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Title

A multidimensional evaluation of the benefits of an ecologically realistic training based on pretend-play on preschoolers' cognitive control and self-regulation: From behavior to the underlying theta neuro-oscillatory activity

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Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

1. Introduction

Development of self-regulation allows children to behave deliberately through the management and modulation of their emotions, thoughts, and actions (Nigg, 2017). Self-regulation relies in part on cognitive control (Bailey & Jones, 2019; Nigg, 2017), a set of partially independent top-down cognitive processes that support goal-directed behavior (Diamond, 2013; Miyake et al., 2000), and involve functions like working memory (updating and manipulating information in memory), response inhibition (inhibiting automatic responses) and cognitive flexibility (switching between task-sets). Cognitive control is important for many aspects of children's daily functioning and academic achievement (Blair & Razza, 2007; McClelland et al., 2000). Individual differences in cognitive control in early childhood partly explain differences in school readiness (Blair, 2002; McClelland et al., 2000), and children with poorer cognitive control have a greater risk to fall behind as soon as they enter school (Blair, 2002; Mcclelland et al., 2000). This influence is explained by the involvement of cognitive control in school learning (Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006) and in children's self-regulatory behavior, which allows them to comply with rules, regulate their emotions and behave in socially appropriate ways (Blair & Raver, 2015). There is, therefore, a great interest in promoting cognitive control of children before they enter school to help them improve their self-regulatory behavior and limit the achievement gap they may have later on (Blair & Raver, 2012; Diamond et al., 2007). This is even more crucial for children facing poverty or adversity, given the growing evidence that poverty-related gaps in school achievement can be explained in part by its adverse effects on children's self-regulation development (Blair & Raver, 2012; Evans & Rosenbaum, 2008). The present study aims to address two questions: what training programs of cognitive control are also effective in promoting children's self-regulation, and what brain mechanisms explain these effects? A list of interventions and training programs to improve children's self-regulation has been proposed by Diamond and Ling (2016). One of these authors’ conclusions is that training programs that engage cognitive control while simultaneously addressing children's emotional, social, and physical needs are the most efficient at improving children's self-regulation. However, the brain mechanisms that account for the impact of improved cognitive control on self-regulation are still under-studied. Examining the influence of training on brain mechanisms underlying cognitive control could be a promising avenue of research that has not been explored yet.

Evaluations of early interventions and training programs aimed at improving children's cognitive control have yielded inconsistent results on self-regulation, in part because of differences in the content of training activities and the context in which these activities occur. Karbach Unger (2014) defined three cognitive control training types: i) strategy-based training, which teaches children certain strategies to help them regulate their behavior; ii) cognitive task-based training, which uses cognitive control tasks to directly and specifically target cognitive control capabilities; iii) and ecologically realistic training, in which children engage cognitive control in conditions close to real-life situations that also involve social and emotional processes.

Strategy-based training that teach children to use private speech or develop breathing habits, help them regulate their behavior, (Berk et al., 2006; Elias and Berk, 2002; Whitebread, 2010) and contribute to their performance in cognitive control in task-switching tasks (Bryck & Mayr, 2005; Emerson & Miyake, 2003). Other strategy-based training that provide children some guidance to a reflection about the relevant instructions and dimensions of the tasks are also effective at enhancing cognitive control (Espinet et al., 2013). Cognitive control task-based training improves children's performance in working memory, response inhibition, and cognitive flexibility (Kloo & Perner, 2003; St Clair-Thompson et al., 2010; Thorell et al., 2009), although mixed results have been obtained for inhibition (Rueda et al., 2005, 2012; Thorell et al., 2009). This training also has impact on brain mechanisms of cognitive control, although it is unclear to what extent these brain changes explain the effects of training on cognitive control. Changes have been reported on cortical thickness (Haier et al., 2009), as well as on brain activity and functional connectivity (Haier et al., 2009; Jolles & Crone, 2012; Rueda et al., 2004, 2012). Training of inhibition and attentional control have been associated with effects on the amplitude, the latency, and the localization of the N2 event-related potential, a neural marker of cognitive control (Pietto et al., 2018; Rueda et al., 2005, 2012), as well as with an increase in effective connectivity between the frontal and parietal areas involved in cognitive control network (Astle et al., 2015). Training effects on children's brains have also led to brain structure and brain functioning patterns that are more similar to those of older children, suggesting that training may stimulate the development of cognitive control network (Jolles & Crone, 2012). However, despite its effects on cognitive control and its brain mechanisms, there is very little evidence that cognitive-task-based training is beneficial for children's academic and self-regulatory skills as very few studies have reported some effects on these skills (Melby-Lervåg & Hulme, 2013; Thorell et al., 2009; Titz & Karbach, 2014).

Ecologically realistic training that also addresses children's social, emotional, and academic needs has been shown to improve academic and self-regulatory skills (Bryck & Fisher, 2012; Diamond & Lee, 2011; Diamond & Ling, 2016). This training approach is in line with the theoretical framework proposed by Bailey and Jones (2019), according to which the development of more elaborate self-regulatory skills in the social, emotional, and cognitive domains (e.g., emotion regulation, perspective taking) is supported by the progressive integration of cognitive control with other domain-specific skills and knowledge (e.g., the development of emotion regulation is supported by the integration of inhibition with emotion knowledge). Following this view, an effective approach to helping children develop their self-regulatory skills through cognitive control training would consist of targeting cognitive control interactions with other domain-specific skills and knowledge. This could be achieved by integrating cognitive control training into school and/or social activities to improve cognitive control interaction with social, emotional, and learning processes. This approach is also in line with the view that effective training must foster the emergence of effective connections between cognitive control brain regions and more specialized regions involved in specific skills and knowledge (Amso & Scerif, 2015).

The Tools of the Mind early childhood curriculum follows this line (Bodrova & Leong, 2018). This curriculum, based on Vygotsky's sociocultural perspective and carried out by several generations of post-Vygotskian scholars (Karpov & Karpov, 2005; Vygotsky, 1978) emphasizes the role of social interactions in child development and learning. In this curriculum, cognitive control is seen as a central mechanism for children's academic and self-regulatory skills and is at the core of some teaching and learning activities. Randomized-controlled trials–based evaluations of this curriculum have shown improved performance in working memory, set-shifting, and inhibition in both preschoolers (Diamond et al., 2007, 2019) and school-aged children (Blair & Raver, 2014), as well as improved vocabulary and mathematics (Barnett et al., 2008; Blair & Raver, 2014; Diamond et al., 2007, 2019) and better self-regulation, with less externalized behavior and better conflict resolution skills (Barnett et al., 2008), although mixed findings on these skills were also obtained in two studies (Wilson & Farran , 2012, Lonigan & Phillips, 2012). At the same time, children’s cognitive and social-emotional gains were smaller when isolated Tools of the Mind activities were added to another curriculum used in preschool (Diamond & Ling, 2016). Among the program's activities, pretend play holds a special place for its role in the development of children's self-regulation (Bodrova et al., 2013; Slot et al., 2017; Vygotsky, 1933), although the causal role of pretend-play in child’s development is still debated (see Lillard et al., 2013 for a review). Pretend play consists of solitary or group activities where children establish a play scenario, select and coordinate their roles, and plan all the actions to be performed (Vygotsky, 1933). When several children are involved in pretend play, they engage cognitive control across various cognitive, social, and emotional domains (Bodrova et al., 2013; Bodrova & Leong, 2006; Slot et al., 2017; Vygotsky, 1933). For example, children hold in working memory information related to the play scenario and their roles, they use inhibitory control to refrain from acting inappropriately with the ongoing play and mental flexibility to adapt their actions to the changes of the play. Pretend play also allows children to exert cognitive control in the social and emotional domains, to take turns, consider other children's ideas, resolve conflict, and regulate their emotions and feelings (Galyer & Evans, 2001).

