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The influence of musical activities on cognitive control processes

PhD thesis summary

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1. Introduction

Cognitive control is a complex system which plays a central role in managing goal-oriented behaviours as opposed to other compelling behaviours that are habitual or better supported by the environment (Cohen, 2017; Egner & Hirsch, 2005), with more efficient cognitive control being reflected in faster interpretation of information (Demetriou et al., 2013). It allows information processing and behavior to vary adaptively over time with changes in task objectives. It also supports the maintenance of the activation level of newly picked-up information and the retrieval of relevant contents from memory, as well as the suppression of irrelevant information and / or behavioural responses (Dudukovic & Kuhl, 2017). The extent to which these behaviours are regulated is of paramount importance for individuals of all ages: it influences physical, mental and psychological health, plays an important role in learning, school achievement and labour market performance (Diamond & Fiske, 2013; Meltzer, 2018), and is closely linked to neurodevelopmental disorders, such as autism spectrum disorder (de Vries et al., 2015; Hogeveen et al., 2017; Solomon et al., 2016), attention deficit disorders (de Zeeuw et al., 2012; Jarrett et al., 2016) and language disorders (Marton et al., 2014; 2016; Pauls & Archibald, 2016).

Musical activities involve a number of cognitive functions and have positive effects on functional and structural brain plasticity (Zuk et al., 2014). Music's widely known transfer effects can be explained by the greatly distributed brain areas involved in music performance that support several other cognitive and perceptual-motor skills as well (Mansouri et al., 2017). Music's benefits have been attributed to the practice of intensive memorization, visuo-motor skills, focused attention and the use of shared performance cues required for learning and performing music (e.g., Cooper, 2019). It is also important to mention that through its emotional and psychological effects music is a good motivator in any pedagogical, developmental, and therapeutic situation. After all, strategies that have been used successfully while making music can be transferred to non-musical contexts and used in everyday life (Varga, 2019).

Cognitive control performance can be improved through targeted tasks and exercises (Diamond & Fiske, 2012, 2013) and a large body of research indicates that musical activities can provide effective tools and frameworks for this purpose (e.g., Colombo et al., 2020; Guo et al., 2018; Jaschke et al., 2018; Zuk et al., 2018), even a short-term, but intensive musical training can enhance cognitive control functions (Moreno et al., 2011).

The integration of the mentioned theoretical fields will result in an interdisciplinary framework that will allow us to describe the association between higher-level cognitive functions and music processing. The following examples show that musical activities provide a rich set of opportunities to train cognitive control functions:

1. Example: while practicing a new piece of music we need more control, but later it becomes automatic. (Cognitive control model: the execution of controlled tasks is slower than that of automatic ones.)
2. Example: while playing music one needs to look at the notes -even preview some beats-, listen to the other musicians, keep the tempo, and the right loudness, etc. (Cognitive control model: the controlled processes may be competing and interfering with each other and with some more automatic processes while playing music.)
3. Example: one’s working memory capacity limits the activities performed in parallel, like it is difficult to play drums and sing at the same time. (Cognitive control model: the controlled processes may rely on a central, limited capacity system) (Varga et al., 2022).

However, the literature is based on very different musical and music theoretical background therefore the results of different studies are difficult to compare or integrate. Another aggravating factor is, that most of the publications related to the topic rely on earlier theories of behavioural control and lack sufficient evidence of targeted investigation of specific cognitive control processes (Guo et al., 2018; Siepsiak & Krejtz, 2016; Thaut, 2010; Thaut et al., 2009). The present research was designed to fill this gap: it was designed in a clear music therapeutical framework and follows Cohen’s (2017) cognitive control model in accordance with Miyake and Friedman's (2012) "unity/diversity" framework, the conflict monitoring theory of Botvinick et al. (2001) and the interference model of Oberauer (2002) targeting specific cognitive control processes, and subsequently draw systemic conclusions from the results.

2. Research aims and questions

The basic aim of the research is to shed light on the effects of musical activities on cognitive control with regard to associated disciplines. The gaps in the literature have caused more specific targets to be identified, such as monitoring, working memory updating, as well as resistance to proactive and distractor interference as mechanisms of cognitive control.

In addition to the theoretical aspects, the enrichment of evidence-based practice has been a major gap and a major effort in the research. Our aim was to develop a consciously structured, intensive music training methodology that could offer a novel, effective, cost-efficient, and widely applicable toolkit for the development of cognitive control (Guo et al., 2018; Siepsiak & Krejtz, 2016; Thaut et al., 2009; Thaut, 2010). Music is not an end in this process, but a means as well as a space and a framework, as it provides a safe and motivating medium (Sachs et al, 2018). The research presented in this thesis is therefore not in the context of music pedagogy or music education: its approach, framework and purpose fit best into the concept of music therapy (Varga, 2018, 2019).

To achieve our objective, we needed to develop cognitive control measurement tools based on non-verbal auditory (pitch and tone) stimuli, in order to fill the gap between two types of existing instruments: those which use mostly visual stimuli, and those based on verbal material.

Our research questions are as follows:

1. Is there a difference between the cognitive control functioning of young adults who have been practicing music intensively for a long time (hereinafter: "playing music") and those who have not received any music education (hereinafter: "not playing music")? If there exists such a difference, then
    a. which specific cognitive control processes differ, and to what extent?
    b. is the difference modality-general or modality-specific?
    c. what characteristics of previous musical activities influence this difference (such as the age at which an individual starts actively making music, the number of hours spent practising, the channels used for practising, the type of instrument and how many instruments are played, whether the music is played individually

or in a group, or the musical style), excluding or controlling for socio-economic and other non-specific influencing factors.)

2. Can cognitive control processes be improved with a short, targeted music training programme? If they can,
   a. which of the cognitive control mechanisms can be most effectively developed from (i) monitoring function and updating of working memory, and (ii) resistance to proactive and distractor interference?
   b. are changes of a modality-general or modality-specific nature detectable?
   c. is there a long-term impact on the development?
   d. does previous music education influence the results, for example, is there a ceiling effect on developmental potential for young people who have been playing music for a long time?

