Universidade Federal do Vale do São Francisco

A Influência do Estudo de Música em Funções Executivas

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Dissertação de mestrado

Petrolina
2018

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Dissertação apresentada como requisito parcial para a obtenção do grau de Mestre em Psicologia sob orientação da Profª Dra Ivani Brys

Universidade Federal do Vale do São Francisco
Mestrado em Psicologia
Linha de concentração em Processos Cognitivos e Comportamentais
Março, 2018

Palmer, Jennifer Lee.
P173i Influência do estudo de música em funções executivas / Jennifer Lee Palmer. - - Petrolina, 2018.
55 f.: il.: 29 cm.

Trabalho de Conclusão de Curso (Mestrado em Psicologia) – Universidade Federal do Vale do São Francisco, Campus Petrolina, Petrolina – PE, 2018.

Orientador: Profª Drª. Ivani Brys

1.Funções executivas. 2. Treino musical. 3. Neoroplasticidade. I. Título. II. Universidade Federal do Vale do São Francisco.

CDD 153.4

Ficha catalográfica elaborada pelo Sistema Integrado de Bibliotecas da UNIVASF.
Bibliotecário: Fabio Oliveira Lima CRB-4/2097

Agradecimentos

Agradeço a Deus, sempre. Agradeço imensamente a Ivani, por ter me ensinado tanto e sempre com muita paciência. Agradeço à minha família, em especial aos meus pais, Joe e Sandy, e às minhas irmãs, Rachel e Brenda, por terem me acompanhado até aqui. Agradeço aos meus pimpolhos Airton e Pâmala, por terem contribuído à pesquisa, e ao Instituto Federal do Sertão Pernambucano por ter permitido que ela fosse realizada em seu campus. Agradeço aos meus amigos e colegas, citando aqui Igor, por ter me feito acreditar que isso tudo seria possível; Matteo, pelo auxílio na etapa de seleção; Merlise, por ter me ajudado no projeto inicial. Agradeço com muito carinho a Suelen, o seu apoio incondicional em todos os aspectos desse mestrado, e por me fazer sonhar naquilo que ele pode me trazer.

Resumo

Funções executivas são processos mentais que regulam o comportamento, tornando possíveis o planejamento, a resolução de problemas, ter pensamento flexível e outas ações. Esses processos giram em torno de três núcleos: controle inibitório, memória de trabalho e flexibilidade cognitiva. Saber fazer música requer horas de treino, sendo necessário exercer diferentes aspectos de funções executivas, o que leva investigadores a pesquisarem se esse treino poderia estar de alguma forma relacionado a funções melhoradas. Essa dissertação é composta de dois artigos. O primeiro é uma revisão de literatura que buscou responder como treino musical se relacionaria a funções executivas. Para isso, foram identificados 20 artigos publicados entre 2008 e 2017, que focaram na performance em funções executivas de músicos adultos saudáveis. Em geral, os artigos encontraram uma relação positiva entre treino musical e algum aspecto dessas funções. O segundo artigo investigou a possível influência de estudo musical nos componentes controle inibitório e memória de trabalho. Nesse intuito, 87 alunos de licenciatura foram recrutados e separados em grupos de músicos formandos e ingressantes para comparar a não músicos formandos e ingressantes. Foi visto melhor desempenho de controle inibitório para músicos formandos, mas não músicos ingressantes. Não foram encontradas diferenças de desempenho em memória de trabalho. Seriam necessários estudos longitudinais para determinar causalidade.

Palavras-chave: funções executivas; treino musical; neuroplasticidade

Abstract

Executive functions are mental processes that regulate and control behaivor. They make possible planning, problem solving, flexible thinking and other actions. These processes have three cores: inhibitory control, working memory, and cognitive flexibility. Musical abilities require hours of training that employ different aspects of executive functioning, leading researchers to study how this training could could relate to these functions' performance. This dissertation is composed of two articles. The first one is was a literature review that sought to answer how musical training would be related to executive functions. For this, 20 studies published between 2008 and 2017 were examined. They all focused on performance of healthy adult musician. In general, the articles found a positive relationship between musical training and some aspect of these functions. The second research aimed to better understand the influence of musical practice on inhibitory control and working memory. For this, 87 students from a teaching college were recruited and separated into four groups: musician seniors, musician freshmen, non-musician seniors, and non-musician freshmen. Better inhibitory control was seen for musician seniors, but not musician freshmen. No differences were found for working memory. Longitudinal studies are needed to assess causality.