While inconsistent findings have been obtained regarding the associations between executive functions and pretend play (see Lillard et al.., 2013 for a review), evaluations of children's self-regulation and cognitive control during play show that children as young as three years of age rely more upon these skills when their pretend play is more mature (e.g., increased complexity of the roles and the scenario, use of pretense). Play maturity is correlated with performance in working memory, inhibition, set-shifting, higher-level executive functions like planning and conflict resolution (Carlson et al., 2014; Vieillevoye & Nader-Grosbois, 2008), as well as with children's emotional self-regulation, (Elias & Berk, 2002; Galyer & Evans, 2001; Gilpin et al., 2015). Furthermore, two studies have shown that when preschoolers were trained to engage regularly in pretend play, improvements in working memory, inhibition, and flexibility (Thibodeau et al., 2016; Traverso et al., 2015) were observed after the training, with larger effects for children who were highly engaged in the play (Thibodeau et al., 2016), suggesting that enrolling preschoolers in pretend play can be an efficient way of training their cognitive control. However, it is unknown whether it can also benefit children's self-regulatory behavior.

In the present study, we assessed whether a training using pretend play could improve children's self-regulation. We also assessed whether these improvements were explained by some changes in the brain mechanisms of cognitive control. Based on Diamond and Ling's (2016) conclusion, we propose that pretend play might be an effective approach to promote children's self-regulation because it engages various instances of control across cognitive, social, and emotional domains. Furthermore, building on the idea that training must foster the emergence of effective connections between cognitive control brain regions and more specialized brain regions involved in specific skills and knowledge (Amso & Scerif, 2015), we further propose that better coordination between brain regions involved in control and more specialized regions would explain these training effects. A possible neural candidate is the midfrontal theta oscillatory activity within the frequency range of 4-8 Hz (MFT), a neural mechanism of cognitive control in adults (Cavanagh & Frank, 2014; Cohen & Cavanagh, 2011), school-aged children (Adam et al., 2020) and preschoolers (Adam et al., 2020; Liu et al., 2014). MFT is thought to serve as a general neural mechanism of cognitive control because it has been associated with various tasks that engage cognitive control, such as conflict processing and novelty (Cavanagh & Frank, 2014, for a review). This general role has also been shown across preschoolers and school-aged children, for inhibiting a dominant response and shifting of task-set (Adam et al., 2020). MFT supports the temporal organization of brain computations involved in detecting the need for control and implementing control across brain areas involved in more specialized processes of the task (Cavanagh & Frank, 2014; Cohen, 2016; Duprez et al., 2020). Given the role of MFT in coordinating the implementation of control across more specialized areas, and its involvement in various instances of cognitive control, we hypothesized that the effects of ecologically realistic training, such as pretend play, on children's cognitive control and self-regulatory behavior could be explained by some changes in mid frontal theta oscillatory activity. Training effects could be observed on MFT power, which reflects the degree of engagement of cognitive control (Jensen & Tesche, 2002; Nigbur et al., 2011; Richardson et al., 2018) or on MFT latency, which reflects the time for theta oscillatory activity to set up, and therefore to engage cognitive control.

Therefore, the present study aims to assess the effects of ecologically realistic training, using pretend play, on preschoolers' cognitive control and self-regulation, and to reveal the brain mechanisms of these effects. The training activities were inspired by the pretend play activities used in Tools of the Mind classrooms. We created a set of pretend play activities using low-cost materials and designed to be ecologically realistic and to fit the context of French preschool classrooms. This 'Tools-inspired' intervention was evaluated using a randomized controlled trial-based approach where children were randomly assigned to a training group with pretend play activities or an active control group where children were provided with manual activities. Pretend play-based training consisted of helping the child play with an increasing maturity level to engage more cognitive control. We tested whether the use of scaffolding strategies to increase children's play maturity, along with rich social and emotional experiences, were enough to improve children's cognitive control and self-regulation, and influence MFT oscillatory activity. Training effects were assessed using a multilevel assessment at the cognitive, brain, and behavioral levels with measures of cognitive control, MFT power and latency, behavioral self-regulation, and play maturity collected before and after the training.

2. Material and methods

2.1.Schools and Participants

The study was conducted in two French pre-kindergarten schools located in disadvantaged districts of the city of Montauban. These schools were part of the French education priority networks that provide additional resources for strengthening educational and pedagogical action to French school districts that face the greatest social difficulties. An oral agreement to participate in the study was obtained from school administrations. The two schools had, respectively, three and four pre-kindergarten classrooms (see Supp. Mat. A for more information on the schools).

Families were informed of the study through a written document sent to them and during an information meeting. They accepted the random assignment of their children to the training or the control group and provided written informed consent for children to participate in both the intervention and evaluation parts of the study. Children gave verbal assent. A separate consent form for collecting EEG measures in children was provided to families. Only children for whom parents provided their written consent were tested with EEG. This study was approved by the local ethics committee (N° 2-15038).

A total of 70 preschool children were initially included in the study (mean age M = 61.2 months, SD = 6.6, range = 48.4–71.8 months, 37 boys and 33 girls). Children included in the study were from four classrooms (two in each school). The data from ten children were excluded from the study due to family relocation (N=1), long absence during the intervention (N=3), or inability or refusal to perform the cognitive task (N=6). The final sample was of 60 children (M = 61.5 months, SD = 6.3, 31 boys and 29 girls).

All children were assessed at two time points: at fall, within 6 weeks before the intervention starting (Pre-test), and at spring, within 6-weeks (with a mean delay of twenty-six days) following the training (Post-test). Assessments were conducted on two non-consecutive days in a quiet classroom of the school. In one assessment session, a fluid intelligence test, a receptive vocabulary test, and a motor self-regulation task were administered in a counterbalanced order between children. The other session involved a cognitive control task and EEG testing. Each session took less than one hour to complete. Questionnaires on children's self-regulatory skills were collected from parents at both time points. Parents were blind to their child's condition and were given one month to complete the questionnaires.

2.2.Measures

2.2.1. Vocabulary ability

Receptive vocabulary ability was assessed with the EVIP (Dunn et al., 1993), the French version of the Peabody Picture Vocabulary Scale. It is adapted to children aged two to six years old and requires them to access and retrieve words from memory. Children were presented with four pictures and had to point to the picture corresponding to the experimenter's word. Raw scores were calculated based on the number of correct responses and were then normalized for age.

2.2.2. Fluid intelligence

Fluid intelligence was assessed using the Raven Colored Progressive Matrices (CPM), a child-friendly version of the Raven's Matrices (Raven, 1947). This standardized test is a multiple-choice test that requires children to complete a series of incomplete patterns. Children are presented with an incomplete pattern from which a single piece is missing. They must select the missing piece, among six possible ones, that best completes the pattern. Children were presented with three sets of increasing difficulty, each containing 12 patterns. The score was the total number of correct responses and was normalized for age.

2.2.3. Motor self-regulation task

The Head-To-Toes-Task (H3T, Cameron Ponitz et al., 2008) was used to assess children's motor self-regulation. It is appropriate for children aged four to eight years old and requires children to execute an action given by an examiner (i.e., touch your head or touch your toes) and then to switch the rules by acting oppositely (touch his/her head when asked to touch his/ her toes). A total of 10 actions were given to the child. A correct behavior (a direct, unhesitant response to the instruction) was scored two; a self-correcting behavior was scored one, and an error was scored zero. The total score was between 0 and 20.

2.2.4. Self-regulatory behavior

Self-regulatory behavior was assessed with the French version of the Behavioral Rating Inventory of Executive Functions (BRIEF, Roy et al., 2013) and with the socio-affective profile (PSA, Dumas et al., 1997). These questionnaires allow assessing children's self-regulation in their home setting during daily activities. They were completed by the parents.