3. Hypotheses

3.1. Musical prehistory hypothesis

Based on conflict monitoring theory (Botvinick et al., 2001), *we hypothesised that long-time musicians would adapt more quickly, so their cognitive control functions would accordingly be significantly better than non-musicians on input tasks, and that measured cognitive control scores would correlate with the number of hours of practice per week and the number of years of music learning and would depend on age at the onset of music learning.* This assumption is based on the existing literature, which shows better cognitive control performance in the population receiving sustained music education, the difference being correlated with the number of years spent playing music (Chaffin, 2007; De Dreu et al, 2012; Holochwost et al., 2017; Jaschke et al., 2018; Moradzadeh et al., 2015; Pallesen et al., 2010), especially when music studies started before the sensitive period of music learning (Herholz et al., 2012; Schlaug et al., 1995).

3.2. Improvability hypothesis

We hypothesised that a targeted, intensive music training programme could improve the cognitive control functions of both music and non-music playing youth in the short term, as indicated by the significant difference between the input and output measures. This proposition is based on examples in the literature showing the effectiveness of brief but targeted music training to improve cognitive control (Bugos & D. DeMarie, 2017; Janus et al., 2016; Moreno et al, 2011). Considering the presumably lower measured input cognitive control scores of the non-musicians and the fact that musical training provides new stimuli to the cognitive control systems of the non-musicians, it can be assumed that their cognitive control functions develop more intensively than those of the musicians. This is also suggested by findings in the literature indicating that individuals with weaker cognitive control functions benefit more from intensive cognitive control development than their peers with more advanced cognitive control (Diamond & Ling, 2016).

3.3. Function-specific development hypothesis

It was hypothesised that different cognitive processes would develop to different degrees in response to music training. This expectation is based mainly on the methodology of music training: the various exercises aim to develop different cognitive components. Moreover, due to the complexity of the cognitive control system (Friedman & Miyake, 2017), each exercise, however specific, develops not only the targeted cognitive component but also other cognitive functions. The more complex a task is, the more cognitive control functions it requires (Cepeda et al., 2013; Marton et al., 2017), but even for simpler exercises, the development of one component will affect the development of others. Participants are assumed to vary in their receptivity to the different tasks (Birren & Fisher, 1995; Mendelson & Ricketts, 2001), their use of strategies, their degree of proficiency and familiarity with the context, and their motivation.

3.4. Modality-specific development hypothesis

In terms of modalities, we hypothesised that for both groups, cognitive functions measured with auditory tools would improve more than those measured with visual tasks. Still cognitive control performance measured with non-auditory tools would also improve significantly, although to a lesser extent (the cross-modality effect). A greater degree of improvement was expected in the results of the auditory tasks, as the music methodology was also based on auditory modality, and because it was assumed that the subjects would perform less well auditory tasks at the input stage, suggesting greater potential for improvement.

3.5. Long-term effect hypothesis

It was assumed that the long-term effect of music training on the cognitive control functions of group members would be significant for both groups. This assumption was based on the literature suggesting that short-term changes in brain structure as a result of intensive musical training led to persistent functional changes (Herholz & Zatorre, 2012), and that the transfer effect of nonverbal experiences during musical activity is maintained in the long term (Urbánné, 2001). Not much literature is available on this topic, therefore it is hoped that the long-term effect study will fill this gap (Janus et al, 2016; Moreno et al., 2011).

4. Methods

To examine our hypotheses an experiment was designed involving two groups of young adults: 1) young people who had been studying music for a long time and regularly played music (hereinafter: "musicians"), and 2) young people who had not received any music education (hereinafter: "non-musicians").

4.1. Participants

Participants of the present study were students, aged 18-21 years, of the ELTE Bárczi Gusztáv Faculty of Special Needs Education and the MZTSZ Kőbányai Music Studio, which is run by the Hungarian Musicians and Dancers Union. After filtering and matching, two groups were assembled, one with members who have been studying music for a long time and regularly playing music (hereinafter: the "playing" group), and another group that have never had music training (hereinafter: the "non-playing" group). The study initially had 22 participants in each group, but due to early dropouts, 18 participants remained in the group of musicians and 21 in the group of non-musicians at the end of the study. The musicians' group spent an average of 38.6 hours per week practising (SD = 4.9). All the musicians started music between the ages of 6 and 7, so the number of years spent practising music showed very low variance.

4.2. Selection

The research was named "Zene Tere" (Music Medium), with its own logo, slogan and identity. The opportunity to participate was communicated through posters, institutional newsletters, Facebook and Instagram. The advertisements placed on the

Facebook page and the website of the research (www.zenetere.hu) provided detailed information about the objectives and framework of the research, the demonstration sessions, the pre-research information sessions and the participation criteria.

In both groups, inclusion in the study sample was conditional on passing a hearing screening test, and the exclusion criteria included factors that have been shown in the literature to affect the development of cognitive control, such as regular activities (aerobics, computer games, traditional martial arts, yoga) and bilingualism. The foreign language skills of the participants were taken into account as covariates if necessary. For the non-music group, there was an entry criterion of participants having no history of instrumental training, and no parents or family members who were music teachers or professional musicians, which would represent their having more contact with music than average (Corrigall & Schellenberg, 2015). For the music group, there was a selection criterion of at least six years of active instrumental training on at least one instrument (singing alone was not considered enough), with at least six hours of practice per week. These factors were assessed by a questionnaire prior to sample inclusion, which included a set of questions exploring the music study and practice habits of the music group.

