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"Tuning in" the developing brain: Neurocognitive effects of ensemble music training on children

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Abstract: The ability to self-regulate has been associated with school-readiness and academic achievement. Research has indicated that young children receiving music instruction perform significantly better on self-regulation tasks. The current study assessed the cognitive neurocorrelates of executive attention using event-related potentials (ERPs) as children between the ages of 9-12 years with and without training in a social music program, OrKidstra, completed an auditory Go/NoGo task involving pure tones at 1100Hz and 2000Hz. Preliminary findings indicate that participating in the OrKidstra program decreases children's reaction times to Go stimuli at 2000Hz and increases the early brain's response to this tone within individuals (2000Hz vs. 1100Hz in the same children) and between groups (OrKidstra children vs. comparison children). Children also completed the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-IV) to allow us to determine the influence of music learning on verbal comprehension. Family demographics and wellbeing were collected through questionnaires completed by the child's guardian. Findings from our research may have implications for music training interventions and music training implementation in the school setting, especially as applied to socioeconomically disadvantaged children.

Keywords: Music Training, Self-Regulation, Event-Related Potentials, Auditory Go/NoGo, Neuroplasticity

1. Introduction

Self-regulation skills refer to the ability to monitor one's emotions and maintain emotional homeostasis, to remain motivated and attentive, to problem solve effectively in order to pursue short-term or long-term goals, and to follow social conventions [1]. It has been proposed that the income-achievement gap can partially be explained by self-regulation; whereby children from higher-socioeconomic status (SES) backgrounds have more opportunity to practice these skills [2].Children growing up in poverty often face a variety of stressors, which are known to impede learning in the school setting. For example, chaotic living environments do not provide children the opportunity to practice self-regulation as they are constantly "on-guard." Therefore, interventions aimed at promoting these skills in a stress-free environment may lead to more adaptive coping, and better life outcomes. Research has indicated that young children receiving music instruction perform significantly better on self-regulation tasks [3,4] however this is untested in a diverse sample.

The current study compares self-regulation ability in children 9-12 years old participating in a music and movement program, OrKidstra with The Leading Note Foundation [5], with children of similar age and socioeconomic status. Self-regulation skills are expected to improve as children must cooperate with their peers, take turns, pay attention to the instructor and follow social norms as they learn to sing and dance in a group. Inhibition control and selective attention were tested using a computer program implementing an auditory task under the Go/NoGo paradigm. Children were asked to respond to one tone at a specific frequency (go-trial) while ignoring the second tone at a differing frequency (no-go trial). This executive function task targets attention, working memory, and inhibition making it a good measure of cognitive self-regulation. Event-related potentials (ERPs, neural correlates of task performance measured using Task referenced EEG recording) were recorded as they completed the task, along with reaction times and accuracy. We expected increases in brain activity related to more efficient task performance based on findings from previous research.

In addition, children were asked to complete the Peabody Picture Vocabulary Test-IV (PPVT-IV) in order to determine if music influences verbal intelligence as demonstrated in previous research [4] and to control for IQ across groups [6, 7]. Parents completed the Strengths and Difficulties Questionnaire (SDQ) to assess child wellbeing.

We expected that for some aspects of information processing linked to attention and cognitive self-control (namely, "executive functions") children enrolled in the OrKidstra music program would perform differently than children not enrolled on the auditory Go/NoGo task (comparison group). We hypothesized that children involved with OrKidstra would show differences in ERPs that are associated with different stages of attention processing, such as:

1) Early sensory attentional processing: ERPs were expected to support behavioural outcomes with children involved with OrKidstra demonstrating greater amplitudes on the early processing waveforms N1 and N2.

2) Working memory: Children in the OrKidstra group were expected to show greater differences between Go and NoGo trials during stimulus evaluation and categorization on the P3.