The BRIEF questionnaire assesses children's and adolescents' behavior aged 5 to 18 years. It provides scores measuring different aspects of self-regulation. We used the Behavioral Regulation Index (BRI), that reflects children’s cognitive flexibility and their capacity to regulate their emotions and behavior. We only used the raw scores because some of the children were too young (four years old) to compute their standardized scores and because we directly compared measures between our training and control groups.

The PSA describes children’s emotional and behavioral tendencies. It provides scores on the child’s social competence, internalizing behavior, externalizing behavior, and general adaptation. We used the General Adaptation score (GAS) of the socio-affective profile questionnaire (PSA), a composite score that reflects children’s abilities to interact positively with others and express their emotions in a socially appropriate manner. This questionnaire is appropriate for children aged two to six years old.

Psychometrics statistics (validity and reliability), descriptive statistics and correlations among the measures selected are provided in Supplemental Material B, C and D.

2.2.5. Sociodemographic information

Parents provided information relative to the family environment (number of children, language spoken at home), and information about them (level of education, occupation, salary range), and their child (age of entrance at school, prematurity, health problems). The demographic characteristics of the sample are presented in Table 1.

Insert table 1 here please

2.2.6. Maturity of pretend play

Pretend play maturity is positively associated with cognitive control and emotional self-regulation (Carlson et al., 2014; Slot et al., 2017). Pretend play maturity was assessed using the rubric consistent with the Vygotskian/Post-Vygotskian views of play (Elkonin, 2005; Vygotsky, 1967). We evaluated five criteria of the original grid (Leong & Bodrova, 2012, Bodrova & Leong, 2018) describing the play's critical aspects (play planning, language use, props use, scenario complexity, and roles complexity). Each of these criteria evolves along five stages as children's play maturity increases. We evaluated all criteria using the five-stage grid, which was converted into a five-level scale. The lowest scores corresponded to less mature play levels and higher scores to more mature levels of play. As a result, each criterion of children's play was scored between 1 and 5.

Pretend play maturity was evaluated by observing groups of four children playing together for fifteen minutes without adult supervision. Each group was evaluated by the two experimenters who supervised pretend play activities. The choice to have the same experimenters conducting and assessing the play activities was justified by the need for good expertise in pretend play to evaluate the play's criteria accurately. Indeed, the experimenters know well the scenarios and the corresponding actions, roles, and props that can be used during play; they can therefore better recognize the elements of the play that inform about the maturity of the play criteria. However, to limit the potential bias of having the same experimenters evaluating children (Lillard et al., 2013), and to ensure the confidence in the maturity of pretend play scoring, we used the following coding procedure. First, groups of four children were created by mixing children of the training group with children of the control group. Second, all children were assessed by two experimenters, one of whom was blind to the child's condition. Therefore, the coding was partially blind as all children were evaluated by one experimenter who was blind to their condition. Third, after the play session, the experimenters questioned children about their play to adjust their scoring of the play (i.e; they asked children whether they played a role, had a scenario…see Sup Mat E). Then, the two experimenters discussed the scores they assigned to each child and then assigned the final scores (average of the two independent scores). Finally, the play sessions were video recorded to allow for additional assessments if necessary. For example, if the independent scores differed by more than three points (this occurred for two children), (see Supp Mat E for more information on the evaluation of play maturity).

2.2.7. Cognitive control task

Cognitive control was assessed using the mixed condition of the Hearts & Flowers task (Davidson et al., 2006; Diamond et al., 2007) as it is the most sensitive to differences in cognitive control for 4- and 5-year-old children (e.g., Diamond & Lee, 2011). This task allows assessing cognitive control in different conditions of interference (see Figure 1). The interference could occur at the response level (between two motor responses) or the task-set level (between two task-sets). There were four interference conditions: the null interference condition (cC) did not involve any interference. In the response interference condition (iI), children had to inhibit the dominant motor response. In the task-set interference condition (iC), children had to inhibit the previous task-set and switch to the current one. Finally, in the task-set and response interference condition (cI), children had to switch of task-set and inhibit a dominant motor response (see Figure 1 for more detailed information on the task). Accuracy (percentage of correct responses) and mean reaction times were calculated for each condition.

Insert Figure 1 here please

2.3. EEG procedure

EEG measures were collected from 48 children (mean age = 61.4 months, SD = 6.4). Data were recorded for 25 children in the training group and 23 children in the control group. EEG testing and material were first presented to children. Once the child was comfortable with the material, the experimenter installed the EEG cap while the child watched a cartoon.

EEG recording and pre-processing parameters were the same as those used by Adam et al., (2020). A Biosemi Active-Two amplifier system with 64-channels positioned according to the 10-20 International system was used. Continuous data were epoched from -1500 to 3000ms relative to the stimulus onset. Epochs containing ocular and motor artifacts during the baseline or stimulus presentation time were rejected. Thereafter, independent component analysis (ICA) was performed (Delorme & Makeig, 2004), and components that did not account for brain activity (eye-blinks, horizontal eye-movements, or muscle activity) were subtracted from the data (Chaumon et al., 2015). Only correct response trials were included in the analysis. Errors, post-errors, anticipatory responses, and warm-up trials (first trial of each block) were removed from the data. Children who were excluded from the behavioral analyses were also excluded from the EEG analyses.

We isolated midfrontal theta (MFT) activity using optimal spatial filters - a weighted combination of all channels - designed to maximize power in the theta band (Cohen, 2017; Duprez et al., 2020; Gulbinaite et al., 2017; Zuure et al., 2020). Interference-related brain activity was extracted during cognitive control processing (stimulus-locked analysis) time windows (Cavanagh et al., 2012; Gulbinaite et al., 2014). Please refer to Adam et al., 2020 for an exhaustive presentation of the analytical EEG procedure.

The surface Laplacian, using laplacian perrinX function (Cohen, 2014), was applied to artifact-free data prior to analysis to increase the topographical specificity and attenuate volume conduction (Kayser & Tenke, 2015). Time-frequency decomposition was performed by convolving stimulus-locked single-trial data from all electrodes with complex Morlet wavelets, which increased from 2 to 40 Hz in 40 logarithmically spaced steps, and wavelet cycles varied from 3 to 6 in logarithmically spaced steps.

From the resulting complex signal, an estimate of frequency band-specific power at each time point was defined as the squared magnitude of the result of the convolution. Single-trial power values were then averaged across trials for each condition separately, and then normalized relative to the condition-average baseline period (−400 to −100ms) using a decibel (dB) transform at each frequency:

dB power = 10 × log 10[power/baseline]

Conversion to a dB scale ensures that data across all frequencies, time points, electrodes, conditions, and participants were in the same scale and thus were comparable. The use of a short baseline window was the most appropriate approach to avoid a contamination of the previous trial activity over subsequent trials as reported in previous studies (150ms to 200ms of baseline window between -350ms to -50ms before the stimulus onset (Cohen & Cavanagh, 2011; Cohen & Ridderinkhof, 2013; Cohen & Donner, 2013).

To examine changes in children's theta activity as a function of interference condition, we compared children's MFT power amplitude for each interference conditions (between assessment times and groups). This approach belongs to the class of “guided” as opposed to “blind” (e.g., independent component analysis) source-separation methods (Cheveigné & Arzounian, 2015; Nikulin et al., 2011). Because the data were firstly pooled over interference conditions, the window selection was orthogonal to the effects that we were interested in (Cohen & Gulbinaite, 2017). The spatial filter was designed in a way that was blind to the interference condition of any given trial. For each participant, a single component with the typical midfrontal spatial peak and theta-band temporal dynamics (phasic theta power increase following stimulus onset) was identified and selected for further analyses. In cases when no single MFT component could be identified, participant was excluded from further analysis. Finally, 38 children were included in the EEG analyses for the pre-assessment (20 for training group and 18 for control group), and 41 children for the post-assessment (22 for training group and 19 for control group).

