Method

Description of the training program

Each session was approximately 1 hour with a target of 40 minutes of computer game play and approximately 20 minutes of coaching. Each session included a brief, 5-minute check-in with a parent or caregiver. The first two sessions began with formal psychoeducation that introduced key concepts about EF and emotion regulation. Scripted content was used to refer to key concepts throughout subsequent sessions. Given that the learning style of many children on the spectrum favors visually presented information, key concepts were presented with consistent language accompanied by visual information. This information was presented on reminder cards that could be referenced throughout the session for prompts, to foster discussion, or as a teaching tool. Parents also received a written handout that provided an overview of key concepts and the training procedures. Finally, some sessions had specific activities (e.g., homework, teaching a family member) to ensure meaningful engagement and promote generalization.

Sample Session Outline:*"Intermediate" Training Sessions (From Session 4 to Level 12 of any Game)*

WITH CHILD ALONE (50 MINUTES)

1. Review session format:
    - 5 minutes of chat/review
    - 50 minutes of training games with two breaks
    - 5 minutes of debriefing
2. Continue to build rapport with child.
3. *(If needed)* Revisit psychoeducation reminders. Use visual cue cards.
4. Revise the plan. Now that the child is advancing in levels, ask if there are any specific goals that he/she has for completing certain levels in this session. Review the backup plan concept. Using the written plan from last session as a prompt, ask him/her how well the backup plan worked. Briefly mention any issues from the last session, if applicable, and prompt discussion about why the backup plan didn't work. Guide child into formulating a new backup plan if necessary.
5. *(If needed)* Revisit games instructions/reminders.
6. Play training games for approximately 10 minutes each, with two breaks at the child's choosing. When appropriate, ask child meta-cognitive questions throughout the training games. More scaffolding may be necessary to elicit responses from children (e.g., multiple choice, yes/no questions, asking "what other special skills did you use?")

WITH PARENTS AND CHILD TOGETHER (5 MINUTES)

Come together to debrief following training session. Highlight child's successes to parent, and briefly mention what will be targeted for improvement in upcoming sessions. Confirm next session with parent. Thank family for their participation and time. Allow the child to pick a prize.

Description of Computer Games. The training consisted of four games: Pirates, Oceans, Robots, and Windows. Each game required multiple aspects of executive function. Across the four tasks, the difficulty of levels advanced by increasing the item set or simultaneous dimensions, decreasing the available response time, requiring greater accuracy, adjusting the proportion of distractors or their complexity, and requiring consecutive runs with high accuracy. The parameters that contributed to the difficulty of each level and passing criteria were fixed; however, children progressed from level to level at their own pace. That is, they could re-play games at a lower level throughout the training program if unable to progress beyond that level of difficulty or they could advance to more challenging levels by unlocking them as they successfully achieved the performance criteria of each level. If children did not meet criteria to advance to the next level after eight consecutive failed attempts, the games also returned to a lower level for additional practice before unlocking higher levels. The intensity (i.e., number of sessions and training activities) was determined from Rueda's prior work with typically developing children and via piloting with children on the autism spectrum.

The training has been developed and used successfully with typically developing preschoolers (as young as 4 years) and early school age children (Pozuelos et al., 2018; Rueda et al., 2005; Rueda et al. 2012 and personal communication with M. Rosario Rueda (2013, 2014) who provided the games for this study and provided input on task selection and calibration). Thus, the games were thought to be appropriate for developmental levels lower than those included and the current study and the training activities were scalable to challenge children who had much higher developmental levels. Our data suggest that the tasks were not too easy for our sample. The number of children who were able to successfully complete all levels for one game or two games was low. Of the 35 children who received the intervention, 16 children completed

all levels of at least one (of four) training game, and of those, only five children completed more than two training games.

The *Pirate Game* was Stroop-like in the sense that it required children to attend to one dimension of information – the quantity of coins contained in each of the pirate's bags – and inhibit information from a second dimension – the size of the bag. During each trial, children were required to select the more valuable of two bags of coins by clicking on it with a computer mouse. Trials were timed so that children were required to complete their response within a time limit. In addition to inhibition, the Pirate Game also required set-shifting because pirates are sneaky and have fake coins in addition to real ones. Real coins were gold, whereas fake coins were silver. When children encountered gold coins they needed to select the bag with the largest quantity of coins and when they encountered silver coins they needed to select the bag with the smallest quantity of coins. The Pirate Game had 18 levels.