Keywords: executive functions; musical training; neuroplasticity

Índice

Funções executivas são um conjunto de processos mentais necessários para controlar e regular comportamentos (Alvarez & Emory, 2006; Clayton et al., 2016; Diamond, 2013, 2014; Slevc, Davey, Buschkuehl, & Jaeggi, 2016; Zuk, Benjamin, Kenyon, & Gaab, 2014). Elas são necessárias para a concentração, ou para quando depender apenas de instintos seria mal aconselhado, insuficiente ou impossível (Diamond, 2013). Tais funções permitem o desenvolvimento e a execução de planos, a resolução de problemas, formar analogias, obedecer a regras sociais, realizar várias tarefas simultaneamente e situar episódios no tempo e espaço (Grafman & Litvan, 1999). Através delas, é possível exercitar escolha, autocontrole, disciplina, ser criativo e flexivelmente se ajustar a mudanças ou a novas informações (Diamond, 2013, 2014).

Esses processos cognitivos podem ser divididos em três componentes principais: controle inibitório, memória de trabalho e flexibilidade cognitiva. Inibição é a capacidade de controlar a atenção, comportamento e pensamentos, principalmente em face a distrações e respostas conflitantes. Assim, é possível ignorar determinados estímulos em detrimento de outros, baseadando-se em alvos e intenções (Slevc et al., 2016). Memória de trabalho é a capacidade de segurar informações na mente e trabalhar com elas mentalmente, mesmo quando não mais presentes para a percepção (Diamond, 2013). Flexibilidade cognitiva é o componente que permite alternar entre atividades ou conjuntos mentais, possibilitando a mudança de perspectiva espacial e até interpessoal, se ajustando a demandas de novas tarefas (Slevc et al., 2016; Zuk et al., 2014).

Funções executivas são essenciais para a saúde física, mental, desenvolvimento cognitivo, social e psicológico, sucesso acadêmico e na vida (Diamond, 2013). Sua capacidade não é estática, considerando que o cérebro tem a habilidade de se modificar ou ser alterado pelo ambiente externo. A performance dessas funções pode ser melhorada por treino e experiência que não precisam estar diretamente ligadas às funções executivas (Moradzadeh,

Blumenthal, & Wiseheart, 2015; Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014). A repetição de tarefas cognitivas pode melhorar o tempo de reação, precisão e alterar a atividade neural em regiões recrutadas pelas demandas da tarefa sendo executada (Sayala, Sala, & Courtney, 2006).

Uma experiência que pesquisadores acreditam que possa alterar o desempenho em funções executivas é treino musical, já que saber fazer música requer várias horas de treino, sendo necessário exercer a memória de trabalho, flexibilidade cognitiva, a inibição de diversos estímulos (Schroeder, Marian, Shook, & Bartolotti, 2016), atenção (Duke, Cash, & Allen, 2011), monitoramento e a capacidade de alternar a atenção entre mais de uma tarefa (Bialystok & Depape, 2009; Moradzadeh et al., 2015). Sendo assim, estudiosos pesquisam buscando entender como essa experiência poderia reorganizar os processos de controle nessas funções cognitivas e quais as vantagens para o seu desempenho (Bialystok & Depape, 2009; Schroeder et al., 2016; Slevc et al., 2016; Zuk et al., 2014).

O trabalho de Zuk et al. (2014), por exemplo, avaliou a relação entre treino intenso de um instrumento musical e funções executivas, constatando que pessoas treinadas demonstraram performance elevada em diversos, mas não em todos aspectos de funções executivas. Bialystok e Depape (2009) também investigaram as vantagens cognitivas advindas do treino musical, inclusive para vocalistas, e constataram vantagens em desempenho de controle inibitório em comparação a não músicos.

Schroeder et al. (2016) constataram que a atividade musical pode aumentar a habilidade de supressão de interferências. Os resultados do estudo de Pallesen et al. (2015) sugerem que músicos são capazes de recrutar mais recursos cerebrais em áreas como o córtex anterior cingulado para sustentar o controle cognitivo durante tarefas de memória de trabalho. Isso foi medido através da análise do sinal de ativação de uma dependente de nível de oxigenação de sangue durante atividades de memória de trabalho utilizando imagem de

ressonância magnética funcional. Para Slevc et al. (2016), as vantagens cognitivas associadas a habilidades musicais não se limitam a processos auditivos, mas sim a aspectos específicos de funções executivas, como a atualização, um processo da memória de trabalho.