Task-related brain activity was extracted on an individual basis during the time window where cognitive control was implemented (stimulus-locked analysis; Cavanagh et al., 2012; Gulbinaite et al., 2014). We first identified individual theta power peak on data averaged across conditions within a large, 200ms to 1,500ms, time window. The latency of this peak was used as the individual theta latency measure. Then, for each participant, a shorter time window was determined around the identified theta power amplitude peak in both frequency (±1 Hz) and time (±150ms). The theta measures were computed by averaging baseline mean-corrected power values of midfrontal theta component into the participant-specific time window (both for average MFT power and average MFT power by condition).

2.4.Intervention

Children were randomly assigned to a training group (N=31) or a control group (N=29). They were then grouped into small groups of four to five children each, mixing boys and girls and children of different classes and ages. The training and control activities lasted forty-five minutes and were held two times a week, on the same days and at the same time. The duration and frequency of our training were similar to those used in cognitive control task-based training (see Diamond & Lee, 2011).

Both training and control activities were carried out in quiet rooms of the school. Two experimenters conducted the training activities, and students in Psychology (Master level) conducted the control activities. The intervention lasted 10 weeks, for a total duration of 15 hours. Children attended an average of 16 sessions (range 9-18) for the training group and 15.4 sessions (range 8-18) for the control group.

2.2.1. Training activities

Training activities were inspired by the pretend play activities used in Tools of the Mind classrooms (Leong & Bodrova, 2012, Bodrova & Leong, 2018). However, since our play activities were not part of a curriculum and were conducted as a separate training, they differ in some aspects from the pretend play of Tools of the Mind (see Supp. Mat. F for more information on the differences between the present intervention and Tools of the Mind curriculum). Play activities were built from key elements of pretend play: the scenario content, the scenario actions, the play roles, and the props provided to children (Leong & Bodrova, 2012, Bodrova & Leong, 2018). Training activities evolved over the intervention to challenge cognitive control and self-regulatory skills continually. The evolution of training relied on the approach to assessing and scaffolding play (Bodrova & Leong, 2018) as well as on strategies developed for the intervention (see (see Supp. Mat. G for more information on scaffolding strategies). Scaffolding strategy was adapted to each child based on their pre-training assessment of play maturity. Training activities also took into account key success factors of efficient training (Diamond & Ling, 2016): children's motivation (the scenario of the play was renewed each week to maintain children's interest in the game), the intensity of the training (the play activity lasted 45 minutes to give children enough time to play) and the increase in training complexity (the scenario evolved over the intervention, with more realistic scenarios at the beginning of the intervention and more fantastic scenarios at the end, as fantasy pretend play requires greater cognitive control resources than realistic pretend play (Thibodeau et al., 2016). Finally, the experimenters' role in creating the scenario evolved over the training with a more experimenter-directed scenario at the beginning of the training and a more child –directed scenario at the end. Children were indeed encouraged and helped to be more and more involved in creating the scenario over the training period.

Children were trained and scaffolded by the experimenters who had an expertise with pretend play prior the training. The experimenters set up the pretend play training sessions of the present study during a pilot study conducted in another school the year before. Each training session was composed of three steps.

i) The briefing (10 minutes). Each session started with presenting the play scenario to children, by reading a story, posting pictures on the wall, or using videos. This presentation allowed all children to have the same information. The experimenter then described the play area with its different parts (the play area was adapted to the scenario with the delimitation of different zones, selection of appropriate accessories, furniture…). Children were then asked to choose one play role and describe the actions they would like to perform. To help children remember the story, their roles, and their actions, we used a storyboard with pictograms representing the characters with their actions. Additional pictograms representing other characters and actions were also displayed to help children develop the scenario. Finally, a play map representing the different locations of the play area was also displayed.

ii) Pretend play session (25 minutes). During play, children had to play their roles and execute the corresponding actions. Children were encouraged to play with one another but they were not forced to do so if they preferred to act out their roles independently. The experimenter supervised the play and helped children act out the scenario, use the props and interact with other children to improve their play maturity.

iii) The debriefing (10 minutes). Children were gathered in front of the experimenter. They were encouraged to recall the play scenario, their roles, and the actions they executed. They were also encouraged to discuss other evolutions of the play for the forthcoming play session.

2.4.2. Control activities

Control activities consisted of art craft activities (i.e., drawing, modeling clay…). The control activities had the same duration and were run with the same group size than the training activities. Furthermore, children of the control group received the same support and help from the experimenter than children in the training group (the experimenter was always present, he helped children when necessary and encouraged them to play together, without forcing them if they did not want to). Control activities were supervised by Master students in Psychology with a major in Developmental Psychology who had experiences with conducting group activities with children.

2.5. Experimental design

The training was evaluated using a pairwise randomized controlled trial. Within each classroom children were grouped into pairs according to their cognitive control, vocabulary, and fluid intelligence (using the normalized EVIP, CPM, and dots scores). Pairs were formed by minimizing the total sum of a Mahalanobis distance between children from the same class and the same EEG category (with or without EEG testing). Optimal pairs were computed using a non-directed search algorithm sampling randomly pairs within strata and looking for the minimum total distance. Randomization to the training or control condition was conducted at the child level. Within each pair, we selected at random (using a pseudo-Random Number Generator algorithm) one child to be in the training group and the other to be in the control group. This pairwise design was also constrained to ensure similar demographics characteristics (for age and sex) between our groups. Finally, to control for potential differences in teacher's characteristics and experiences on training outcomes, randomization was conducted in each classroom. Therefore, children of each pair had the same teacher and had sociodemographic characteristics, fluid intelligence, cognitive control, and vocabulary performance as similar as possible.

Analysis of the experimental results was conducted using a linear model with both pair and children as effects, ensuring that all pre-post comparisons were done within pair, and a group factor was coded as 0 for control and 1 for training group. For some variables, the pre-post comparison is much noisier than the post variable because of large amounts of measurement error. In such case, we chose to report results from within pair comparison of post outcomes. We chose a pairwise design in order to increase the precision of our experiment as much as possible. However, in a pairwise design, any attrition dramatically affects the sample size because, for each child lost from the initial sample, the paired children were also excluded. Eventually, the final analysis included 26 pairs of children (52 children in total). We also assessed whether training effects on cognitive control (accuracy and reaction times) and MFT (MFT power and latency) differed according to the interference type to resolve, by adding an interference condition (iI, iC, cI, cC) as a fixed effect in the model. When needed, planned contrast analyses were further conducted to compare brain and cognitive measures between groups. Finally, additional analyses were conducted without the pair factor on the whole participant's sample. Results did not differ from the pairwise analyses. All analyses were run with R software (R Core Team, 2014). We reported effect sizes using Cohen's d (in standard deviation), with its associated standard error and 95% confidence interval. The effect size is considered large when Cohen's d is around .8, a medium effect size for d around .5, and small and minimal effects for d around .2 and below. We also reported the t-values and their associated p-values with the number of subjects and pairs included in the analyses. Additional analyses were conducted without the pair factor on the whole participant's sample. Results did not differ from the pairwise analyses and are presented in supplemental material H.

2.5.1. Power analysis and pre-registration

The minimum detectable effect size was calculated for the main outcome (mean accuracy for cognitive control). The standard error of the training effect estimator, including pair fixed effect, is of 0.122, which implies a minimum detectable effect size (for one-sided t-test of size

5% and power 80%) of 0.303. We made no deviations to the pre-analysis plan, except for analyzing maturity of play, dealing with missing observations and choosing the most precise estimators between the pre-post and post comparisons.