The *Oceans Game* presented children with a set of sea creatures at the top of the screen. On the bottom of the screen were a different array of creatures that comprised the possible response options. The goal was to either select the creature at the bottom that exactly matched one of the creatures at the top (i.e., same animal and same color as one of animals above) or was the most different (i.e., a different animal and different color than any of the animals above). Selections were made by clicking on the animal with a computer mouse. As such, the game required set-shifting to alternate between the two sorting rules and sorting dimensions. Additionally, because the game was timed, as the number of animals increased the visual working memory load also significantly increased. The Oceans Game included 21 levels.

The *Robots Game* was a Go/Nogo task wherein children quickly "fed" robots metal nuts if the shape of the nut matched the shape of the robot (i.e., "Go"). They fed the robot the nut by

clicking on it with their computer mouse. However, they were not to feed the robot nuts that were a different shape than the robot (i.e., "Nogo"). Children also used set-shifting between two rules during the game because some nuts were rusty and were not to be fed to the robot even when their shapes matched. The Robots Game included 20 levels.

The *Windows Game* was an n-back task that involved remembering the previous locations of windows that opened and closed in a sequence. Spans ranged from 1-back to 3-back as the task difficulty progressively increased. In addition to the sequence of locations, the task also included sequences with differing colors inside the window for which the sequence of colors must be remembered. These sequences combined both location and color requiring set-shifting. When the location and/or color of the n-back window matched the current window, children indicated the match by clicking the computer mouse. The Windows Game included 21 levels.

Manualized Metacognition Training. Metacognition Coaching was provided following a manual developed specifically for this study. Consistent with Wood, Bruner & Ross (1976), the metacognition coaching manual provided coaching strategies that: meaningfully engaged children with the tasks, simplified the tasks to make them manageable, supported sustained effort on the tasks, emphasized key EF skills needed for each task, provided coping strategies and sought to reduce frustration associated with challenging aspects of the tasks, and used guided conversations to aid children with solving each task. In order to support the needs of children on the autism spectrum, key concepts were described using consistent language throughout training sessions (e.g., inhibition was described as "stopping myself") and visual supports were used (i.e., a stop sign).

Metacognitive strategy	**Example**
Meaningful engagement with the task	Forming a Plan A and Plan B (demonstrating and modeling an approach to the games that is deliberate and draws on metacognitive strategies). Plan B specifically models being flexible and having a backup plan. Examples of some Plan Bs are: *Try a different order, skip around after playing 5 minutes of each game, etc.* Use of homework sheets with four prompts: *I stopped myself when….* *I was flexible when….* *I made a plan for….* *I remembered the details when…..* Teach a Family Member Activity – as the child becomes an EF "expert" they lead a family member in a discussion of the EF psychoeducation materials. Trainers ask: • *"Who would you like to teach today?"* • *"Can you tell __ what kinds of things you need your problem solving skills for?"* • *"Are there special skills that help you solve tricky problems?" (Prompt with: Are you forgetting any?)* • *"Can you tell __ about one of the games and how you use these skills during the game?"* • *"Why don't you tell __ about some things you can do when you get frustrated."*
Simplification of tasks to make them manageable	Introduction of the tasks to highlight key strategies: *In this game you have to pick the bags that have the most treasure inside. Pay close attention to the rules. When you see GOLD coins, pick the bag with the BIGGER number. Pirates are sneaky, so they may put a bigger number of coins in a tiny bag. Don't let them trick you!*
Support of sustained effort on the task	Normalization that sustained effort is challenging but will lead to positive change: *Our brains are kind of like muscles that get stronger when they get exercise.*
Emphasis of key EF skills needed	Basic psychoeducation at the beginning: *One special skill is being able to stop ourselves from doing or saying things that we don't want*

	to do. If we have a good plan, we don't want to do things that will mess up the plan. Like, when we are trying to clear a tricky level in a video game, we don't want to push all the buttons at the same time. (Can modify examples to be relevant to child's interests)
Provision of coping strategies to reduce frustration associated with challenging aspects of the task	Psychoeducation and use of strategies from cognitive behavioral therapy (e.g., awareness of feelings) and guided relaxation: *Sometimes it's hard to solve tricky problems and accomplish our goals when we are feeling emotional. Let's use this meter as a tool to help keep track of where our emotions are so we know if we need to take a break to calm down!*
Guided conversations to aid children with solving each task	Use of meta-cognitive questions throughout the training games: *"Why do you think you missed that one?"* *"What can you do differently next time?"* *"What strategy are you using to beat this level?"* *"How does your strategy help you?"* *"Why was this level easier/harder for you?"* *Try to get the child thinking in terms of the 3 special skills (inhibition, set-shifting, working memory).*