Estudos que investigam os efeitos do treino musical em funções executivas incluem, praticamente na sua totalidade, grupos de músicos possuidores de uma ampla experiência e treino musical intensivo. Os músicos que participaram do estudo de Zuk et al. (2014) começaram a estudar música antes da idade de dez anos, e não tendo parado desde então estudaram por pelo menos dez anos. Bialystok e Depape (2009) analisaram a performance de músicos que têm estudado instrumento ou voz por pelo menos metade de suas vidas, resultando em uma média de dezesseis anos de estudo. O grupo de músicos no trabalho de Clayton et al. (2016) era composto por músicos de pelo menos dez anos de treino musical formal. Moradzadeh et al. (2015) analisaram o desempenho de músicos que tinham pelo menos doze anos de treino formal.

Os estudos anteriormente mencionados não levaram em consideração músicos com menos de dez anos de estudo intenso em escolas de música e conservatórios. Não se sabe se os resultados apontariam um efeito benéfico igual, ou pelo menos similar caso o tempo de treino fosse reduzido, ou se esse estudo de música fosse em contexto que não priorizasse a prática intensa de um instrumento. Nesse sentido, considera-se importante investigar se o estudo de música é uma experiência que gradualmente melhora o desempenho das funções executivas, ou seja, entender seus efeitos em função do tempo de estudo. Como seria se os participantes não fossem intensamente voltados a música, será que mesmo com menos prática musical seria possível músicos demonstrarem melhor desempenho em funções executivas quando comparados a não músicos?

A primeira etapa dessa dissertação foi a realização de uma revisão de literatura a fim de estudar quais aspectos das funções executivas são afetadas por treino musical; o passo

seguinte foi a elaboração da pesquisa experimental tendo como participantes alunos de licenciatura em música do IF Sertão Pernambucano. Idealmente o foco desse curso de graduação é instruir professores de música, e não necessariamente músicos de alta performance. Foi também pensado nos alunos não músicos dos outros cursos de licenciatura da mesma instituição como grupo de comparação, já que estariam em situação parecida, mas sem a prática da música. Ainda no intuito de entender a relação tempo de estudo musical e seu efeito sobre funções executivas, foram comparados os recém ingressos nos cursos com os que estavam próximos de se formarem.

Como resultado desse estudo foram escritos dois artigos: uma revisão de literatura que buscou relatar como o treino musical afeta diferentes aspectos de funções executivas; e um artigo experimental que teve como objetivo melhor compreender a influência da prática musical em controle inibitório e memória de trabalho. Os dois artigos que seguem foram escritos em inglês e formatados para submissão em revistas norte americanas: a revisão de literatura em *Psychology of Music* e o artigo experimental em *Cognition*.

The Impact of Music Training on Executive Functions – A Literature Review

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Abstract

Executive functions are a group of mental processes necessary to regulate behavior and can be improved by the repetition of cognitive tasks. These processes have three cores: inhibitory control, working memory, and cognitive flexibility. One suspected agent of their improvement is musical training, leading researchers to study its relationship to executive functions. This literature review identified 20 studies between 2008 and 2017 that focused on the performance of healthy adult musicians relative to non-musicians in tasks related to executive functioning, the goal was to answer: in what ways does musical training affect different aspects of executive functions? Musicians showed some differences in brain activation when compared to non-musicians, as evidenced by ERP and fMRI studies. The studies regarding inhibitory control showed mixed results, some found that musicianship enhanced inhibition, while others found no influence. Almost all papers in this review found a relationship between improved working memory and musical training. Studies in cognitive flexibility were scarce and do not point to a conclusive tendency. In general, it could be said that musical training is related to enhancements in executive function, but longitudinal studies are necessary to confirm the inferred causality.