3) Executive control related to emitting or inhibiting a response: Children involved with OrKidstra were expected to show greater differences between Go and NoGo trials on late potentials (Lps): Lp 400-1000ms, suggesting more regulatory control of top-down processes.

We hypothesized that the predicted differences in one, all, or a combination of the above functions would partly reflect the effects of practice acquired during musical training. The particular outcome found would however clarify whether the changes associated with the music training are general or rather domain-specific, that is, the influence of the training can be pinpointed to a specific subset of perceptual or cognitive skills and does not transfer across the entire neurocognitive system.

2. Methods

2.1. Auditory Go/NoGo Task

Children were asked to participate in an auditory selective attention task under the Go/NoGo paradigm (Fig. 1) where they were asked to respond to a pure tone at a specific frequency (go-trial) by pressing a button and to withhold their response to a tone played at a different frequency (no-go trial). The stimulus included two pure tones: 1100Hz and 2000Hz. Each sound was played at the duration of 100 milliseconds (ms) with an interstimulus interval varying between 1000ms – 1400ms. The attended sound was presented 70% of the time (go trial); whereas the unattended sound was presented 30% of the time (no-go trial). Children completed four blocks of 100 trials making a total of 400 trials. The classification of the Go and No-Go sound was randomized across blocks and children were presented with each sound prior to testing. They were given the option to have the sounds repeated as often as they liked prior to testing for each block. Children received a practice session of four blocks of 10 trials (total of 40 trials) with the first block providing visual feedback with the word "GO!" flashing on screen during go trials. The remaining practice blocks and the testing blocks did not involve any feedback. Children were told to keep as still as possible and to look straight ahead at a white cross fix on a black screen. They were told to press the green button on the response pad with their dominant hand in response to the go sound. Accuracy and reaction time was recorded for the go-trials, along with errors on the no-go trials.

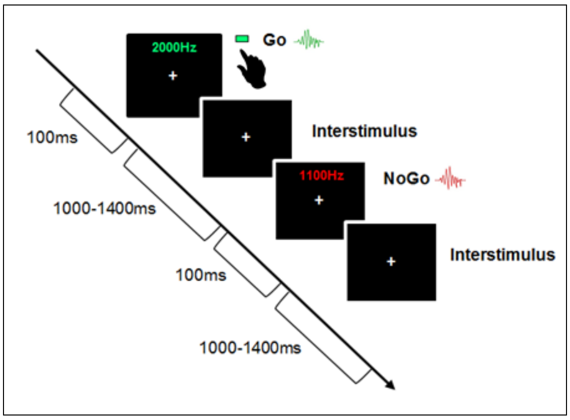

Figure 1. *Visual display of the Auditory Go/NoGo task, Go trial is 2000Hz, NoGo trial is 1100Hz. Children were asked to respond to a pure tone at a specific frequency (go-trial) and to withhold their response to the tone played at a different frequency (no-go trial). The stimulus included two tones: 1100Hz and 2000Hz. Each sound was played at the same duration (100ms) with an interstimulus interval varying between 1000 – 1400 ms. The attended sound was presented 70% of the time (go trial); whereas the unattended sound was presented 30% of the time (no-go trial). Each block contained 100 trials making a total of 400 trials. Children received a practice session of four blocks of 10 trials (total of 40 trials).*

2.2. Peabody Picture Vocabulary Test –IV

A computerized version of the standard Picture Peabody Vocabulary Test (PPVT-VI), measured the child's receptive vocabulary and word comprehension [8]. The PPVT is an accepted measure of word comprehension and semantic elaboration. The strong relationship between the processes measured by the PPVT-IV and language comprehension [9, 10] show correlations between the PPVT-IV and kindergarten language comprehension are very strong (median r > 0.65, see [8]), therefore, performance on the PPVT-IV would likely reflect the child's preschool level of linguistic processing. This has been confirmed by studies in aphasiology [11, 12, 13], intelligence [8], and clinical neuropsychology [14] in children and adults. The PPVT-IV includes a total of 19 sets with 24 target words per set presented aurally followed by a corresponding four-color picture display. This includes at least eight practice trials where participants are asked to identify two concrete words by correctly selecting the target picture from a set of four pictures. The items are intended to teach the child how to use the response pad to make a correct response. If the child responds correctly to two training items, the experiment begins. If the child responds incorrectly to either of the first two training items, a reduced level of training is first administered. All children responded correctly to the first set of training items.