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3. Results

3.1. Baseline differences

As already detailed, training and control groups were formed to ensure similar performance for cognitive control (mean accuracy across all conditions), vocabulary, and fluid intelligence before the training. We also checked if potential differences between control and training groups on other outcome variables were present before the training. Two-tailed unpaired student t-tests showed that both groups were well-matched regarding MFT power, MFT peak latency, the maturity of play, and self-regulation (all t; $-1.44 < t > 1.28$; all $p>0.08$).

3.2. Training effects

The evaluation of pretend play-based training was conducted on children's play maturity, cognitive control, midfrontal theta oscillatory activity, and self-regulatory behavior. The Cohen's d are reported in Figure 2 and Table 2)

Insert Figure 2 here please

Insert Table 2 here please

3.2.1. Behavioral measures

3.2.1.1. Maturity of play

We first assessed whether scaffolding strategies for helping children play were effective at improving their maturity of play. An effect of training was found on the five criteria of play maturity. Higher scores for training group compared to the control group were observed on planning (t(20) = 3.11, p < .01; d = 0.85 ; role : t(20) = 2.49, p < .05; d = 0.78) ; propels (t(20) = 2.57, p < .01; d = 0.76 ; language (t(20) = 3.94, p < .01; d = 1.03) ; and scenario (t(20) = 3.25, p < .01; d = 0.93). These effects were important as the effect sizes were found to exceed, or to be close to the Cohen's convention for a large effect size (d = .8).

3.2.1.2.Self-regulatory behavior

We then examined whether the training benefitted children's self-regulatory behavior in their daily life activities. Self-regulation measures were obtained from parents' reports of their children's behavior using i) the Behavioral Regulation Index (BRI), of the BRIEF questionnaire, and ii) the General Adaptation score (GAS) of the socio-affective profile questionnaire (PSA). No training effect was observed on the BRI index (t(7) = 0.72, p=.497, d=0.35, 95% CI[-0.60;1.31]). For the PSA, an increase of GAS score was observed for the control group (t(8) = -2.53, p < .05; d = -0.57, 95% CI[-1.02;-0.13]). However, these results must be taken with caution as these analyses were conducted on smaller groups (8 and 7 pairs of parents for the BRIEF and the PSA, respectively). Indeed, we had to exclude some parents' reports from the analyses because of incomplete or inappropriately completed questionnaires. These parents were not used to complete questionnaires on their child's behaviour and daily life, and had poor French language skills. Support and help (explanation of the questions and translation in their mother tongue) was provided to them but it was not sufficient to get more completed questionnaires. Finally, no training effect was observed on the motor dimension of self-regulation (t(26)=-0.70, p=.49, d=-0.18, 95% CI[-0.70;0.33]). Overall, these results showed that pretend play training did not benefit children's self-regulatory behavior.

3.2.2. Cognitive measures

3.2.2.1.Cognitive control

Effect of training on children's cognitive control was assessed using a task that required resolving an interference occurring at the motor level (inhibiting a dominant motor response) or the task set-level (shifting from one task-set to another task-set). Overall, the training did not benefit children's cognitive control as no significant differences between training and control groups were observed on mean accuracy, (t(26)=0.02, p=.99, d = 0.0; 95% IC[-0.55;0.56]) and response times (t(26) = -1.01, p=.32; d = -0.22; 95% IC[-0.66;0.21]). Assessing the impact of training on each condition of interference, we did not obtain any training effects on motor-interference conditions and task-set interference conditions (for accuracy: all, t(26): -0.91<t >-0.07; p: .37<p>.94 ; d: -0.23 <d>-0.02 ; for RT: all, t(26): -

1.61< t>-0.37; p: .12< >.71; -.41<d>-0.10) , (see Figure 3). These results show that pretend play training did not improve children’s cognitive control, irrespective of the interference condition.

Insert Figure 3 here please

3.2.2.2. Fluid intelligence and vocabulary

We also examined the effects of the training on children’s fluid intelligence and vocabulary. We found no effects of the training on these measures (EVIP: t(26) = -0.23; p=.82; d = -0.06; 95% IC[-0.55;0.44]; CPM: t(26) = 1.41; p=.17; d = 0.35 95% IC[-0.14;0.83]), showing that children’s nonverbal IQ and vocabulary did not benefit from pretend play training.

3.2.3. Brain measures

3.2.3.1. Mid frontal theta power and latency

Effects of pretend play-based training on brain mechanisms of cognitive control were assessed on MFT power, which reflects the engagement of cognitive control (Cavanagh et al., 2011; Nigbur et al., 2011), and MFT latency, which reflects the time at which theta oscillatory activity reaches its maximal power. Overall, there were no effect of the training on mean midfrontal theta power (t(14) = -0.94, p=0.37, d = -0.21; 95% IC[-0.63;0.22]) and on mean latency MFT (t(14) = -0.02; p=.98, d = -0.01; 95% IC[-0.90;0.88]) (see Figure 4). We also assessed training effects in each interference condition, no training effects were observed on MFT power and MFT latency (see the statistics in Table 2). These results indicate that pretend play training did not influence MFT activity (see Figure 3).

Insert Figure 4 here please

4. Discussion

Ecologically realistic training of cognitive control, which emphasizes the importance of training cognitive control while taking into account children's social, physical, and emotional needs, is viewed as one of the most effective approaches for promoting children's self-regulatory skills (Diamond & Ling, 2016). However, it is unknown whether self-regulation improvement is explained by some changes in the brain mechanisms of cognitive control. We implemented an ecologically realistic training program based on pretend play, and we evaluated its effects on preschoolers' self-regulatory behavior, cognitive control, and a neural mechanism of this control, the mid frontal theta oscillatory activity (MFT). Our intervention was inspired by the approach to assessing and scaffolding pretend play advocated by the authors of Tools of the Mind (Bodrova & Leong, 2018; Leong & Bodrova, 2012). This approach when implemented in the conjunction with other activities designed to support cognitive control has shown benefits on children's cognitive control and self-regulatory behavior (Blair et al., 2018; Diamond et al., 2007, 2019). Therefore, we assessed whether the same beneficial outcomes would be achieved with our pretend play intervention, also examining the brain mechanisms underlying these effects. We conducted a multilevel evaluation to compare preschoolers' brain activity and behavioral and cognitive performance between a training group who received pretend play-based training and an active control group who received manual art activities.

The principle of cognitive control training based on pretend play is to help children improve their play's maturity because more mature play implies greater use of cognitive control resources. Using scaffolding strategies for play, we show that a low-dosage play training can increase the maturity level of pretend play in most vulnerable children. Training effects were observed on several criteria of play maturity: the richness of the scenario, with more elaborate and complex situations, mixing realistic and fantasy play elements; the roles complexity, with children playing different roles associated with the same scenario; the plan of the play, with more elaborate planning before the play; and the use of language to describe scenarios, roles, and actions during the play. However, the improvement in the children's play's maturity did not benefit children's self-regulation in their daily activities, nor did it influence cognitive control and midfrontal theta oscillatory activity.

A higher level of play maturity is associated with increased performance in cognitive control (Carlson et al., 2014; Slot et al., 2017; Vieillevoye & Nader-Grosbois, 2008), but there is little evidence that pretend play is effective for training preschooler's cognitive control. Only two studies have shown that regularly engaging children in pretend play increases their inhibition and set-shifting performance (Thibodeau et al., 2016; Traverso et al., 2015). However, play criteria (scenarios, roles, actions, language, and props) were not assessed in these two studies; it is therefore unclear whether these effects were explained by an improvement in one or several of these criteria. In the present study, we showed that an increase in play maturity was insufficient to improve children's cognitive control. Cognitive control was assessed with tasks requiring resolving an interference occurring at the level of motor response (inhibiting a predominant motor response) and/or the task-set level (shifting between two tasks-sets). Our pretend play-based training did not affect children's cognitive control performance for resolving interference at the motor level or the task-set level. Therefore, our present results showed that regularly engaging cognitive control in pretend play training activities was insufficient to improve its efficiency. Other studies have reported training effects only in task conditions that required higher cognitive control resources and were the most challenging for children (Diamond et al., 2007; Schmitt et al., 2015). For preschool children, resolving an interference at the task-set level is more difficult than resolving an interference at the motor level, as evidenced by slower and less accurate responses (Adam et al., 2020; Davidson et al., 2006). However, we did not observe any training effects in the task-set interference condition, suggesting that pretend play-based training was not effective in improving children's cognitive control even in conditions that required greater cognitive control resources.