To ensure meaningful engagement with tasks and generalization of metacognitive concepts to other settings, children completed homework in the later sessions (after reaching level 12 of any game). The homework sheet included 4 prompts and children demonstrated their understanding of key concepts. For example, one child described "*stopping myself"* from hitting a peer when upset and another noted *"I was flexible when"* I wanted to stay home and play video games but had to go out to eat with my family instead. Children reported making plans and "remembering the details" when completing school work and during social interactions with family and peers.

The Metacognition coaching manual is available from the first author.

Details of electrophysiologic methods

Data acquisition. Neural responses were continuously recorded via a Net Amps 400 (Electrical Geodesics, Inc.) using the 128-channel hydrocel sensor net 2.0 (HSN). Impedances were below 50 kΩ at the start of the session. EEG signals were recorded online using the vertex reference electrode with a 4 KHz antialiasing hardware filter and a sampling rate of 500 Hz. Data were re-filtered off-line using a 0.1 Hz high-pass and 30 Hz low- Kaiser-type FIR filter with 2 Hz rolloff.

Data editing and extraction. For both tasks, EEG data were segmented with a 200ms baseline period preceding stimulus onset and 800ms after the stimulus onset. Baseline correction used the 200ms baseline period. Trials with incorrect behavioral responses or artifacts were excluded from the averages using the following criteria: (1) presence of an eye blink using the Netstation Eye Blink algorithm set at 220 μV with an 80ms moving average and confirmed by visual inspection, (2) more than 10 channels with fluctuations exceeding 140 μV or less than 1 μV with an 80ms moving average. Data were visually inspected for additional artifacts by a team member who was naïve to treatment assignment and segments were excluded if they contained significant drift, movement artifacts, eye movements, or mechanical artifacts. Channels marked with artifact for >20% of the trials were interpolated using spherical spline interpolation. Data were averaged for each condition, re-referenced to the average of all electrodes minus the four eye channels using the polar average reference effect correction (Junghöfer et al., 1999), and baseline corrected again. N2 amplitude was extracted between 300-400ms over the frontal midline (Fz cluster: HSN electrodes 19, 11, 4; Faja et al., 2016; Lamm, Zelazo, & Lewis, 2006; Samyn et al., 2014).

Results

Fidelity. Data confirmed that children played all four training games during each session unless they had completed the highest level of a game during a previous training session. Of the 35 children who received the intervention, 16 children completed all levels of at least one training game, and of those, five children completed more than two training games. During each training session, children spent 30 to 40 minutes playing the training games (*M*=36.12min, *SD*=2.92). The total number of minutes spent on computer tasks ranged from 209-403 (*M*=354.59min, *SD*=39.63). In addition, all children completed both the EF and basic emotional regulation psychoeducation modules at the first and second training session, respectively. These modules were reviewed throughout the remaining visits. Participants set goals (*M*=7.9/9.8 opportunities, *SD*=1.63, range=3-10), generated a "Plan A" goals (*M*=9.3/9.8 opportunities, *SD*=1.17, range=6-10), and "Plan B" (*M*=8.4/9.8 opportunities, *SD*=1.86, range=4-10) for each session (e.g., the order they would play the games), and worked to generalize EF skills by identifying situations in which they used their EF skills at home and at school. At a final training session, all children completed an exercise to consolidate their learning by presenting the EF psychoeducation module to a family member and teaching that person how to play the games. All trainers received formal instruction on how to deliver the content of the training manual and direct supervision for their initial sessions. Ongoing fidelity data were reviewed and trainers who did not adhere to manualized procedures were retrained. Additionally, all trainers received ongoing supervision from a licensed psychologist to consult about optimal strategies for responding to challenging behaviors and obstacles to delivering intervention.

Feasibility and Acceptability. Prior to beginning the study, the training (including

metacognition coaching) had been used with typically developing children from preschool to school age (Pozuelos et al., 2019; Rueda et al., 2005, 2012). Additionally, the training was piloted in a small group of children on the autism spectrum. This piloting led to adaptations including development of the coaching manual, selection of tasks and task difficulty, and the structure and maximum duration of sessions.