Each picture of the display set has a rectangular frame with the colour corresponding to a button colour at the same spatial location on the response pad as shown on the screen (Fig. 2). Children heard a word, presented at 60 dBHL, over insert earphones and were asked to select the picture that best illustrated the meaning of the target word by pressing the corresponding button on the response pad. Each coded button on the pad had an equal probability of response (25% of 24 words per block). The pre-recorded words were of an English speaking female recorded at a rate of 250 Hz. Each new trial was self-initiated by pressing any button on the response pad. A set was completed successfully until three consecutive words were responded to incorrectly. The task was programmed to discontinue when this occurred and that final set was considered the maximum performance level assigned to the participant.

The stimulus sets were arranged in order of decreasing concreteness and increasing abstractness (i.e. norm-based critical range going from concrete to more abstract and complex) so that the task could be calibrated to the child's vocabulary level as assessed by the norm-based standardized critical range. All children performed at or above age-appropriate level and no systematic differences were detected between the music and the comparison group.

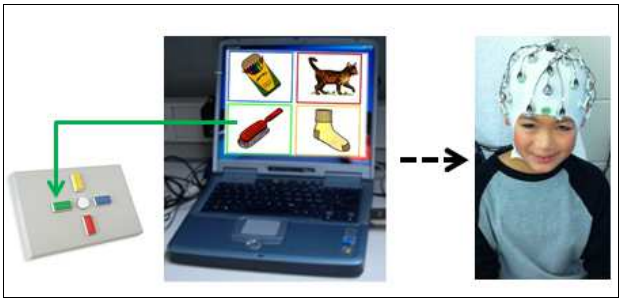

Figure 2. *Children completed an electronic version of the PPVT-IV [9] prior to being capped.*

2.2.1. The Strengths and Difficulties Questionnaire (SDQ)

The SDQ is a brief behavioural screening questionnaire used with children ranging from 3-17 years of age [15]. Considering there were children younger than 11 years of age in our study, wording from the parent version for children 4-10 years was used and the children's guardian/parent were asked to complete the questionnaire electronically. The parent version 10-17 years is composed of the same questions and categories with only minor changes in terminology (for example, "children" is replaced by "youth"). Given our sample was on the lower end of the age range (9-12 years) we did not feel it necessary to provide both options.

Parents were asked to respond to questions assessing their child's psychological attributes on five scales:

1. Emotional symptoms (5 items)
2. Conduct problems (5 items)
3. Hyperactivity/inattention (5 items)
4. Peer relationship problems (5 items)
5. Prosocial behaviour (5 items)

Responses on scales 1-4 are added to obtain a total difficulties score. A follow-up questionnaire assessed whether the child's difficulties have an impact emotionally, socially, behaviourally and with concentration.

2.2.2. Event-Related Potentials (ERPs)

ERPs refer to a change in brain activity following an internal or external sensory stimulus. This is a non-invasive technique with effective temporal resolution providing an accurate measurement of when processing takes place in the brain. ERPs are characterized by their latency following stimulus presentation in milliseconds and by their polarity (negative or positive). They are calculated by averaging the summed potentials following the repetition of stimulus presentation during a task. They are often used in research involving the study of human cognition [16].

