analyses were run in Mplus for outcome variables and mechanism variables that significantly changed due to the intervention (all models were run separately to prevent multicollinearity of mediator variables). All models control for baseline measures of the mediator and outcome variables. Main effects of the mediator on the outcome are reported (*B*, β, IRR as appropriate) along with indirect effects of intervention group via each mediator (*B*, percent of total effect that is mediated, bootstrapped 95% bias-corrected confidence intervals).

Statistical Power and Attrition

The mean effect size for main effects in Lakes and Hoyt (2004; $N = 207$) was small, ranging from very small to medium (whole sample mean Cohen's $d = .26$, range = .06–.49). Our sample of 240 provides 80% power to detect effects of $d = .36$ (small to medium). Thus, our study provides a modest increase in power with the additional benefits of assessing EFs and motivational beliefs and statistically adjusting for classroom clustering.

All children completed the intervention; there was no attrition in this respect. A small number of children did not have posttest data: 11 self-reports (4.5%), eight teacher reports (3.3%), and 13 computer assessments (5.4%). Noncompleters differed from completers on only two study measures (we tested all baseline scores and group and control variables). Older children were more likely to have missing teacher report data ($r = .14$, $p = .03$), and children with missing self-report data had lower switching costs at baseline ($r = -.15$, $p = .02$). These associations are likely to be spurious and of little consequence for our results. Furthermore, we analyzed the data using full information maximum likelihood, which adjusts estimates for such patterns of missingness. We also included the baseline equivalents of the outcome measures and additional covariates in our analyses, which should help to make the missing at random assumption more plausible.

Results

Acceptability of Taekwondo Classes

At baseline, a large proportion of children said they would like to take Taekwondo lessons (79%). Postintervention, most children in the intervention group enjoyed the Taekwondo lessons (89%) and found lessons interesting (88%), and two thirds said they would like to continue with Taekwondo lessons (67%). Postintervention, the proportion of children finding PE enjoyable was slightly higher in the Taekwondo group (88.7%) versus controls (83%). Logistic regression analyses found no significant difference between control and intervention groups in postintervention enjoyment of PE, $OR = 1.41$, 95% CI [.54, 3.68]. The proportion of children finding PE "boring" was similar across Taekwondo (14.9%) and control groups (14.6%). Logistic regression analyses again found no significant difference in finding PE "boring" postintervention, $OR = 1.54$, [.54, 4.41]. There were no significant gender or age interaction effects.

Does Taekwondo Instruction Increase Self-Regulation at School?

This section reports the findings of analyses assessing the effects of the Taekwondo intervention on teacher-rated measures of self-regulation. Results from a negative binomial regression model show that the Taekwondo intervention group had lower levels of teacher-rated conduct problems at posttesting ($B = -.23$, 95% CI [−.44, −.02], $p = .03$, IRR = .79). Inspection of group means (see Table 1) shows that this was due to children in the Taekwondo group having relatively stable levels of conduct problems, while the average level of conduct problems increased in the control group. There was no evidence of intervention effects on

Table 1
Unadjusted Means and Standard Deviations for Observed Outcome Scores Preintervention and Postintervention, by Group (Intervention Versus Control)