4.3. Stimuli

4.3.1. Pre-tests

Participants' perceptual ability was examined primarily to allow for the analysis of the results to identify and, where necessary, take into account any perceptual development in the participants. The reason for this was that the training and the research were not aimed at developing perception, but at developing higher-level cognitive processes. The perception tasks also provided information about the participants' ability to use the musical exercises and auditory measures employed (an error rate of less than 10% was the criterion for inclusion in the sample). To measure musical perception, we used the perception module of the Kwalwasser-Dykema standardized test, which is designed for participants aged 10-22 years, and which can be used in a group setting (Kwalwasser, 1953)

As cognitive control assessments assume vigilance and a general ability to maintain attention (Burgoyne & Engle, 2020; Engle & Kane, 2004; Verguts, 2017), attention was tested in all three test sessions. In the attention task, the subject was required to respond to on-screen stimuli using the keyboard keys.

4.3.2. Cognitive control tasks

The cognitive control task set included tasks based on N-back and conflict paradigms (KFP = Complex Recall Paradigm tasks) implemented in E-Prime software (Marton et al., 2014; Wadhera et al, 2018; Szöllősi, 2021). These assessment procedures were developed by a research group at the Cognition and Language Laboratory, the Graduate Center of the City University of New York (Marton et al., 2016), and the newly designed versions using pitch and tone stimuli, were developed at the Bárczi Gusztáv Faculty of Special Needs Education (Varga et al., 2022).

Table 1. Measures used to measure each cognitive function and their abbreviations

cognitive control functions	measure tools	abbreviation
resistance to distractor interference	attention control /distractor tasks	FF-B
resistance to proactive interference	guided forgetting tasks (KFP Baseline and KFP Cue tasks)	KFP-B KFP-Cue
	verbal categorisation tasks	VK-0; VK-P
working memory updating	N-back tasks	N-back
monitoring	post error slowing (were examined in N-back tasks)	*(no specialised task)*

The FF-B task was used to test the resistance to interference caused by distractor interference. The guided forgetting tasks selected from the KFP (the Complex Recall Paradigm) task set are complex measuring tools for a range of cognitive control functions. The task set comprises the KFP Baseline task and the KFP Cue task, which are both based on 21 abstract figural stimuli. The KFP Baseline task measured the storage function of short-term working memory and the ability to keep the representations stored in working memory active. The KFP Baseline task thus required choosing based on familiarity and novelty and suppressing irrelevant stimulus representations. The results of this task were compared with the results of the KFP Cue task, which measures more complex interference processes, and further conclusions could be drawn. The KFP Cue task tested the ability to select items based on familiarity, the ability to suppress irrelevant stimuli, and resistance to proactive interference from the updating and processing of working memory. The theoretical background for this task is provided by Oberauer's (2009) model, which emphasises the importance of content-context ties for both retention in memory and recall and retrieval. Resistance to proactive interference occurs when the content and contextual properties of previous trials influence the decisions of the current trial because the working memory is not or only partially updated.

Table 2. Functions assessed by the KFP Baseline and KFP Cue tasks

KFP Baseline	KFP Cue
the short-term working memory storage function	the processing and updating of working memory
maintaining the activation of representations stored in working memory	conflict resolution
resistance to distractor effects	resistance to proactive interference

The verbal categorisation tasks developed by Marton et al. (2014) were designed to investigate resistance to proactive interference in a linguistic context. Two sub-types of the task set were performed with the subjects in the study: 1) the VK-0: verbal categorisation task without interference: in all cases, the interfering target words were words that did not belong to the category and had not been encountered by the subject earlier in the study, nor their category; and 2) the VK-P: verbal categorisation task with proactive interference: some of the confounding target words contained a proactive element, as they belonged to one of the categories previously presented (Marton et al, 2017). Failure to reject the distractor stimulus (the distractor) indicated weaker working memory updating, and proactive interference with an item previously held in attentional focus.

The N-back assessment is commonly used as continuous performance assessment that measures the updating of working memory. The encoding, refreshing and retrieval processes that occur during this task require the attribution of each stimulus (the content) to the appropriate temporal position (the context), known as content-context bindings. The variations of the task differ in set size, stimulus type and modality type (Wadhera et al., 2018). In the research both visual (letters and shapes) and auditory (pitches and timbres) versions of the task were used to investigate whether modality type influences working memory performance.

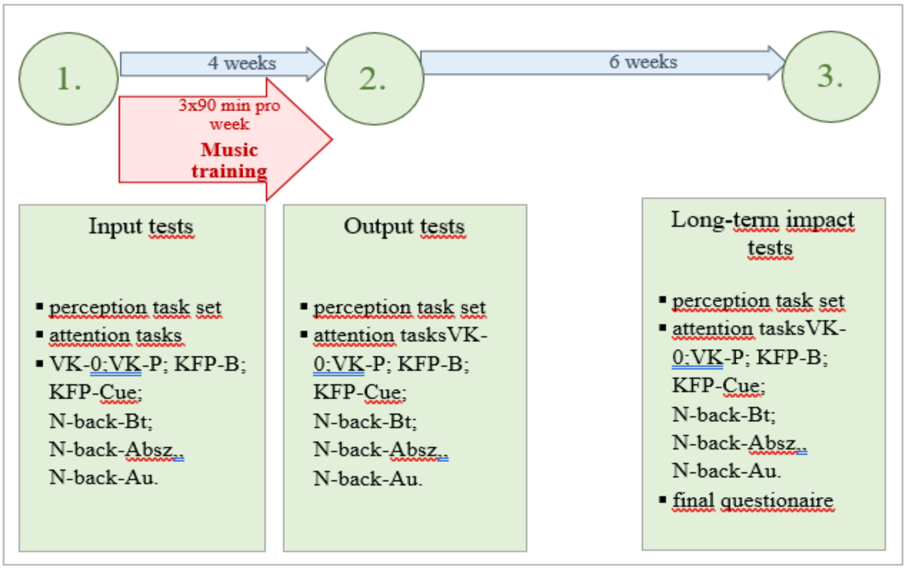
The research was concluded with a questionnaire at the end of the sampling to measure the long-term impact, which provided information on, among other things, the level of difficulty of the tasks, the use of strategies and the emotional and physical state of the participants.