Cognitive control training can have an impact on brain mechanisms of cognitive control. These effects were obtained with cognitive control task-based training (Espinet et al., 2013; Rueda et al., 2005) in children as young as three years old (Rueda et al., 2005, 2012). The impact of ecologically realistic training on brain mechanisms of cognitive control is very poorly known as very few studies have investigated these effects, and none of them have used pretend play. Only one study showed that training preschoolers to interact with a doll to teach it the rule of a shifting task increased brain activity within the lateral prefrontal cortex (Moriguchi et al., 2015), a cognitive control brain area. However, in the present study, we did not observe any training effect on midfrontal theta oscillatory activity (MFT), a neural mechanism of cognitive control. Training did not impact the power amplitude of mid frontal theta activity, showing that the training had no effect on the engagement of control in the task. Other studies have reported brain activation patterns after training similar to that observed in older children (Rueda et al., 2005), suggesting that training may accelerate cognitive control development (Jolles & Crone, 2012). This development is associated with shorter MFT latency between preschool and school ages (Adam et al., 2020), indicating that MFT is set up more rapidly in school-aged children than preschoolers. However, we did not observe any training effect on MFT latency, suggesting that pretend play did not either affect the time required to set up MFT activity, and therefore the time for engaging cognitive control.

Another main objective of the present study was to assess whether pretend play-based training benefits children's self-regulatory behavior in their daily lives. Indeed, regular engagement of cognitive control in the cognitive, social, and emotional domains has been proposed to explain the transfer effects of cognitive control training on children's self-regulatory behavior

(Diamond & Lee, 2011; Moreau & Conway, 2014). Furthermore, early childhood interventions that emphasized pretend play were shown to benefit children's self-regulation in social contexts, with a reduction in externalized behavior and an improvement in conflict resolution capacity (Barnett et al., 2008). Pretend play provides children with appropriate experiences for engaging cognitive control in the social and emotional domains. For example, children had to take turns, refrain from acting impulsively to let another child act, or manage frustration or excitement. However, parents' evaluations of their child's behavior during daily activities did not reveal any training effects on children's self-regulatory behavior. Our findings, therefore, suggest that providing children with play activities that also meet their social and emotional needs is insufficient to improve their self-regulation.

We propose that the absence of training effects on cognitive control, MFT and self-regulation can be explained by the intensity and the content of our play training. Training intensity is a crucial factor for effective training (Diamond & Ling, 2016) and is determined by training frequency (how often training is delivered) and training duration (how long training is provided). Although the intensity of our training was sufficient to improve the maturity of play, it might have been insufficient to improve children’s cognitive control and self–regulation. Indeed, a long duration and a high frequency of training are necessary for regularly activating cognitive control brain networks (Diamond & Ling, 2016; Jaeggi et al., 2008) and coordinating them with specialized processes on which cognitive control operates (Amso & Scerif, 2015). In the present study, the training duration and frequency were the same as those used in cognitive task-based training that were shown to be effective (Diamond & Ling, 2016). In cognitive task-based training, cognitive control operates on a few elements that are repeated throughout the training. Consequently, cognitive control interacts with the same specialized processes throughout training. However, in our training, cognitive control was engaged in various situations involving cognitive, social, and emotional processes, greatly increasing the variety of specialized processes with which cognitive control interacts. Therefore, the intensity of our intervention might not have been high enough to improve the efficiency of cognitive control and its interactions with the various specialized processes activated during the play. Differences in intensity could also explain differences in training effects between our pretend play-based training and other play-based interventions for which improvements in cognitive control was obtained. For example, in Tools curriculum, children attended classrooms five days a week for at least forty weeks (Barnett et. al., 2008, Diamond et al., 2007). Furthermore, the entire classroom reflected the current play theme which provides children with additional opportunities for play interactions which happen through the day (Bodrova & Leong, 2006). While some of these activities directly target cognitive control, others provide children with practice in self-regulation as they engage in social interactions and literacy- or math-related activities. Therefore, the positive effects of the curriculum on cognitive control could also be explained by other curriculum tools that assist child's self-regulatory behavior (Lillard et al., 2013). In the present study, the training was delivered for ten weeks and children had no time specifically allocated to pretend play outside these training opportunities as pretend play was not integrated into the classroom curriculum. As a result, children did not have access to additional activities to play, and therefore had fewer opportunities to engage their cognitive control and practice self-regulation.

The content of our play intervention could also explain the lack of beneficial effects on children's self-regulation. In other play-based interventions that have shown training effects on self-regulation, children also had opportunities to engage in activities that appeal to their metacognitive skills (Bodrova & Leong, 2006). During play, they learned some self-reflective strategies to enable them to reflect and become aware of their own and others' actions and their consequences on others. They also learned self-regulatory strategies to regulate their behavior, such as using private speech or developing breathing habits, (Berk et al., 2006; Elias & Berk, 2002; Whitebread, 2010). Children were not provided with some strategies to regulate their own behavior in our play intervention, as a consequence it might have reduced the effectiveness of our play intervention on children's self-regulation.

Several recommendations can be proposed for future studies on the role of pretend play training on cognitive control and self-regulation. First, future studies should take into account the limitations of the present study regarding the duration and the frequency of the training as well as the absence of metacognitive strategies and address their effects on cognitive control and self-regulation. Second, the multidimensional approach of the present study should be generalized in future studies to better understand the effects of training on the cognitive, neural and behavioral dimensions as well as their interactions. In particular, the neural effects should be further investigated as the neural mechanisms of pretend play training, and ecologically realistic training in general, remain largely unknown. Finally, future studies should involve an evaluation of all play criteria to better understand how the training impacts the different dimensions of the play as well as characterize their effects on cognitive control and self-regulation.

5. Conclusion

The present study evaluated the effects of pretend play-based training on children's cognitive control, mid frontal theta oscillatory activity, and self-regulation. Although the training improved the child's play's maturity, reflecting the child's greater autonomy in the play context, the training did not affect children's cognitive control, its underlying brain mechanisms, and their self-regulatory behavior in everyday life. These results show that providing children with cognitive control training activities embedded in socially salient conditions might not be enough for improving their cognitive control and self-regulation. The intensity of training, and the use of metacognitive strategies may be key factors for ecologically realistic training to improve children's cognitive control and self-regulatory behavior.

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i. Figures and Tables

	Training group				Control group			
	16 boys - 15 girls				15 boys - 14 girls			
Demographic measures	**N**	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**
Age (months)	31	60,5	6,4	48,2 - 70,9	29	62,6	6,1	52,2 - 71,4
Household monthly salary (€)	23	2152	1175	1000 - 3000	19	2368	1297	1000 - 5000
Mother Education (years)	21	12,1	5,9	9 - 17	18	11,9	5,7	5 - 15
Father Education (years)	22	10,7	5,4	5 - 15	14	10,9	4,8	5 - 17

Children's measures	**N**	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**
fluid Intelligence (CPM)	31	19,6	6,3	8 - 30	29	20,4	6,1	10 - 29
Language comprehension (EVIP)	31	105,2	21,7	67 - 160	29	105,5	23	62 - 147

Table 1 Demographic characteristics for the training and control groups and performances for the Colored Progressive Matrices (CPM) and the French version of the Peabody Picture Vocabulary Scale (EVIP) in the pre-training assessment.