Keywords: executive functions; musical training; neuroplasticity

Executive functions are a group of mental processes necessary to control and regulate behavior (Alvarez & Emory, 2006; Clayton et al., 2016; Diamond, 2013, 2014; Slevc, Davey, Buschkuehl, & Jaeggi, 2016; Zuk, Benjamin, Kenyon, & Gaab, 2014). These functions are necessary for concentration, or for when depending solely on instincts would be ill advised, insufficient or impossible (Diamond, 2013). They allow the development and execution of plans, resolution of problems, formation of analogies, obedience to social rules, multitasking, and situating episodes in time and space (Grafman & Litvian, 1999). Through them, it is possible to exercise choice, self-control, discipline, creativity, and flexibly adjust to new information (Diamond, 2013, 2014).

These cognitive processes have three cores: inhibition, working memory, and cognitive flexibility. Inhibition is the capacity to control attention, behavior, and thoughts, even in the face of conflicting stimuli (Slevc et al., 2016). Working memory is the capacity to mentally hold and work with information (Diamond, 2013). Cognitive flexibility is the process that allows to alternate between activities or mental sets, permitting for change in spatial and interpersonal perspectives (Slevc et al, 2016; Zuk et al., 2014).

According to Diamond (2013), working memory and inhibition generally need one another to occur, since it is necessary to keep a goal in mind to know what is relevant and what needs to be inhibited, and for a well-functioning working memory, it is necessary to inhibit distractors. Cognitive flexibility builds upon these both, for to change perspective, it is necessary to inhibit the previous perspective and load into working memory a new one (Diamond, 2014). Although these are the core components of executive function, it is common to see other terms that relate, such as attention control (Slater, Ashley, Tierney, & Kraus, 2017) and interference suppression (Schroeder, Marian, Shook, & Bartolotti, 2016) for inhibition; updating (Slevc et al, 2016) for working memory; dual task (Cocchini, Filardi,

Crhonkova, & Halpern, 2017) and task switching (Moradzadeh, Blumenthal, & Wiseheart, 2015; Slevc et al., 2016) for cognitive flexibility.

Sayala, Sala, and Courtney (2006), and Millner, Jaroszewski, Chamarthi, and Pizzagalli (2012) state that the repetition of cognitive tasks alters the neural activity in regions recruited for the task. Training induces changes in cognitive function (Moradzadeh et al., 2015), therefore specific experiences could give rise to significant individual differences in executive functions (Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014). One of these experiences is musical studies, since it requires hours of training and employs inhibition, working memory, and cognitive flexibility (Amer, Kalender, Hasher, Trehub, & Wong, 2013; Clayton et al., 2016; Schroeder et al., 2016; Zuk et al., 2014).

Playing an instrument requires many hours of practice that involves sub-skills associated with executive functions, such as attention, monitoring and inhibitory control (Amer et al., 2013; Bialystok & Depape, 2009; Duke, Cash, & Allen, 2011; Jentzsch, Mkrtchian, & Kansal, 2014; Palmer, 2013; Schroeder et al., 2016; Slevc et al., 2016; Vuust, Wallentin, Mouridsen, Ostergaard, & Roepstorff, 2011; Zuk et al., 2014;), goal-directed behavior (Zuk et al., 2014), working memory and updating (Bialystok & Depape, 2009; Clayton et al., 2016), cognitive flexibility and task switching (Bialystok & Depape, 2009; Moradzadeh et al., 2015; Zuk et al., 2014), and dual task performance (Moradzadeh et al., 2015). It also requires the integration of sensory and motor information (Amer et al, 2013; Münte, Altenmüller, & Jäncke, 2002), extensive auditory training (Berz, 1995; Clayton et al., 2016), the coordination with other people (Palmer, 2013), and therefore being able to switch between multiple auditory streams (Loehr, Kourtis, Vesper, Sebanz, & Knoblick, 2013).

This literature review aims to answer the question: In what ways does musical training relate to different aspects of executive functions? Results can be divided into an overview of

research in the field; neural correlates; what is found related to inhibition, working memory, cognitive flexibility; and limitations presented in these researches.

Method

This literature review focused on the effects of musical training on executive functions. First, an electronic search using Google Scholar was conducted with the keywords *music* and "*executive functions"*, between quotation marks so that the expression would be searched, and not the individual words. Second, the list of "cited by" for each article was searched. Last, an ancestral search of the reference list for each of the initially found articles was completed. Only results in English were considered.

To be included in this literature review, studies had to meet the following inclusion criteria: (a) use of an experimental design; (b) publication in a peer-reviewed journal between 2008 and 2017; (c) healthy adult musicians as experimental subjects; and (d) the assessment of performance on an executive function task. The focus of this study is not the use of music as therapy for the improvement of executive functions, nor how music affects its listeners. Therefore, articles that were about some form of music therapy or about listening to music were excluded.