4.3.3. The tools of musical training

The music training was based on a functionally appropriate, easily available, inexpensive, mobile and sufficiently colourful set of instruments to keep the participants motivated (for example so called Boomwhacker coloured tubes which have the advantage of being clearly tuned, light, exciting, possible to play separately or in harmony, as well as being combined with colour cards and coloured discs, requiring only a small amount of movement, and being easily used by anyone). In all cases, the instruments were at least in pairs and in different sizes, which stems from the approach of music therapy and offers many advantages and opportunities in session planning, as well as variability in volume, ergonomics, tone, weight, and character. The exercises also relied on the use of the participants' own voices, with body sounds such as clapping, finger-snapping, drumming, tapping as well as singing and speaking. Regarding singing voices, individual performances were avoided (singing only took place in groups). This is partly explained by the shortness of the training: the singing voice is our most intimate means of expression, and its use requires consciously structured, time-consuming work.

4.4. Procedure

The two experimental groups received one and a half hours of music training three times a week for four weeks. The research design is illustrated the next flowchart:



1. figure. Flowchart of the research design

Regarding musical training, the aim of the exercises was not to develop musical skills, instrumental instruction, or fine motor skills, does not require any musical training, instrumental or vocal skills on the part of the participants and does not focus on the development of these areas. Cognitive control performance was in the focus. Each exercise was designed to develop a targeted cognitive control function with specific, predefined rules and frameworks. The characteristics of the training to be highlighted are:

- In this process, music was a tool and not a goal.
- The training was led by a qualified, certified music therapist, using a music therapy approach and following the structure of music therapy.
- The objective of the training was to improve cognitive control, indirectly improving the quality of life of the participants.
- The methodology used music and the elements of music (sound, rhythm, melody, harmony, timbre, and dynamics) both together and separately.
- The music training methodology was based on group work (participants worked individually, in pairs, in small groups and in whole groups), but the research did not include the effects of changes in group dynamics and other group-related influencing factors (Yalom, 1985).
- The musical exercises followed each other in a mosaic, repetition of each type of exercise in different contexts being an important element.
- The active music therapy methodological part also used song writing, composing and musical improvisation games, but they were all accompanied by some rules. In addition to the elements of active musical therapy, the study also contained receptive exercises, in which the participants listened to music or a series of sounds or rhythms consisting of musical elements and performed mental operations with them.

4.5. Data analysis

The raw data for the statistical operations was obtained from tables recorded by the E-Prime software. To improve the quality of the data, manual data filtering was undertaken. After cleaning and sorting the data, descriptive analysis was performed in order to understand the main characteristics of the data set. The independent variables were based on group affiliation, that is, the group of non-musicians and the group the group of musicians, and characteristics related to each task, such as the type of stimulus (audio versus visual), the presence or absence of different interference elements. Among the dependent variables, accuracy was calculated from the number of correct responses, and reaction time (unit: ms) was calculated as mean and standard deviation, trimmed mean (20% trimming) and winsorized standard deviation.

The aim of the analysis of distributions was to determine the dispersion of data points. A two-pronged approach was used to filter out extreme values: absolute thresholds (response times below 20 ms and above 10,000 ms were excluded from the analysis), and trimmed means following Vargha (2020) and their corresponding winsorized variance indicators.

The study also examined normality in the calculation of both individual and group averages, using indicators of peak and skewness: the use of different indicators was determined as a function of the normality of the distribution and the existence of homogeneity of variance. When testing the hypotheses on the means, normality was tested using skewness and kurtosis. It can be said that, with very few exceptions, one cannot speak of a normal distribution in terms of both response times and precision, and therefore, in addition to a small number of t-tests, robust tests were used, for the most part.

The correlations between cognitive control processes and music training, as well as the effect of training, were investigated using multivariate analysis of variance, which allows for a good analysis of complex interactions between individual variables. Where the results indicated, additional statistical methods were applied to each sub-domain, for example, linear regression, correlation analysis, and other ANOVA analyses.

Several approaches were used to define performance, in accordance with the procedures employed in the literature. Generally speaking, the analysis of reaction time and accuracy provides a simple, well-understood picture of performance. However, it can be difficult to rank respondents' performance and interpret it on a scale. The main problem with examining reaction times and correct response rates separately is that they tend to be related in a trade-off fashion: the cost of increasing speed is typically an increase in the number of errors (see also, for example, Pachella, 1974; Schouten & Bekker, 1967; Wickelgren, 1977). Both reaction time and accuracy provide valuable information about the difficulty of a task or the ability of an individual, but their isolated assessment can be misleading, since no clear ordering can be established if reaction time averages and error rates do not follow exactly the same ordinal sequence for different respondents - or task types. It may be that the difference between two subjects is not measured in the individual indicators, but in the decision strategy used. A further drawback is that both reaction time and speed are typically analysed as means, so that the additional information carried by the distribution or variance is lost in the analyses.

To address this issue and to explore deeper relationships, the diffusion model (Ratcliff, 1978) was applied, to separate the extent of evidence collection in the decision process from the decision criterion and non-decision-related components of processing (Ratcliff, Thapar, Gomez, & McKoon, 2004). The model was designed for relatively fast binary decisions (maximum response time of 1-1.5 seconds) and for decision processes requiring one-step decision making (Ratcliff & McKoon, 2008; Zeguers et al., 2011). The advantages of using a diffusion model are as follows:

- Various cognitive processes can be associated with different psychologically relevant parameters.
- It not only shows whether one group of respondents is slower or has a higher proportion of correct answers for one type of task, but also why.
- Equal performance, expressed for example in terms of reaction time, may be due to completely different mechanisms (some participants have a lower information processing time, others a lower non-response time) (Diederich & Busemeyer, 2003; Voss et al., 2004).