Measure	Intervention group		Control group			
	Baseline *M* (*SD*)	Postintervention *M* (*SD*)	Baseline *M* (*SD*)	Postintervention *M* (*SD*)	*d*	Minimum/maximum possible range
PE attitudes						
Enjoyment	0.87 (0.33)	0.89 (0.32)	0.84 (0.37)	0.83 (0.38)		0/1
Boredom	0.10 (0.30)	0.15 (0.36)	0.20 (0.40)	0.15 (0.35)		0/1
Self-regulation						
Conduct problems	0.95 (1.72)	0.99 (1.73)	0.77 (1.33)	0.89 (1.30)	−.13	0/10
Prosocial behavior	7.10 (2.35)	7.96 (2.45)	6.94 (2.40)	7.79 (2.44)	−.01	0/10
Attentional focusing	3.77 (1.10)	4.06 (1.01)	3.68 (1.16)	3.89 (0.99)	.14	1/5
Inhibitory control	4.05 (0.87)	4.06 (0.85)	4.00 (0.87)	4.05 (0.88)	−.02	1/5
Activation control	3.82 (1.08)	4.07 (1.01)	3.66 (1.08)	4.00 (1.03)	−.07	1/5
Impulsivity	2.09 (0.98)	1.95 (0.98)	2.19 (1.03)	2.00 (1.01)	.04	1/5
Executive functions						
Executive attention	0.07 (0.15)	0.05 (0.12)	0.05 (0.15)	0.07 (0.15)	−.28	−∞/∞
Response inhibition	0.21 (0.17)	0.24 (0.17)	0.20 (0.14)	0.24 (0.15)	−.05	0/1
Verbal working memory	0.25 (0.14)	0.27 (0.15)	0.25 (0.12)	0.28 (0.16)	.03	0/1
Switching accuracy	78.33 (18.93)	80.61 (19.40)	80.66 (15.38)	82.36 (16.80)	.00	0/100
Switching costs	10.30 (16.98)	10.20 (17.40)	10.35 (14.00)	6.72 (16.26)	.21	−∞/∞
Mixing costs accuracy	−2.19 (15.23)	−0.96 (12.07)	−4.38 (14.08)	−0.46 (12.65)	−.09	−∞/∞
Mixing costs RT	203.38 (380.30)	242.93 (364.47)	209.55 (368.34)	120.26 (339.52)	.23	−∞/∞
Global switch costs accuracy	85.59 (13.36)	85.24 (13.68)	85.75 (13.41)	87.31 (11.50)	−.23	−∞/∞
Global switch costs RT	331.11 (384.41)	307.74 (655.00)	359.77 (405.66)	238.40 (404.60)	.15	−∞/∞
Self-regulatory motivation						
Success expectancies	3.19 (0.44)	3.32 (0.50)	3.15 (0.57)	3.22 (0.52)	.11	1/4
Intrinsic value	3.00 (0.63)	3.04 (0.68)	3.06 (0.70)	2.97 (0.65)	.27	1/4
Attainment value	3.10 (0.58)	3.18 (0.66)	3.18 (0.59)	3.08 (0.70)	.22	1/4
Utility value	3.44 (0.49)	3.57 (0.45)	3.48 (0.54)	3.41 (0.54)	.29	1/4
Costs	2.36 (0.86)	2.33 (0.90)	2.28 (0.86)	2.22 (0.86)	.10	1/4

Note. PE = physical education; RT = reaction time; *d* = unadjusted Cohen's *d* (i.e., not controlling for gender and age) comparing change in the intervention versus control group, presented here for descriptive purposes to enable comparisons with effect sizes reported in Lakes and Hoyt (2004). For effect sizes from full models utilizing the most appropriate statistical models, see main text.

teacher-rated prosocial behavior ($B = -.06$, [−.22, .11], $p = .49$, IRR = .94).

Results from structural equation models show that the Taekwondo intervention group had higher levels of teacher-rated attentional focus at posttesting ($B = .12$, 95% CI [.02, .22], $p = .02$, $\beta = .07$). There was no evidence of intervention effects on teacher-rated inhibitory control ($B = -.02$, [−.10, .06], $p = .63$, $\beta = -.01$), activation control ($B = -.07$, [−.14, .01], $p = .07$, $\beta = -.04$), and impulsivity ($B = .03$, [−.04, .10], $p = .43$, $\beta = .02$). There were no significant gender or age interaction effects.

Does Taekwondo Instruction Influence Performance on Executive Function Tasks?