Of the 35 families randomized to training, all completed training and returned for follow-up demonstrating that the procedures were feasible. Additionally, within training, there were 10 planned sessions and 31 families completed all 10 sessions (89%). Two families completed 9 sessions, one completed 8, and one completed 7 sessions. Children played all four training games during each session unless they had already completed the highest level of a game; training was discontinued early in some cases when children reached the final level of all games.

To determine whether training was acceptable, family feedback was systematically elicited at the end of each training session about child behaviour during the session. These responses were monitored and children or families who reported difficulty with the training program or sessions were reviewed with a licensed psychologist who oversaw the trainers so that adaptations could be made including additional coaching surrounding emotion regulation, additional structure during sessions, or supports to decrease technical challenges associated with accessing the training games via the internet.

At the final session of the training program, parents/caregivers were asked to provide written responses to three open ended questions about the training program aimed to gather information about possible changes and benefits:

1) Did you notice any changes in your child that you think may be related to our training program? If yes, what were they?

2) If not already described above, do you think there have been any improvements in your child's executive function since starting training?
3) Did participating in the study improve your understanding of executive function or strategies for helping your child develop executive functioning skills?

Twenty-three families returned the responses to these questions. Of these families, 14 (61%) described a clear and positive change related to training, 3 (13%) reported possible positive changes related to training, 5 (22%) reported no changes, and 1 (4%) reported a negative change. Examples of positive changes included, "Yes, he is more flexible and seems more focused and stays on task and he doesn't get as upset if he is not 100% perfect doing something" and "Yes, he is trying to do difficult tasks by talking them out step by step to himself." Possible changes included, "Perhaps. His transition to 5th grade has been surprisingly easy thus far" and "He was in a good mood." Several parents reported no clear child-related changes, "I didn't notice anything specific, but the worksheets gave me more language to use to talk to him about his day" and "No, but he was more aware after an 'episode' of what he wants." One family reported that they did not observe changes, but had already engaged in an extensive executive function program elsewhere. Finally, one family indicated that the additional hour of training each week on top of an already busy schedule caused stress saying, "the only change that can be directly related is that by having an activity every afternoon Monday-Thursday is he was overloaded."

With regard to specific changes related to executive functioning, seven families reported increased flexibility after training (e.g., "she seems a little more flexible"), three commented on increased inhibition (e.g., "her impulse control seems better"), and one on working memory (e.g., "I find myself not having to repeat things over and over. He gets it! He has a great memory!"). Three families reported increased planning or organization (e.g., "Yes, he seems to keep track of his assignments and things a lot better.") and eight families reported noticing increased metacognition ("He is more aware of his need to be flexible, stop, etc."). One family described

overall improvements in executive functioning (i.e., “I think he improved overall.”), and five noted improved mood or emotion regulation skills (e.g. “He doesn't get as upset if he is not 100% perfect doing something.”). Nineteen (83%) of parents/caregivers also reported increased knowledge of EF or strategies for helping their children develop EF. Two of the four families who reported not learning about EF from the training reported that they were already very familiar with the concepts. For example, one said, “No, we are well-versed. However, (I was) impressed with games and skills my child was able to use to complete them.” The remaining two parents described either not being engaged with the sessions or struggling with EF in their own functioning. Of the parents who described benefits to themselves, some described using metacognitive language such as, “I have used some new strategies like talking through things so he can see how I got from point A to point B,” while others gained insight about their children, “I understand more about how to improve his understanding, how his mind works.” These responses demonstrate that the training was generally viewed as acceptable and beneficial to the majority of families who participated.

Globally, after the final post-testing session, all families (training, waitlist groups) were asked whether they would recommend the study to other families in general. Thirty-two of the 35 training families responded to this item. All 32 (100%) of the responses were positive. In an open-ended question about positive experiences in the study (i.e., “What did you or your child like about the study?”) 16 of the 32 responders spontaneously noted that their children enjoyed the games or the training sessions. Some examples included, “My son liked playing the games,” “He really liked earning money, the snacks were good. He seemed to enjoy the games as well,” and “My child liked the games. He had lots of fun, didn't want it to end. I love that he was enjoying himself and also that I have more insight on how he is learning new things.”

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