5. Main results and discussion

5.1. Musical prehistory hypothesis

When analysing the different cognitive functions regarding reaction time and accuracy, the better performance of the musicians was evident, but the difference was typically not significant. However, when looking at the reaction time and accuracy indicators simultaneously, a marked difference between the two groups can be seen: while the musicians performed homogeneously (that is, with fewer outliers, the whole group produced stable results), the strong positive correlation between the two indicators for the non-musicians suggests that the group members consciously or unconsciously chose between a strategy of higher accuracy and higher reaction time, or more errors and higher tempo. Analysing the data using the diffusion model revealed that the significant difference between the two groups does not lie in the decision threshold, but in the deflection rate - meaning that both groups processed the same amount of information in their decision making, but the musicians did so more quickly and efficiently.

With regard to the individual cognitive control components, it was found that musicians performed outstandingly well in the pitch N-back task in terms of accuracy, and their effectiveness in resisting proactive interference is noteworthy. This latter finding confirms the cross-modal transfer effect of music learning and the modality-independent, domain-general nature of the mechanism of the resistance of cognitive control to proactive interference.

A surprising result of the research was that musicians showed no advantage over non-musicians in error detection. This may be explained by the fact that the previously mentioned advanced error detecting ability of the musicians is presumably context-dependent and process-dependent (linked to the musical activity, including playing a particular instrument), and often requires auditory feedback (although a "silent" high level of error detection among highly skilled professional musicians was previously shown). The part of the hypothesis related to practice habits and the number of years spent playing music could not be tested due to the homogeneity of the musicians' sample. Thus, based on the performance of the musicians and the non-musicians on input tasks, notable differences were only identified for two cognitive control components.

Investigating this hypothesis has identified several further research directions, including the consideration of right and left handedness in the analysis of reaction times and accuracy, the conducting of similar studies of professional musicians in other musical genres, and comparisons of musicians by instrument or instrument family.

5.2. Improvability hypothesis

A detailed analysis of the results of the individual procedures measuring cognitive control functions supported the hypothesis that a targeted, intensive music training programme can lead to a demonstrable improvement in cognitive control functions in both young musicians and non-musicians. The effect of the training was mainly manifested in a reduction of reaction times: in virtually all test situations, respondents became faster. However, the rate of acceleration showed no significant relationship with group membership or with the specific characteristics of the different tasks. The results therefore suggest that generic change was achieved, even following a relatively short training. The proportion of correct answers typically did not change between the two surveys, that is, the research participants were able to perform with the same accuracy faster. These findings suggest that activities learned in one situation (playing music) were transferred to other situations, and a distal transfer of musical activities was observed. As a result of the music training, an improvement in the cognitive flexibility of the participants was observed: they made decisions faster, but at the same time they did not make more mistakes than before.

The hypothesis that musicians show less improvement was not clearly supported, although when the results were analysed in detail, the non-musicians showed a higher rate of improvement in all the functions tested. The only evidence of a ceiling effect in the performance of musicians can be assumed for the KFP Baseline and Cue tasks, which may be due to prior music learning rather than training - and may also explain why musicians did not improve in this area as a result of training.

Using the diffusion model, a pattern was revealed according to which the drop in reaction time may have been driven by a different psychological process in the two groups: while non-musicians improved their information processing efficiency, the musicians' decision making process tended to be more information-intensive.

5.3. Function-specific development hypothesis

Comparison of the development of different cognitive functions was made by analysing reaction times, as this indicator varied significantly for most task types. For each version of each task type, a one-way analysis of variance was performed on trimmed RT data to calculate pre- and post-training reaction time means. The results showed a decrease in reaction time observed across the whole sample, which in most cases represented a significant change in the non-musician group, while this was observed only only a few of the musicians. The largest proportion of acceleration was observed for the tasks measuring resistance to proactive interference, with a reduction of more than 20% for the non-musicians, across sub-trials (either separately for the musician/non-musician groups or for the different stimulus types - although the improvement for musicians is only marginally significant). This result can be explained by the fact that the music training methodology included a number of exercises manipulating proactive interference. This change could have a wide-ranging impact on the participants' everyday lives: it allows for more present-focused, effective work and task solving in all areas of life, in which it is important that past experiences do not influence present decision-making, regardless of their relevance. In the context of interference models, these results reflect that the developmental effect of music has amodal, domain-independent and partly process-specific effects on cognitive control mechanisms, and that significant changes in content-context binding can be achieved with short, intensive therapy. Given that these tests of proactive interference were conducted in a visual format, the results also support the cross-modal developmental impact of music development training.

In the case of resistance to distractor effects, there is a striking difference between the two groups: while non-musicians had an acceleration rate above 10%, musicians did not achieve this rate for any of the tasks. This can be explained by the fact that the musicians were subjected to constant distractor effects during musical activities (they have to pick out their own voice from other instruments, the voice of the fellow musician they are interacting with, or, to use another example, they have to keep the correct tempo despite the sliding tempo).

In terms of working memory updating, the similar magnitude of improvement across the whole sample also shows a complex picture: musicians improved more in visual tasks, while non-musicians improved more in auditory tasks.

To sum up, the hypothesis was confirmed: the individual cognitive control functions improved to different extents both relative to each other and as a function of group membership - but the improvement is in the same direction across the whole cognitive system, which is consistent with the basic framework of the unit difference model proposed by Miyake et al.

5.4. Modality-specific development hypothesis

The validity of this hypothesis depended to a large extent on the development of the participants' auditory attention and their attitude towards the working method of manipulating auditory information as a result of the music training. Therefore, the perceptual development of the participants was taken into account when analysing the results, as the research was not focused on the development of this, but on higher cognitive processes. As no significant change was observed, the results suggested that the latter effect did not need to be included as a covariate in further analyses.