The N1 and P2 are components commonly present during early sensory processing of stimuli during the auditory Go/NoGo task. The N1 was found to have a fronto-central maximum maximal in the right hemisphere among 10-year-olds, and was larger to NoGo stimuli; whereas the P2 was larger to Go than NoGo stimuli and had a parieto-central maximum [17]. Developmental research involving a Go/NoGo task generally centers on the N1-2 [18, 19] and P3 [20, 21]. It has been suggested that the N1 and N2 in children can be associated with attention and sensory-perceptual processing [22]; whereas the P3 is commonly associated with stimuli identification and working memory [23]. ERPs in the later stage of processing are thought to reflect a planned response to a desired goal and changes related to them can reflect aspects of withholding or emitting a valid response. Larger differences between peaks on Go and NoGo trials indicates early attention (N1/N2), working memory (P3), and planned responses (N4/P6).

3. Results

3.1. Behavioural Findings

The behavioural analysis involved twenty children between the ages of 9-12 years with eleven children in OrKidstra (mean age 10.8 years; 5 females) and nine in the comparison group (mean age 9.5 years; 4 females). 37.5% of the children in the comparison group had some form of musical training outside of OrKidstra. Despite a higher percentage of children with parents as musicians in the OrKidstra group (63.6% versus 12.5%), this difference was not statistically significant ($p = 0.059$). There was a significant difference between groups for age ($p = .027$), which was used as a covariate for further analyses, in order to "control" for this confound. An ANOVA focused t-contrast revealed a significant difference between groups on reaction times when the Go tone was 2000Hz ($t(19) = 2.29$, $p < .05$ two-tailed) (Fig. 3). However, there was no difference between groups for reaction times to the Go tone at 1100Hz.

Accuracy and false alarm rates were comparable between the two groups (Note that the interaction between Group (OrKidstra vs. Comparison) and Tone condition (1100Hz vs 2000Hz) was marginally significant, $p < 0.08$). There were no significant differences between groups for performance on the PPVT-IV or in parental responses on the SDQ.

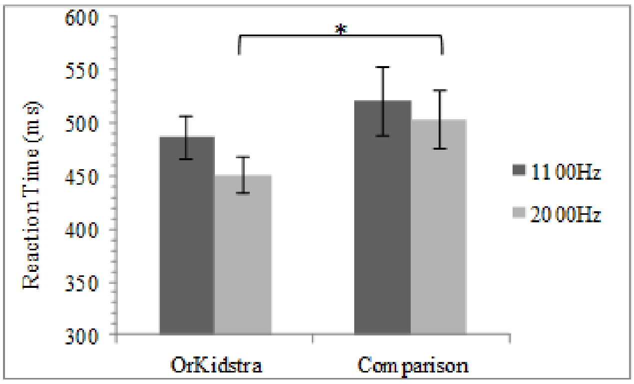

Figure 3. *Difference of reaction times between groups on go trials for the two conditions: 1100Hz and 2000Hz.*

3.2. Neuro-Electrophysiological Findings

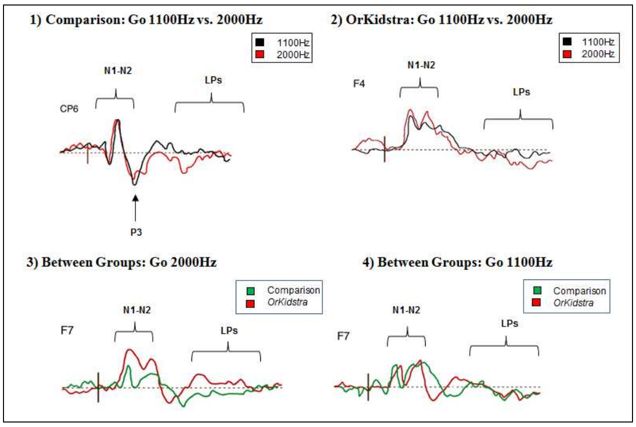

Figure 4. *Examples of averages demonstrating targeted ERPs: (1) Comparison group: Central-parietal (CP) response difference between the Go at 1100Hz vs. 2000Hz; (2) OrKidstra group: Frontal response difference between the Go at 1100Hz vs. 2000Hz; (3) Between-Groups comparison: Frontal response to the Go at 2000Hz; and (4) Between-Groups comparison: Frontal response at 1100Hz.Epochs: from -200ms (pre-stimulus) to 1000ms (post-stimulus)*