Linear regression results show that children in the Taekwondo intervention group had better executive attention (i.e., flanker effect) at posttesting ($B = -.03$, 95% CI [−.04, −.02], $p < .001$, $\beta = -.13$). There was no evidence of intervention effects on response inhibition measured as commission errors ($B = -.03$, [−.14, .08], $p = .63$, IRR = .97). There was no evidence of intervention effects on verbal working memory ($B = .01$, [−.04, .05], $p = .90$, $\beta = .01$), switching accuracy ($B = .10$, [−.09, .28], $p = .31$, IRR = 1.10), switching costs ($B = 3.53$, [−1.23, 8.29], $p = .12$, $\beta = .11$), mixing costs accuracy ($B = -.37$, [−3.97, 3.23], $p = .82$, $\beta = -.02$), mixing costs RT ($B = 114.07$, [−9.59, 237.74], $p = .07$, $\beta = .16$), global switch costs accuracy ($B = -.01$, [−.09, .07], $p = .88$, IRR = .99), and global switch costs RT ($B = 77.15$, [−109.69, 264.00], $p = .36$, $\beta = .07$). There were no significant gender or age interaction effects.

Does Taekwondo Instruction Increase Expectancies and Values to Use Self-Regulation?

Results from structural equation models show the intervention group had higher levels of self-regulation success expectancies at posttesting ($B = .06$, 95% CI [.01, .11], $p = .02$, $\beta = .06$). The intervention group perceived self-regulation to have higher intrinsic value ($B = .14$, [.06, .22], $p = .001$, $\beta = .14$), higher attainment value ($B = .14$, [.06, .22], $p < .001$, $\beta = .11$), and higher utility value ($B = .11$, [.02, .20], $p = .01$, $\beta = .15$) at posttesting. There was no evidence of intervention main effects on the perceived costs of self-regulation ($B = .10$, [−.14, .34], $p = .42$, $\beta = .05$).

There were no significant gender interaction effects. There was, however, one significant age by group interaction for costs ($B = -.25$, 95% CI [−.39, −.12], $p = .001$, $\beta = -1.24$). Simple slopes showed that for the youngest pupils (7.38 years), the perceived costs of self-regulation were higher in the intervention group ($B = .59$, [.23, .95], $p = .001$), whereas for pupils at the mean age of our sample (9.37 years), the perceived costs of self-regulation did not differ between groups ($B = .09$, [−.06, .24], $p = .23$). Finally, for

the oldest pupils (11.27 years), the perceived costs were lower in the intervention group ($B = -.39$, [−.62, −.15], $p = .001$). Thus, Taekwondo increased the perceived costs of using self-regulation for young children but decreased the perceived costs for older children.

The main effects reported here did not differ when statistically controlling for children's prior experience of Taekwondo (see Supplemental Table S3). We ran sensitivity analyses for all outcome variables.

Do Changes in EF and Motivational Beliefs Mediate Intervention Effects on Self-Regulation at School?

Changes in executive attention were not associated with changes in either measure of teacher-rated self-regulation (see Table 2). Thus, the effects of Taekwondo on classroom self-regulation were not driven by improvements in EFs. Changes in motivational beliefs (i.e., expectancies and values) were consistently associated with changes in teacher-rated attentional focusing (see Table 2). Furthermore, Taekwondo had indirect effects on attentional focusing via changes in all four of the tested motivational variables. Intrinsic value was the motivational variable that mediated the largest proportion of the intervention effects on teacher-rated attentional focusing (82%). Thus, the effects of Taekwondo on classroom attention may be driven by increased expectancies and values, particularly by increasing the intrinsic value of self-regulation. Changes in motivational beliefs were not associated with changes in teacher-rated conduct problems, and there was no evidence of Taekwondo exerting indirect effects on conduct problems via changes in motivational variables (see Table 2). Thus, intervention effects on conduct problems did not operate via EFs or motivational beliefs.

Discussion

Children had very positive views of Taekwondo, and the majority of those who participated in Taekwondo classes during the study were very positive about them. Taekwondo received high ratings on measures of enjoyment and low ratings of boredom, comparable to those received for children's usual PE lessons. Post-intervention, children in the intervention group had fewer symptoms of behavioral/conduct problems and better attentional focus. We found some evidence of Taekwondo improving EFs and broad support for Taekwondo improving expectancies and values for self-regulation. Intervention effects on teacher-rated attentional focus were mediated by increased expectancies and values.