The initial Google Scholar search numbered close to fifteen thousand results classified in order of their relevance. Only the first 500 Google Scholar hits were examined, considering that they were sorted in order of relevance and after looking into the first 250, no more articles were seemed to remotely match this review's subject of interest. The second 250 texts were examined just to be thorough, but no hits were found in these. At first, the titles were read, and if they related to this review, the abstracts were read. If the abstract seemed of interest, the article was read for final decision of inclusion. After searching and

applying the abovementioned inclusion and exclusion criteria, 20 articles were deemed pertaining to this review (See Table 1).

Results and Discussion

Of the 20 studies used in this review, two focused on how music practice affects older adults' executive functions (Amer et al., 2013; Moussard, Bermudez, Alain, Tays, & Moreno, 2016). All studies had behavioral approaches, but seven also used imaging techniques to assess the relationship between musicianship and executive functions (George & Coch, 2011; Jentzsch et al., 2014; Kaganovich et al., 2013; Moreno et al., 2014; Moussard et al., 2016; Oechslin, Van De Ville, Lazeyras, Hauert, & James, 2013; Pallesen et al., 2010; Zuk et al., 2014). Four studies had, besides a control group, bilingual participants to compare with musicians (Bialystok & Depape, 2009; Moradzadeh et al., 2015; Moreno et al., 2014; Schroeder et al., 2016). The average number of participants was 60.95 per study. Different aspects of executive functions were assessed, such as auditory and visual conflict resolution, visual and auditory working memory, inhibitory control, dual task performance, conflict and post error adjustment, task switching, and cognitive flexibility.

As for older adults, Amer et al. (2013) postulate that the demands of musical expertise aid the preservation of domain-general, cognitive control abilities, and that this is perhaps due to the improvement of neural efficiency of general control networks. Moussard et al. (2016) agree with this, and although they did not find significant differences between musicians and non-musicians on a visual spatial working memory task, musicians had better inhibition performance, conferring an executive function advantage at an older age.

Four studies also assessed bilinguals' executive function measures alongside musicians'. The justification is that people who use two languages on a regular basis

demonstrate higher levels of executive control than monolinguals. Identifying, comparing, and exploring the possibility of additive effects of experiences with similar consequences on cognition helps isolate the mechanisms and contributes to understand how experience potentially reorganizes control processes in cognitive functioning (Bialystok & Depape, 2009; Moradzadeh et al., 2015; Moreno et al., 2014; Schroeder et al., 2016).

On a spatial conflict task more situated in the auditory experience, musicians performed better than bilinguals and monolingual non-musician controls, but for the visual version, both groups performed similarly better than the controls (Bialystok & Depape, 2009). Moradzadeh et al. (2015) found musical, but no bilingual advantage in task switching, but argue that it may be due to having used a verbal paradigm, which could be more difficult for bilinguals to process. Only Schroeder et al. (2016) found an additive effect to being both musician and bilingual, but just for the Simon effect, which is the measure of interference suppression calculated by subtracting response time on congruent trials from response times on incongruent trials. However, Simon effects are difficult to interpret because of a congruent facilitation (the reduction of interference effects after the experience of conflict in the previous trial). More research is needed to clarify this phenomenon.

Moreno et al. (2014) found no behavioral differences for measures of executive function between musicians and non-musicians, which was expected since they used a simple go no-go task with reduced difficulty, for it is not uncommon that behavioral output be similar for recognizably different groups in these cases. They also used ERP to study these groups and found that even performing similarly, bilingualism and music training have different mechanisms in brain networks supporting executive control over behavior. The overall pattern was that musicians showed stronger signs of activating early components of performance associated with behavior regulation, while bilinguals showed stronger signs for later components.

Neural Correlates

Event related potential (ERP) studies were an interesting addition to behavioral data. George and Coch (2011) showed that improvements in working memory, and perhaps attention, could be seen in the P3 component, which is known for its relationship with working memory. ERP waveforms are named to indicate polarity (positive/negative) and latency in milliseconds, so for example, the P3 was a positive going waveform that occurred around 300 milliseconds after the event. Jentzsch et al. (2014) noticed a better engagement of cognitive control processes, seen as larger error related negativity (ERN) and N2 amplitude for musicians. ERN is known to be an electrophysiological index of error perception and the N2 a marker of conflict monitoring, which leads Jentzsch et al. (2014) to suggest that musicians can respond quickly to error and adjust their behavior more effectively in conflict-rich contexts.