Fifteen children wore a Brain Vision electrode cap recording EEG from 32 sites while completing the auditory Go/NoGo task, with seven children in the OrKidstra group (mean age 11.2 years, 2 females) and eight children in the comparison group (mean age 9.8 years; 4 females). A preliminary qualitative analysis revealed that there was no significant difference between the proportion of difference waves on Go and NoGo trials between the two groups. Based on the behavioral outcomes, we then examined the degree of difference in amplitude between the Go response at 1100Hz and the Go response at 2000Hz, within and between the two groups.

Qualitative analyses of the differences of the raw effect sizes of ERP averages (measured in unstandardized mean microvolt distances, Fig. 4) across the 32 electrodes revealed that children in the OrKidstra group had a significantly higher proportion of difference between Go trials at 2000Hz compared with Go trials at 1100Hz during early ERPs (38% vs. 6%: $Z = 3.02$, $p = 0.002$) (refer to Fig. 5 for frequency). Furthermore, when comparing the difference waves between the OrKidstra group and the comparison group on the Go response at 1100Hz with the Go response at 2000Hz, there was a greater proportion (56% vs. 22%) of difference between the two groups for the Go response at 2000Hz during early processing for the N1 and N2 ($z = 2.79$, $p = 0.005$) (refer to Fig. 6 for frequency). In addition, there was a marginally significant difference in the proportions relative to the groups (2000Hz: 41% vs. 1100Hz: 19%) during late potentials ($z = 1.92$, $p = 0.05$). There was no significant difference within or between groups when comparing the Go at 1100Hz with the Go at 2000Hz for the P3.

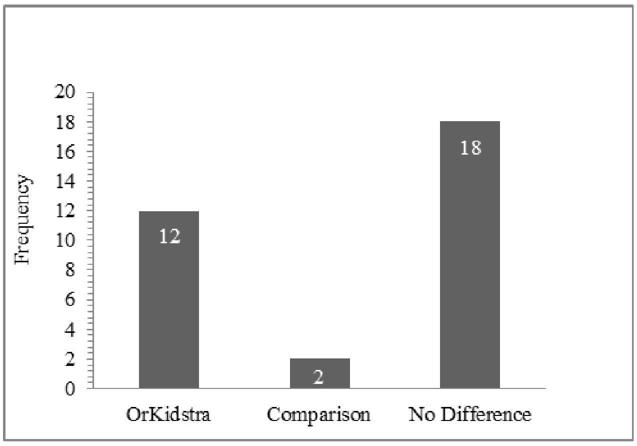

Figure 5. *Within groups comparison of the frequency of differences between Go trials at 2000Hz and Go trials at 1100Hz*

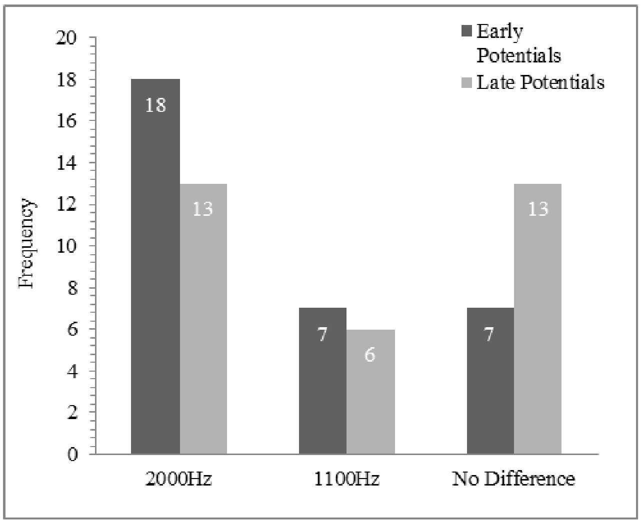

Figure 6. *The frequency of differences between OrKidstra and Comparison group on Go trials: Evaluation of the degree of difference for the Go response at 2000Hz vs. the Go response at 1100Hz during early potentials and late potentials (OrKidstra – Comparison).*