The hypothesis was tested in the N-back tasks, as they comprised both auditory and visual task performance. Looking at the reaction time indicators for the whole sample, it was found that the improvement in the auditory tasks was greater than that shown in the visual tasks, thus the hypothesis was confirmed. For non-musicians, the difference is significant, whereas for musicians the difference is minimal or of opposite sign. In the analysis, the findings of the third hypothesis were taken into account, that the least detectable improvement was in the working memory refreshment component as a result of the training.

On the whole, the hypothesis was supported for the non-musician group: greater improvement was measured in the auditory channel than in the visual channel, and as expected, the improvement was stronger for non-musicians. The demonstrated effect certainly merits further research - either by increasing the number of items or by including auditory test procedures measuring additional features.

The results contain several lessons for practical application. They stress the importance of the auditory channel in learning, teaching and various cognitive processes (mainstream education, remedial education, development, therapy and even music education), which is increasingly underused due to the activities relying on digital and written flows of information.

5.5. Long-term impact hypothesis

This hypothesis was verified by analysing the results of the N-back test procedures in which auditory and visual explanatory variables were available. Only the long-term evolution of reaction time was examined, because there was no detectable long-term improvement in accuracy in the tasks tested. In light of the results the effect of training is maintained in the long term, therefore the hypothesis is confirmed. Group affiliation had no significant effect, that is, the findings are valid for both groups, while type and n-value also showed an interaction effect with the time factor.

In terms of modality, there was no significant difference between the post-training and the six weeks' post-training results for visual stimuli, so the effect of training was maintained at east in timespans of intermediate length. An even more pronounced effect was observed for audio stimuli: reaction times were also reduced in the audio N-back tasks in the longer term. Since the training ended after four weeks and the subjects did not continue with the music exercises, this result suggests that the participants started to use and incorporate the cognitive control strategies learned during the training into their daily routines and other activities (the transfer effect) and that the music training used induced system-level, domain-specific changes.

When examining working memory load, it can be concluded that while the immediate effect of training was stronger for the 2-back tasks, the long-term reduction was of the same magnitude for both task types.

Examining the latent variables of the diffusion model, the time factor showed a significant improvement in the long run for the deflection rate and the decision threshold, with all other factors held constant. The time factor expresses the time spent on basic encoding and response execution processes, that is, the speed - in this case, the speed-up - of the configuration of working memory for a task. This means that the subjects were more flexible and faster to respond to contextual changes and are ready for a new task sooner.

6. Limitations and opportunities

The small size of research groups can be interpreted as a limitation. The primary reason for this can be found in the framework of the music training used: for an effective group process, a number of more than 18-20 participants cannot be considered, even taking into account dropouts (Yalom, 1985). With regard to research methodology, it was important that the same music trainer, observer and research assistant lead the process of both groups, which limited the possibility of starting additional groups. An equally limiting factor was the location of the tasks and training sessions, which the institutions concerned could not provide for an extended period of time, and the time available was also limited. The mentioned limited factors we attempted to compensate for by sample matching, and training regime that we considered adequate for influencing domain-general cognitive functions.

Another limitation was that it was difficult to acquire and control musical and non-musical history as input criteria. For example, in the case of the music group, it was only possible to assess the start of music learning and the number of music lessons and hours of practice per week and per year based on the subjects' self-reports. This data could potentially be imprecise, and its quality is difficult to determine.

The prevention of the non-music group from engaging with music presented another difficulty. We tried to overcome this by allowing interested people to try the session, become familiar with the venue and the prospective group leader, ask questions and volunteer to participate. However, the members were quick to disengage, enjoyed the sessions and remained motivated until the end of the training - as confirmed by the responses to the exit questionnaire.

The music group had problems maintaining motivation. For professional musicians, it was a challenge to maintain interest in simple rhythmic games that did not challenge their musical skills. Exams and closed papers during the data collection periods, might have affected the performance of the participants. We have recorded these factors in the research report but have not yet taken them into account in our calculations.

The results may have been influenced by the fact that our computer tasks started randomly with different key assignments: the right or left key was the correct answer (this was recorded in the research protocol for each task type and for each person). When data cleaning was performed, the results and the research protocol were compared to find a set of responses that showed that the subject consistently used a reversed key combination. An attempt was made to filter out these cases, but it is important to note that the extent to which this lateral shift played a role in the response time of each subject remains unknown. Furthermore, the literature shows that, for example, the left hand makes significantly more errors than the right hand in N-back tasks (Okhrei et al., 2016), and this can be assumed for the other task types used, so it will be worth considering this factor in the future as well as the press-mb distribution.

An additional limitation is that the data sets under study were, for the most part, not normally distributed after manual data cleaning, although this was compensated for by applying adequate statistical procedures after appropriate tests. In several cases, however, the results were not significant or only at the trend level, so further testing on a larger sample size is recommended.

Due to volume limitations, this thesis presents only a subset of the tasks included in the paper: among others, the N-back test procedure with proactive and retroactive interference and several auditory tasks were omitted. Their analysis adds information to the conclusions drawn so far.

The group of musicians who participated in this study came from jazz and popular music and, due to their specific genres, presumably have a different type of training, different practice routines and different musical ability structures than, for example, the classical musicians who are often studied (Norgaard et al., 2019). I aim to extend the scope of the study to other musical genres and to compare the results of different groups of musicians.

Another direction of research could be to compare musicians by instrument or instrument family. This would provide a more detailed picture of how specific cognitive control functions are developed by each musical sub-activity. The literature shows that instrument type influences cognitive control ability structure (Porflitt & Rosas, 2020).

It is of utmost importance to include special needs populations in future studies and to adapt the developed music therapy method to atypical populations. The research could be conducted in the future on other age groups, so that its results could be applied in educational, school psychological and neuropsychological practice.

7. Conclusions

7.1. Theoretical conclusions

The presented dissertation and the underlying empirical research investigated the effects of musical activities on cognitive control processes. We analysed the cognitive control functions of a musician and a non-musician group before, immediately after and six weeks after an intensive music training program.