For Kaganovich et al. (2013), the difference was found in N1, suggesting that musical training is associated with a general enhancement in the early neural encoding of complex sounds. Moreno et al. (2014) found an increase in P2 amplitude for musicians, marker usually associated with attention. They also noticed a subsequent decrease in N2 amplitude, and therefore theorize that the larger amplitude in P2 reduced the need for cognitive control indexed by the latter component, N2. Moussard et al. (2016) performed the same experiment, but on older adults, and found no significant difference in P2 but an increase in N2 amplitude, which could mean that with the absence of early facilitation, older musicians manifested an advantage in N2. Moreno et al. (2014) and Moussard et al. (2016) concluded that musicians experience less conflict and require less subsequent inhibitory control to perform the same task relative to non-musicians.

Two studies paired working memory behavioral tasks with fMRI. Oechslin et al. (2013) found that music training led to changes in activation levels occurring in brain regions linked to universal functions of target detection and novelty processing, such as anterior cingulate cortex, supramarginal gyrus, pre-supplementary motor area and pars opercularis. This leads to believe that there are transfer effects of such brain plasticity beyond the auditory domain, especially in the field of inhibitory control and working memory. Pallesen et al. (2010) also noticed a greater activity in the anterior cingulate cortex, right-lateralized to the dorsomedial, frontopolar and orbital pre-frontal cortex regions and to the superior and inferior lateral parietal areas, in the insula and putamen, posterior dorsal pre-frontal cortex, anterior cingulate gyrus, and a left-side response in the precentral gyrus. For Pallesen et al. (2010), this, coupled with better behavioral outcome on the working memory test, supports the theory that cognitive control may be enhanced in musicians.

Inhibitory Control

When the subject was inhibitory control, results were mixed, while Clayton et al. (2016), Slevc et al. (2016), and Zuk et al. (2014) found no musical advantages, Amer et al. (2013), Bialystok and Depape (2009), Jentzsch et al. (2014), Kaganovich et al. (2013), Rodrigues, Loureiro and Caramelli (2013), Schroeder et al. (2016), and Slater et al. (2017) report enhanced interference suppression. Moreno et al. (2014) and Moussard et al. (2016) argue that even though no behavioral differences were found between musician and non-musician groups, differences were found for either the N2 or the P2 ERP components, which could suggest that musicians experience less conflict and therefore require less inhibitory control to perform the same task as non-musicians.

The most used were the Stroop task and the Simon task. The traditional Stroop task consists of showing participants color names, sometimes printed in a color that is not denoted

by the name. Naming the color takes longer and is more susceptible to error if the color name and ink do not match, as opposed to when they do. Modifications are made for auditory versions, for example, displaying the words "high" or "low" while presenting a high or low-pitched sound (Bialystok & Depape, 2009). For the Simon task the participant is usually placed in front of a screen and required to press a right or left key depending on the stimulus' color, no matter on which side of the screen it appears. Reaction times are found to be faster and more accurate when the stimulus occurs closer to the response.

It is interesting to note that not all studies measured both auditory and visual inhibition, but when they did, they either found that musicians showed enhancements in both (Amer et al., 2013; Bialystok & Depape, 2009; Slater et al., 2017) or did not differ significantly in both (Slevc et al., 2016), which leads to wonder if there is another factor besides musical training or inhibitory capabilities that could have influenced musician and non-musician results. No test seemed to favor musicians in detriment of other tests measuring the same aspect of executive functioning.

Working Memory

Out of the eleven studies that examined the influence of music practice on working memory, ten found that musicians performed significantly better in working memory tasks (Amer et al., 2013; Clayton et al., 2016; Franklin et al., 2008; George & Coch, 2011; Hansen, Wallentin, & Vuust, 2013; Oechslin et al., 2013; Pallesen et al., 2010; Slevc et al., 2016; Talamini, Carretti, & Grassi, 2016; Zuk et al., 2014). Moussard et al. (2016) did not find musical advantages but argue that this may be due to having compared an older group of musicians to younger non-musicians.