Level	Outcome	N (pairs)	t	p	Cohen D	low IC	high IC
Maturity of play	Planning (PG)	20	3,11	**0,006**	0,85	0,31	1,39
	Role (PG)	20	2,49	**0,022**	0,78	0,17	1,40
	Propels (PG)	20	2,57	**0,019**	0,76	0,18	1,34
	Langage (PG)	20	3,94	**0,001**	1,03	0,52	1,55
	Scenario (PG)	20	3,25	**0,004**	0,93	0,37	1,49
Self-regulatory Behavior	H3T	26	-0,70	0,490	-0,18	-0,70	0,33
	BRI (BRIEF)	7	0,72	0,497	0,35	-0,60	1,31
	GAS (PSA)	8	-2,53	**0,040**	-0,57	-1,02	-0,13
Cognitive Control	Response Time	26	-1,01	0,320	-0,22	-0,66	0,21
	cC trials	26	-0,88	0,389	-0,19	-0,62	0,24
	cI trials	26	-0,37	0,712	-0,10	-0,61	0,42
	iC trials	26	-0,54	0,596	-0,12	-0,57	0,32
	iI trials	26	-1,61	0,120	-0,41	-0,91	0,09
	Accuracy	26	0,02	0,987	0,00	-0,55	0,56
	cC trials	26	-0,15	0,886	-0,05	-0,68	0,59
	cI trials	26	-0,91	0,370	-0,23	-0,73	0,27
	iC trials	26	-0,07	0,942	-0,02	-0,57	0,53
	iI trials	26	-0,13	0,898	-0,04	-0,62	0,55
Midfrontal theta	Power	14	-0,94	0,371	-0,21	-0,63	0,22
	cC trials	14	-0,09	0,929	-0,02	-0,42	0,38
	cI trials	14	-0,60	0,557	-0,19	-0,80	0,43
	iC trials	14	-0,70	0,496	-0,26	-1,00	0,47
	iI trials	14	-1,14	0,275	-0,39	-1,06	0,28
	Latency	14	-0,02	0,985	-0,01	-0,90	0,88

Table 2: Statistics of the training effect for each level of analysis

The effect is represented through the cohen's D with associated 95% confidence interval, t and p-values are also reported as well as the number of pairs of children considered for each result. (PG: Propels Grid; H3T: Head to Toes Task; BRI: Behavioral Regulation Index; GAS: General Adaptation score; PSA: Socio-Affective Profile questionnaire; cC: null interference condition; ii: response interference condition; iC: task-set interference condition; iI: task-set and response interference condition).

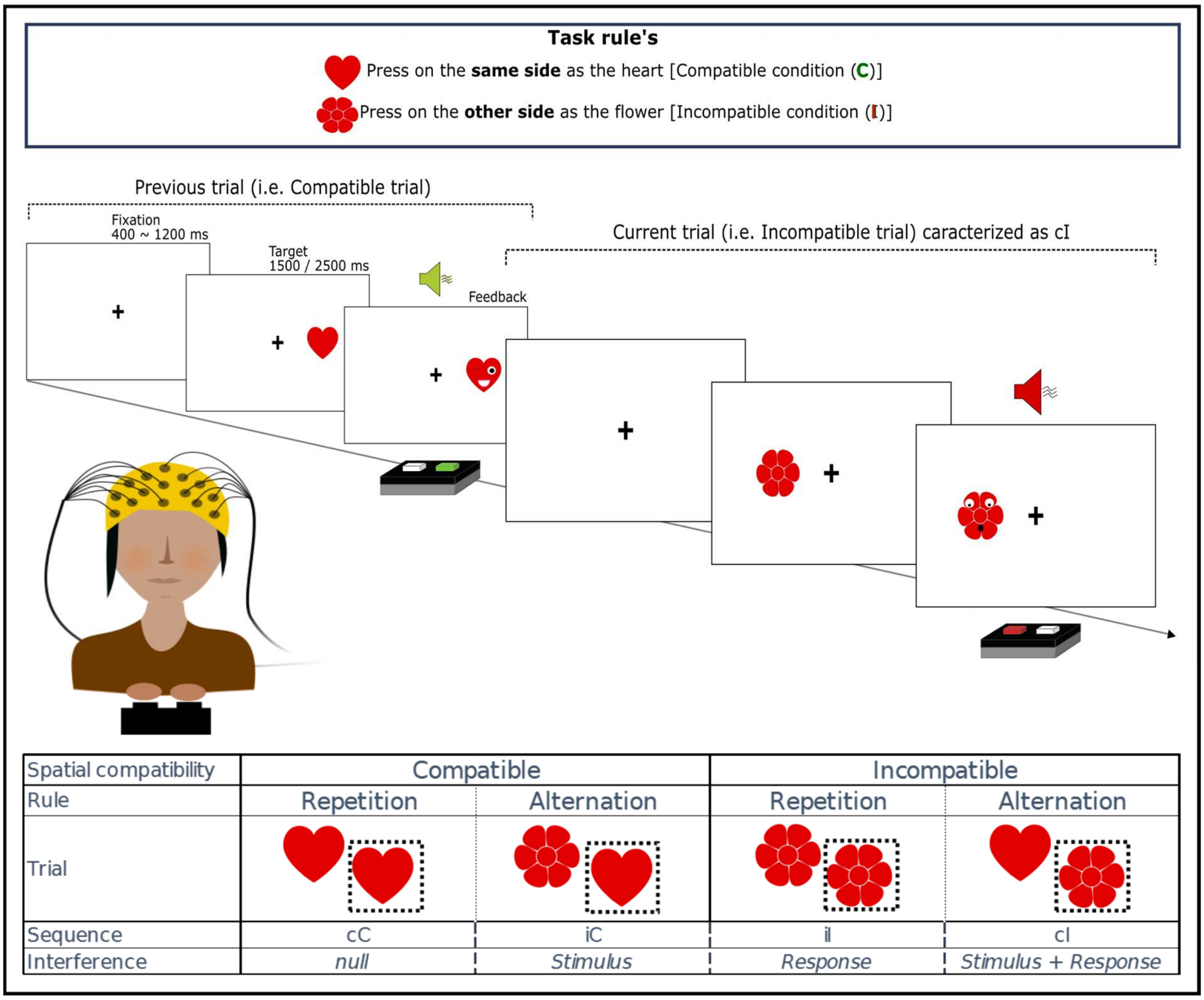

Figure 1: Experimental paradigm of the Heart and flower Task

Children were presented with a central black fixation cross (70 mm diameter, 1°), with either a red heart or a red flower (30 mm diameter, 4.3°) appearing on the left or the right (20mm, 2.87°) of the fixation cross. Children were instructed to respond as fast as possible when a stimulus (a heart or a flower) appeared. They had to press the key on the same side as the heart (compatible trials) and on the side opposite the flower (incompatible trials). Compatible and incompatible trials were randomly presented, resulting in trials where children had to switch of task-set and trials in which the task-set was maintained. The stimulus remained on the screen until a response was made, or up to a maximal time duration of 2500ms. Once the children gave a response, they received visuo-auditory feedback with a low-pitched tone of 500ms accompanied by a surprised face for an incorrect response or an absence of response, and a high-pitched tone of 500ms accompanied by a happy face for a correct response. There were 8 blocks of 16 trials each.