Taekwondo's Effects on Self-Regulation at School

The effects of Taekwondo training on effortful control were specific to improvements in children's capacity to pay attention and focus. It has been suggested that improvements to self-regulation come about when children engage in activities involving repeated practice and that persistently challenge their self-regulatory skills (Diamond, 2013). A core feature of Taekwondo training that meets these criteria is the memorizing, practicing, and mastering of complex forms (Diamond & Ling, 2016). Forms start as relatively simple routines but become incrementally more challenging as students progress. Such practice and mastery goal pursuit may be a key component of attention training. Future research could further test this possibility by examining the effects of other activities that require children to learn and memorize physically demanding routines—for example, dance routines (Diamond & Ling, 2019). Questionnaire reports show linear decreases in attentional control from late childhood through adolescence (Atherton et al., 2020); therefore, activities like Taekwondo may be especially beneficial to children's development if they are able to attenuate these decreases.

Taekwondo training did not improve teachers' ratings of inhibitory control and activation control. One explanation for this is that introductory courses in Taekwondo may not provide the opportunities required for children to practice inhibiting dominant motor responses, but this may come later. For example, as students progress, they will spar with partners, requiring them to exercise restraint to prevent injury. Sparring can involve being paired with students of different skill levels, strength, and size, which means more advanced students must learn to inhibit and modulate physical responses when matched with weaker or less-skilled partners. Similarly, effective sparring involves not striking right away but waiting for your opponent to be slightly off balance; this is another aspect that would seem to improve inhibitory control. Thus, longer-term studies are required to fully test whether lengthier courses of training lead to improvements in inhibitory control. Activation control refers to children's ability to do things they may find boring or unappealing (e.g., choose work over play, tidy up). There are normative reductions in activation control during adolescence (Atherton et al., 2020), and this likely reflects the fact that young people often prioritize different goals from their parents and teachers—for example, socializing and having fun over studying and

Table 2
Results of Mediation Analyses

	Outcome: Attentional focusing		Outcome: Conduct problems	
Mediator	Indirect effect of intervention group via mediator *B* [95% CI] % indirect	Direct effect of mediator on outcome *B* [95% CI] B	Indirect effect of intervention group via mediator *B* [95% CI] % indirect	Direct effect of mediator on outcome *B* [95% CI] IRR
Executive attention	.00 [−.01, .01] 0%	.00 [−.003, .004] .00	.004 [−.03, .03] 2%	−.001 [−.01, .01] −1.00
Success expectancies	.02 [.00, .06] 19%	.41 [.23, .64] .24	.01 [−.01, .10] −6%	.18 [−.37, .68] 1.19
Intrinsic value	.10 [.01, .21] 82%	.68 [.13, 1.60] .38	−.06 [−.30, .06] 23%	−.40 [−1.69, .30] 0.71
Attainment value	.06 [.02, .12] 53%	.44 [.28, .71] .31	.04 [−.01, .21] −16%	.28 [−.07, .97] 1.32
Utility value	.04 [.02, .10] 35%	.40 [.12, 1.15] .17	.01 [−.02, .05] −4%	.09 [−.51, .55] 1.09

Note. CI = confidence interval; IRR = incidence rate ratio.

chores (Blakemore & Choudhury, 2006). Thus, while we did find that Taekwondo increases how much children value self-regulation (more on this below), this did not extend to more activation control in the classroom.

Children who are impulsive tend to rush into things, interrupt others, and generally show a lack of forethought and planning. Many studies have conceptualized good self-regulation as the inverse of impulsivity (e.g., Ng-Knight & Schoon, 2017). Like Lakes and Hoyt (2004), we found no effects of Taekwondo on impulsivity. This further refines our understanding of the effects of short-term Taekwondo training in children, showing that specific components of effortful regulation like attentional control are improved, but impulsive behavior is not. Alternative intervention strategies (potentially including longer martial arts interventions) may be needed if impulsivity is the key target of intervention efforts.