4. Summary and Interpretation of Preliminary Findings

Our findings demonstrate that children involved with OrKidstra are faster than a comparison group of children at responding to Go stimuli at 2000Hz which is supported by a greater degree of activation during early potentials, such as the N1 and N2. These findings suggest musical training with OrKidstra influences early sensory processing leading to faster behavioural performance. Reference [17] suggested that a slower reaction time on the auditory Go/NoGo task may reflect difficulty discriminating effectively between the two stimuli leading to focused attention on the NoGo tone. Children in OrKidstra had a faster response time when the Go tone was 2000Hz, and a greater degree of early neuronal processing in response to this frequency. This effect was apparent both within and between groups, suggesting a practice effect leading to an improved ability to discriminate between sounds. It is possible that as children develop more practice in listening and deciphering sounds, they shift from recruiting top-down frontal to more "sensory" centroparietal processes. As children learn to manually shift their focus through musical training, attentional processing becomes more automatic and is done at a lower level in the neural network cognitive system. That is, they do not use the executive functions at all, they use a more perceptual mode of processing.

This is supported by the finding that there was no significant effect at the P3 and late potentials, which are known to be implicated in working memory and executive control. This shift from late to early processing may free cognitive executive resources for more flexible control of attention and allow children to do other tasks (possibly simultaneously) in working memory. However, why this effect was only seen in response to the Go tone at 2000Hz and not 1100Hz is not yet understood. We speculate that the 2000Hz tone may be subjectively more similar to acoustic properties of the sounds children are exposed to while participating in the music training. If this result were to be confirmed with a larger sample, it would shed some light on the underlying memory processes that allow children to automatize and make more efficient neural response to musical and sound stimuli with practice. This opens the field to novel intriguing phenomena that await further scientific investigation.

5. Limitations and Future Directions

Our findings suggest there is a difference in early attention between children involved with OrKidstra and a comparison group of children. This effect is present in spite of the fact that 37.5% of children in the comparison group had some form of music experience. The latter supports the interpretation favouring a direct effect of OrKidstra training. However, given the small sample size it is premature to assume that these findings can be projected to a wider population. We plan to continue testing children with and without OrKidstra training to determine accuracy and validity of our preliminary findings, and in order to confirm the ERPs differences found in this preliminary analysis. In addition, we plan to use a series of alternative analytical approaches (i.e., EEG Band Frequency spectrum analysis) to further validate some of the findings and relate them to metabolic functions associated with brain growth and development.

More participants will also contribute to our behavioural data and will reduce confound of age between the two groups. Since we initially began testing children between the ages of 5-12 years, our behavioural data currently includes children younger than 9 years of age. Furthermore findings related to the questionnaires, more specifically the SDQ, will have stronger statistical power with more participants, therefore, we will be able to detect more subtle differences among groups.

Despite no significant differences on the SDQ between groups, there was an effect in the expected direction in the area of conduct problems ($p = 0.137$) with children involved with OrKidstra demonstrating fewer difficulties. This is worth examining further and may help us understand the positive social/emotional impact attributed to participation in the OrKidstra program (Note that increasing our sample of a few additional children would likely make the statistics relative to this finding significant).

6. Conclusion

In conclusion, the current study examined the effect of participation in a social music and movement program, OrKidstra, on children's ability to self-regulate. The preliminary findings indicate that children participating in the OrKidstra program seem to benefit from the training in terms of perceptual processing, reflected at both behavioral and neural level. However, the validity of the present findings need to be confirmed with a larger sample.

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