The theoretical framework of our investigation and the theoretical novelty which carries future application potential is the KZF (Controlled Musical Processes) concept constructed after synthesizing the relevant literature, which was based on the interaction of musical activities and behavioral control mechanisms, situated on a continuum of both automatic and controlled processes, and resulted in a targeted methodology based on repetition and contextual change, which can transfer music's mechanism of action into remote and system-level generalizable processes (Botvinick & Cohen, 2014; Cohen et al. , 1990; Turmezeyné Heller, 2015). The KZF concept can serve as a framework for further research in the future and will hopefully be refined, built upon and developed - benefiting research related to music activities.

The conclusions drawn from the results of the empirical experiment included questions such as which of the cognitive control mechanisms can be developed most effectively and whether there is a long-term effect of developing cognitive control through short, targeted music training. We also sought answers to the question whether the effect in the group of young musicians and non-musicians differs significantly and whether the cognitive control functions of young people who have been playing music for a long time can be further developed by the music training we developed. The answers to these questions may provide a basis for further research on this topic in the future.

The analysis of input differences between musician and non-musician groups was based on the conflict monitoring theory of Botvinick and colleagues (2001), previous research with professional musicians (Chen et al., 2020; 2021; Fennell et al, Herholz et al., 2012) and studies on the developmental effects of music learning on long-term behavioural control (Nutley et al., 2014; Oechslin et al., 2013; Pallesen et al., 2010; Slevc et al., 2016). As shown in the discussion, several segments of the input difference hypotheses were not confirmed in this study. In the future, it is worth testing these hypotheses on study groups with larger numbers of items and different characteristics to prove possible contradictions or coincidences with previous theories.

In order to explore the deeper relationships behind the conclusions, we also analysed the data using a diffusion model (Ratcliff & McKoon, 2008), which revealed that the difference between the two groups at the initial condition was not significant in the decision time but in the deviation rate, leading us to conclude that both groups process the same amount of information in their decision making, but that musicians are faster and more efficient at it. From the above, we conclude that the use and practice of cognitive control processes in different contexts during musical activities primarily improves decision-making efficiency and decision readiness.

On their input tasks, musicians showed outstanding performance in two cognitive control components, which indicate the following: their performance in the N-back tasks, which they frequently use to manipulate pitch, suggests a domain-general and modality-specific transfer effect of music learning, and in the tasks measuring resistance to proactive interference, suggests a cross-modal transfer effect.

However, the performance of the music-learning group, reflecting the whole cognitive control system, underperformed with regard to the expectations of this study and those predicted by the literature. Regarding this finding we suggest that when comparing the results of the present study with any future ones, it should be borne in mind that 1) previous studies were conducted in the context of various behavioural control paradigms, based on different working memory and other models 2) the characteristics of the musician population they investigated were also somewhat diverse, although they mainly worked with classical musicians.

A further theoretical conclusion for future consideration is to reformulate the research questions and related hypotheses in terms of a diffusion model: the research work has shown that the use of this model refines the conclusions that can be drawn from the data collected from the studies and is therefore extremely useful - but also requires a slightly different conceptualisation and collocation (see: bias rate, decision threshold, etc.).

The novelty of this research is that, to our current knowledge, it is the first time in the literature that the resilience of musicians to proactive interference has been investigated in the framework of the Oberauer (2009) model. To our present knowledge, the literature has not yet addressed the effect of music specifically in relation to this type of interference, which, together with retroactive interference, also represents an area to be explored.

7.2. Implications for practice

The main finding of the research was the positive and long-lasting effect of the intensive music training program, which manifested in a reduction of reaction times: in practically all test situations, the participants became faster. The results suggest that even a short, targeted music training session can achieve generic changes in music and non-music groups.

Another important finding that the music-therapy-based methodology is more effective in developing young people who have not played music before. However, our research also suggests that the development of participants with a musical background depends primarily on maintaining their motivation, and that the musical methodology developed can be adapted for them and thus be used effectively.

By applying the diffusion model, we were able to uncover a pattern that suggests that different psychological processes may have been behind the decrease in reaction time in the two groups: while the non-musicians improved their information processing efficiency, the musicians' decision-making process tended to be more affected by a decrease in the amount of information needed to make a decision. This suggests that non-musicians learned new strategies in a new musical environment, while musicians, based on their previous contextual knowledge, required less information for their decisions and progressed towards automatization in the tasks under study. These insights can help to find more specific tools for the different groups to be developed in the future.

A further conclusion of this research is that music training influenced the development of various cognitive functions to different degrees. The largest rate of acceleration was found for tasks measuring resistance to proactive interference, which was found to be greater than 20% for the non-musicians, in sub-tests. From this result, it can be concluded that the applied music training exercises manipulating proactive interference were effective. With respect to the updating of working memory, the similar magnitude of change across the whole sample also shows a complex picture: the musicians improved more in visual tasks, while the non-musicians improved more in auditory tasks. It can be concluded that working memory tasks based on visual stimuli, which are less used by musicians, can also be developed well with music, suggesting a cross-modal effect, and that the progress of the non-musicians in auditory tasks suggests that updating working memory in young adults can also be developed effectively with music. These findings have applied educational, remedial and developmental lessons: again, they encourage the targeted use of auditory tools.

The differential improvement in each cognitive function is mainly explained by the fact that each exercise in the music training methodology targeted specifically one chosen cognitive component. In addition, the performance development of the group members was influenced by a combination of several other factors, such as the existing pattern of cognitive control mechanisms (Friedman & Miyake, 2017; Friedman et al., 2008), the individual experiences and contextual sensitivity of the participants, or the extent to which this was altered by the methodology of the training targeting different components. Finally, it is also worth mentioning the different levels of motivation of the participants, which is a prerequisite for progress, but obviously contributed differently from individual to individual to the development of each cognitive control function.