Symptoms of conduct problems in this sample (see Table 1) were comparable to national norms (U.K. norms: $M = .90$, $SD = 1.60$) and below clinical levels. Conduct problems were fairly stable in the intervention group but showed a slight increase over the 12-week study period in the control group. This suggests participation in Taekwondo classes may protect against increases in problem behavior rather than reduce them per se. Small age-related increases in symptoms of conduct problems are fairly normative and so unlikely to be of concern, but larger increases may be indicative of adolescent-onset conduct disorder, which is associated with poorer psychosocial outcomes (Gutman et al., 2019). Previous research has shown Taekwondo training has clinical utility among samples high in conduct problems (Trulson, 1986), and we extend this finding to a nonclinical sample. While the effects were relatively modest, antisocial behavior is a key concern among school leaders even when it does not reach clinical levels. Conduct problems are more prevalent among boys, and there may be concern that teaching martial arts to boys will worsen behavior like fighting and bullying. However, concern seems unwarranted as Lakes and Hoyt (2004) found conduct problems decreased most among boys, while we found beneficial effects among both boys and girls. In sum, Taekwondo may serve as a useful universal intervention for symptoms of conduct problems in nonclinical samples.

Lakes and Hoyt (2004) found the Taekwondo program they evaluated increased prosocial behavior at the whole sample level, and this was strongest among boys. We found no evidence that a standard beginners' Taekwondo program influenced prosocial behavior. Content differences in the two interventions may explain differences in results. The program Lakes and Hoyt evaluated placed greater emphasis on emotional control, leadership, social responsibility, and conflict resolution (Pasquinilli, 2001). In the future, it will be important to manualize and assess the components of Taekwondo courses to enable research to clarify the active components of courses and their specific effects.

Possible Mechanisms of Effect

There were improvements in executive attention in the intervention group but no other EF domains. Thus, the effects of this brief Taekwondo course on EFs were specific rather than broad. This is consistent with Diamond and Ling's (2019) conclusion that mindfulness-based activities (whether sedentary or active) have more effect on attentional control than any other EF. Effect sizes for executive attention (equivalent to $d = .28$) were highly respectable given the brief nature of the intervention (11 weeks, 16.5 hours) and the use of a relatively strong, active control condition (the control group took part in regular PE lessons). Furthermore, as this study was conservatively designed with the power to detect small-medium effects only, Taekwondo training may have generated small improvements in other EF domains that could not be detected from the current study design. As mentioned above, this is consistent with the positive effects on attention reported by classroom teachers and with previous research (Lakes & Hoyt, 2004). However, mediation analyses suggest intervention effects on task-based and teacher-rated assessments of attention are independent. Thus, improved attentional control appears to be a key effect of Taekwondo instruction, but improved EFs do not account for improved attentional focus observed by classroom teachers.

Our findings show Taekwondo is a good method of increasing the value children place on self-regulation as well as making children feel more able to exert self-regulation (i.e., success expectancies). To our knowledge, this is the first study to assess success expectancies and values specifically about self-regulation and the first to show that these motivational constructs can be increased via intervention. Academic values tend to be stronger predictors (than expectancy beliefs) of self-control and related behaviors like task persistence and effort (Galla et al., 2018; Trautwein et al., 2006, 2012; Wigfield & Cambria, 2010). Likewise, we found Taekwondo had larger effects on valuing self-regulation compared to expectancy beliefs. Intervention effects on teacher-rated attentional focus were mediated by changes in values, particularly intrinsic value. Hence, Taekwondo appears to improve children's school behavior by making self-regulation more enjoyable, important, and useful. During longer periods of Taekwondo training, these motivational changes may precede larger changes in self-regulation. Promoting the value of self-regulation may be an important feature of self-regulation interventions that requires further consideration.

In the current study, there was very little evidence of gender and age differences. We found one age by group interaction where Taekwondo training increased the perceived costs of exerting self-regulation for younger children but decreased perceived costs among older children. This may be because the tasks generally associated with good self-regulation (paying attention, planning, etc.) become easier with age. Thus, stressing the importance of self-regulation to younger children who likely have lower ability to perform self-regulated tasks may have specific negative consequences for motivation (i.e., higher perceived costs). This would not necessarily preclude the teaching of Taekwondo to younger children as other positive effects did not differ across age groups. However, when taken together with previous findings of stronger effects among older children (Lakes & Hoyt, 2004), further research is needed to clarify if Taekwondo is more beneficial in older versus younger students.