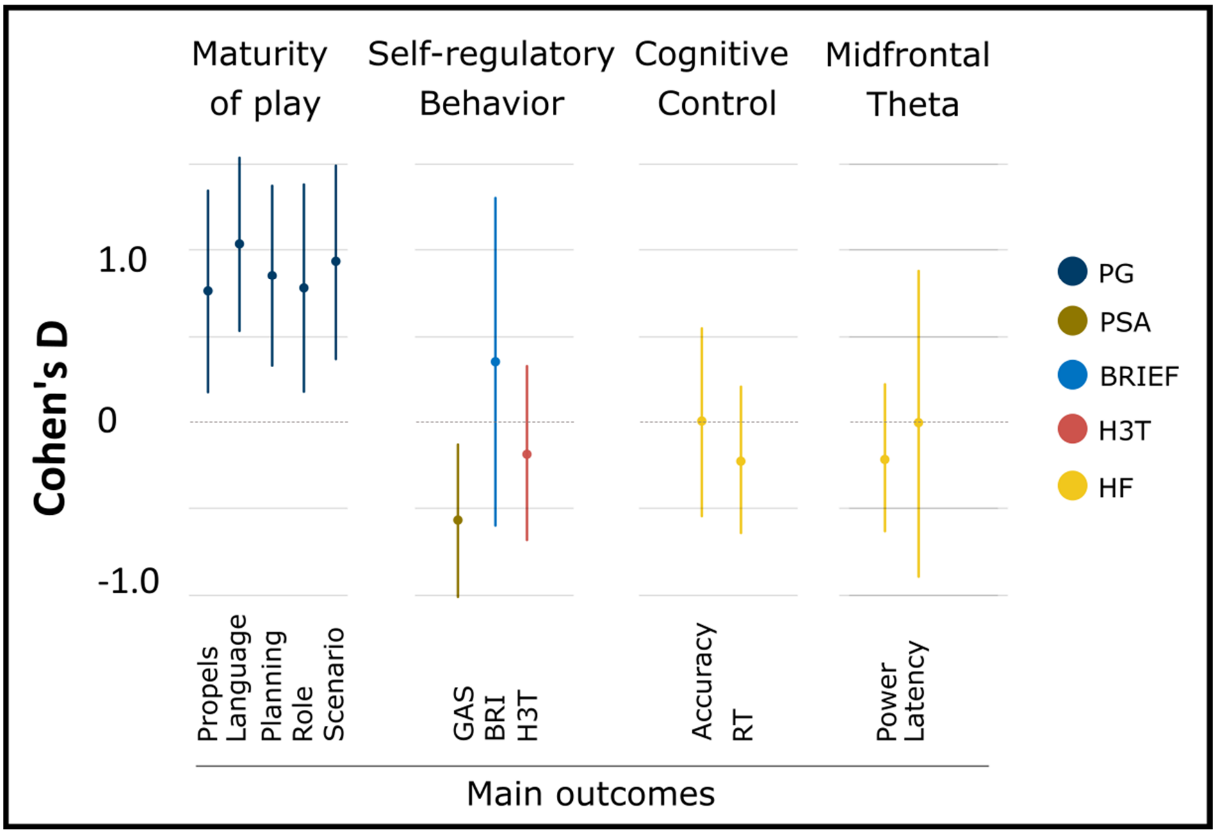

Figure 2: Visualization of the training effect with regard of the level of analysis

The effect is represented through the cohen's D and its associated 95% confidence interval. Each level of analysis is composed of a set of outcomes (indicated by a variable) relying on a set of measures and tasks (symbolized by the color of the variable). (PG: Propels Grid; PSA: Socio-Affective Profile questionnaire; BRIEF: Behavioral Rating Inventory of Executive Functions; H3T: Head to Toes Task; HF: Heart and Flower Task; GAS: General Adaptation; BRI: Behavioral Regulation Index; RT: Response time).

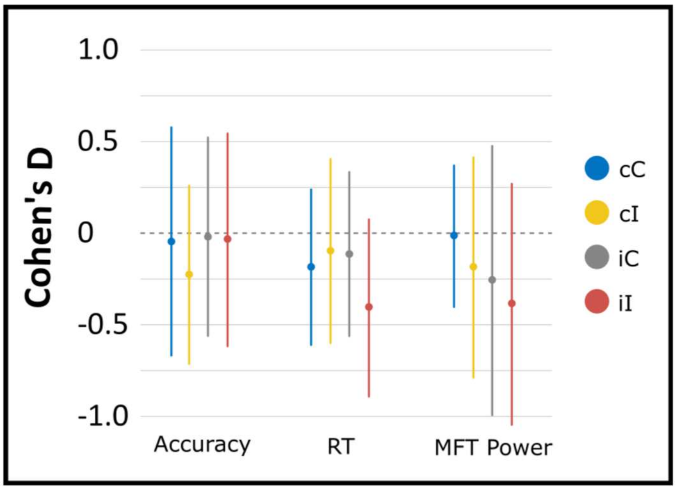

Figure 3: Visualization of the training effect associated to the Heart and Flower Task at the cognitive control and midfrontal theta levels.

The effect is represented through the cohen's D and it associated 95% confidence interval for Accuracy, Response Time (RT) and Midfrontal Theta Power for each interference condition (cC : null interference condition; ii: response interference condition; iC: task-set interference condition; iI: task-set and response interference condition).

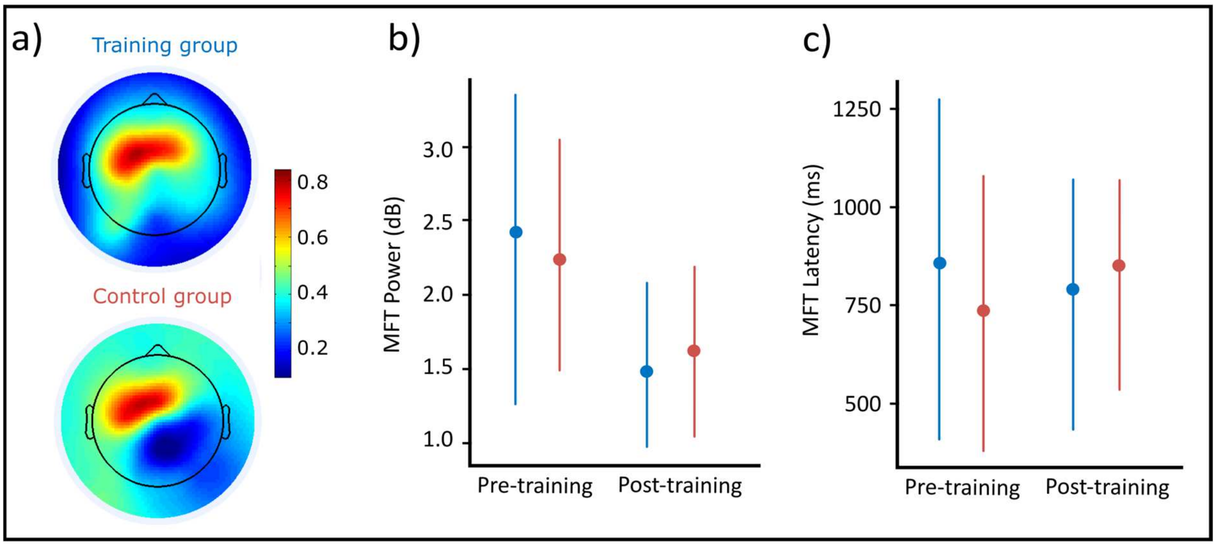

Figure 4: Visualization of the training effect at the level of the midfrontal theta (MFT) component underlying the realization of the Heart and Flower task

a) Topographic electroencephalogram maps showing the increase of voltage (relatively to the baseline) of the MFT component in post training for training and control groups; b) Power spectra of the MFT component (with standard deviation) for all conditions averaged in pre and post training for training group (in blue) and control group (in orange) ; c) Latency of the peak of the MFT component (with standard deviation) for all conditions averaged in pre and post training for training and control groups