The practical lesson learned from the above is that even in the case of precise and targeted planning of the musical tools in a developmental methodology the same degree of change in the participants should not be expected: different cognitive control sub-functions will develop in the course of the group work, even if the same training package is used. It is important to build on strengths and maintain motivation where possible for effectiveness.

8. Closing thoughts

The chosen topic provides a missing link in providing evidence-based professional support for the effectiveness of music as a tool to improve cognitive control.

In terms of the theoretical implications, Cohen's (2017) model of cognitive control as a framework of investigation and the music therapy approach that permeates music training are novel, opening up a new direction of inquiry in the palette of research related to music activities in the home. Also of novel value is the concept of KZF

(Controlled Music Processes), which is introduced and described in this thesis, along which a number of related research projects can be conducted in the future. I plan to apply the model to a larger sample of items and target groups. As mentioned in the thesis, new insights could be gained, for example, by comparing professional musicians of diverse genres, by examining populations of different ages, by including developmental neurological disorders affected by different cognitive control functions, by taking into account lateral factors, by conducting a more complex analysis of the types of stimuli under investigation (for example, verbal versus non-verbal stimuli, or different types of interfering elements) and by developing additional auditory testing procedures.

One practical outcome of this study is the implementation of a short, intensive cognitive control training session with music, which offers an effective, inexpensive and widely applicable method for the development of cognitive control functions. The music methodology developed for its role in facilitating cognitive control learning may be applicable in educational and labour market settings. This bears further implications for the application of music training in therapeutic education and clinical settings, given the relevance of cognitive control processes to neurodevelopmental disorders and brain injuries. Following the necessary adaptation of the methodology to the needs and strengths of the target populations, the training will be applicable in the therapy of populations with autism spectrum disorder, attention deficit hyperactivity disorder and specific language development disorder, among others.

These possibilities also point towards further research for developing, testing and evaluating the impact of adapted versions of the training, which could be aided by the auditory N-back testing procedure developed in this research.

We plan to further develop the aforementioned auditory N-back testing procedure, to disseminate the music training methodology in a practice-oriented way and to initiate a dialogue with relevant professionals and colleagues in order to make the most effective use of these results and to further develop them.

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EÖTVÖS LORÁND TUDOMÁNYEGYETEM

ADATLAP a doktori értekezés nyilvánosságra hozatalához

I. A doktori értekezés adatai

A szerző neve: Varga Ágnes..

A doktori értekezés címe és alcíme: Zenei tevékenységek hatása a kognitív kontroll folyamatokra..........

A doktori iskola neve: ELTE-PPK, Neveléstudományi Doktori Iskola ....

A doktori iskolán belüli doktori program neve: Gyógypedagógiai Program ....

A témavezető neve és tudományos fokozata: Dr. Marton Klára, habilitált egyetemi tanár és Dr. Jakab Zoltán, egyetemi docens...

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MTA Adatbázis-azonosító: 10057770..

DOI-azonosító[1]: 10.15476/ELTE.2022.175 ....

II. Nyilatkozatok

1. A doktori értekezés szerzőjeként[2]

a) hozzájárulok, hogy a doktori fokozat megszerzését követően a doktori értekezésem és a tézisek nyilvánosságra kerüljenek az ELTE Digitális Intézményi Tudástárban. Felhatalmazom az ELTE-PPK Neveléstudományi Doktori Iskola hivatalának ügyintézőjét *Barna Ildikót*, hogy az értekezést és a téziseket feltöltse az ELTE Digitális Intézményi Tudástárba, és ennek során kitöltse a feltöltéshez szükséges nyilatkozatokat.
b) kérem, hogy a mellékelt kérelemben részletezett szabadalmi, illetőleg oltalmi bejelentés közzétételéig a doktori értekezést ne bocsássák nyilvánosságra az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban;[3]
c) kérem, hogy a nemzetbiztonsági okból minősített adatot tartalmazó doktori értekezést a minősítés (..................*dátum*)-ig tartó időtartama alatt ne bocsássák nyilvánosságra az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban;[4]
d) kérem, hogy a mű kiadására vonatkozó mellékelt kiadó szerződésre tekintettel a doktori értekezést a könyv megjelenéséig ne bocsássák nyilvánosságra az Egyetemi Könyvtárban, és az ELTE Digitális Intézményi Tudástárban csak a könyv bibliográfiai adatait tegyék közzé. Ha a könyv a fokozatszerzést követőn egy évig nem jelenik meg, hozzájárulok, hogy a doktori értekezésem és a tézisek nyilvánosságra kerüljenek az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban.[5]

2. A doktori értekezés szerzőjeként kijelentem, hogy
a) a ELTE Digitális Intézményi Tudástárba feltöltendő doktori értekezés és a tézisek saját eredeti, önálló szellemi munkám és legjobb tudomásom szerint nem sértem vele senki szerzői jogait;
b) a doktori értekezés és a tézisek nyomtatott változatai és az elektronikus adathordozón benyújtott tartalmak (szöveg és ábrák) mindenben megegyeznek.

3. A doktori értekezés szerzőjeként hozzájárulok a doktori értekezés és a tézisek szövegének plágiumkereső adatbázisba helyezéséhez és plágiumellenőrző vizsgálatok lefuttatásához.

Kelt: Budapest, 2022.08.31.

Varga Ágnes

a doktori értekezés szerzőjének aláírása

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[1] A kari hivatal ügyintézője tölti ki.

[2] A megfelelő szöveg aláhúzandó.

[3] A doktori értekezés benyújtásával egyidejűleg be kell adni a tudományági doktori tanácshoz a szabadalmi, illetőleg oltalmi bejelentést tanúsító okiratot és a nyilvánosságra hozatal elhalasztása iránti kérelmet.

[4] A doktori értekezés benyújtásával egyidejűleg be kell nyújtani a minősített adatra vonatkozó közokiratot.

[5] A doktori értekezés benyújtásával egyidejűleg be kell nyújtani a mű kiadásáról szóló kiadói szerződést.