Future Research, Implications, and Limitations

How best can we administer Taekwondo intervention in schools? Taekwondo is typically taught by experienced practitioners (it takes a minimum of 4.5 years to achieve a black belt), and subsequently administering Taekwondo interventions has financial implications. Using schoolteachers to teach martial arts

may be a cheaper option, though it is currently of unknown feasibility. Research needs to (a) assess whether schoolteachers (rather than instructors) are able (and willing) to be trained to deliver martial arts classes and (b) explore the possibility of developing a simpler martial arts curriculum that can be taught by less experienced practitioners (e.g., teachers). Regardless, adequate investment in martial arts instruction will be needed before mainstream rollout.

What are the effects of longer programs of martial arts training? We now know that short courses (11–12 weeks) of Taekwondo have some attentional, behavioral, and motivational benefits for children. It has been suggested that activities that will have the most substantial effects on self-regulation need to occur for longer periods of time and need to persistently challenge children's self-regulation skills (Diamond & Ling, 2019). Other physical education programs also indicate much longer time frames (e.g., from 1 to 3 years in duration) are needed before the full benefits to self-regulation can be observed (Holochwost et al., 2017; Pesce et al., 2020). Martial arts are also likely to work in this way as students are engaging with a system of mental and physical training that takes many years to master. Thus, rather than being overly concerned about the effects of short interventions not persisting postintervention, future research should comprise longer-term studies of children undertaking martial arts to track the development of self-regulation. This is particularly important where far transfer effects of physical intervention are hypothesized—for example, to academic outcomes and EF performance (Blair & Raver, 2014; Holmes et al., 2009).

How do features of our study design influence interpretation of the findings? A strength of our study design was assessing the assumed mediator and outcome variables from different perspectives/raters. However, our mediation analyses relied on only two waves of data, so it is possible the proposed outcomes actually mediated the proposed mediators. Future research should collect more than two waves of data to reduce this possibility. Our control group completed "business as usual" (BAU) activities, which has two limitations. First, this may inflate intervention effects as any novel activity can induce positive change (McCarney et al., 2007). Second, it means activity in our control group varies, and more research is needed with a uniform control group. Nevertheless, many studies have not found any effects of educational interventions (Lortie-Forgues & Inglis, 2019), so it is important to show that new programs provide an improvement compared with BAU, and this should not be taken for granted. Also, while a BAU control group has limitations for eliminating Hawthorne effects, it leads to a conservative study design that reflects a meaningful comparison with clear implications for practice. This allows determination of the efficacy and acceptability of Taekwondo as an intervention (Shawn Green et al., 2019).

What were the limitations of our measures? We did not obtain independent behavioral assessments of classroom behavior. Instead, we relied on teacher reports. Teachers were not blind to study condition, and this may have influenced their assessments of children's self-regulation. Future research should collect independent behavioral ratings of children's self-regulation as was done in Lakes and Hoyt (2004). Future research should include measures of inhibitory control that more closely mirror inhibition in the classroom. The go/no-go task used here simply requires inhibiting a response by doing nothing, whereas more real-life inhibitory control typically requires inhibiting one response to make another. Finally, children had unlimited time to respond on the flanker and switching tasks, which might have reduced the demand on EF skills.

Conclusions

Taekwondo lessons were viewed positively by young school children. A short course of Taekwondo improved aspects of school children's behavior, attention, and motivational beliefs about using self-regulation, highlighting primary school as a developmentally appropriate period for administering self-regulation interventions. However, multiple aspects of self-regulation and EF were not improved by the Taekwondo intervention. This suggests domain specificity in the positive effects of Taekwondo. Motivational beliefs in the form of expectancies and values were identified as an underlying mechanism of Taekwondo's effects on self-regulation at school. The positive effects were found in a mainstream primary school and with standard/untailored Taekwondo lessons, which further supports the generalizability of Taekwondo's effects. Work is now needed that investigates the effects of children's age, intervention dosage, curriculum design, and delivery of Taekwondo interventions to maximize gains within the constraints of feasible delivery.

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