The main tests used were: the digit span backwards, in which a series of digits are presented verbally or visually and participants are then asked to recall them in reverse order

(Clayton et al., 2016; George & Coch, 2011; Talamini et al., 2016; Zuk et al., 2014); the Corsi block task, that consists of nine spatially arranged squares that briefly and sequentially change color, participants are required to recall the order in which this happens (Amer et al., 2013; Moussard et al., 2016); and the *n*-back task, where a series of letters is presented individually and participants are required to answer for each letter presented if they also appeared *n* items before (Oechslin et al., 2013; Slevc et al., 2016).

Three authors studied working memory in both auditory and visual forms. Slevc et al. (2016) and Talamini et al. (2016) found advantages for both domains. Only Hansen et al. (2013) state that while musicians display an enhancement of verbal working memory storage capacity, it does not extend to the manipulation of items in verbal memory, nor to the visual-spatial domain.

Cognitive Flexibility

Fewer tests aimed to measure cognitive flexibility aspects of executive functioning. Cocchini et al. (2017) found that musical expertise has minimal impact on dual-task performance, and Clayton et al. (2016) concluded that musician and non-musician groups did not differ significantly. For Slevc et al. (2016), higher levels of musical ability predicted somewhat worse performance, and suggests that their higher performance inhibitory control could make it more difficult to flexibly shift between tasks. Zuk et al. (2014) report a positive relation between musical training and cognitive flexibility. Contrary to Cocchini et al. (2017), Moradzadeh et al. (2015) claim that musicians have better dual-task and task switching performance.

Cognitive flexibility was more difficult to uniformly examine due to the several ways it was described in the papers, a difficulty also noticed by Dajani and Uddin (2015) in their article on the subject. The tests employed looked into fluency (Clayton et al., 2016; Zuk et

al., 2014), dual-task (Cocchini et al., 2017; Moradzadeh et al., 2015), and task-switching (Moradzadeh et al., 2015; Slevc et al., 2016). This leads to reason that first the construct must be consolidated before making significant advances in understanding if and how it is related to musical training.

Limitations

The main caveat mentioned in these articles is that only longitudinal training studies could address causality, therefore they only discuss correlation (Amer et al., 2013; Clayton et al., 2016; Franklin et al., 2008; George & Coch., 2011; Hansen et al., 2013; Jentzsch et al., 2014; Moradzadeh et al., 2015; Moussard et al., 2016; Pallesen et al., 2010; Rodrigues et al., 2013; Schroeder et al., 2016; Slater et al., 2017; Slevc et al., 2016). Only four studies did not mention limitations (Cocchini et al., 2017; Moreno et al., 2014; Oeschlin et al., 2013; Talamini et al., 2016). Some reported failing to check the socioeconomic status of their participants, a measure that affects executive functions (Amer et al., 2013; Bialystok & Depape, 2009; Schroeder et al., 2016).

Other afterthoughts mentioned were: not having checked for physical effort associated with regular practice, since this and pleasure of playing with others could have enhanced executive function (Amer et al., 2013); overt timber perception should have been measured (Kaganovich et al., 2013); some strategy should have been in place to avoid possible bias or niche picking (Moussard et al., 2016); and subjective measures of musical proficiency could have masked true results (Schroeder et al., 2016).

Even though studies mentioned the problems with causality, some argued that it could be inferred. According to Franklin et al. (2008) and Schroeder et al. (2016), since the study provided a good match between musicians and non-musicians on at least gross measures of cognitive skill, it would be odd to find that only measures of executive function were

enhanced on participants that are predisposed to musical ability. Pallesen et al. (2010) thought it reasonable to assume that it would be musical skill rather than cognition the primary determinant in musicians' choice of career. For Slevc et al. (2016), it would be improbable not to exist a causal relationship between musicianship and enhanced executive function, since musicians performed better selectively to working memory updating and not to inhibition or switching performance. Besides the belief that causality could be inferred, all authors recognized the need for longitudinal studies to further research in this field.

Conclusion

This literature review considered 20 articles that researched the effect of musical training on executive functions. These papers point to a relationship between musical training and enhanced executive function performance that surpass the musical domain. To explore this, researchers used several tests that not only considered different categories of executive function, but also if it was a visual or auditory experience.

Unlike Benz, Sellaro, Hommel, and Colzato (2016), this literature review focused solely on executive functions, but also found that making music is positively related to enhanced cognitive performance, including that of older adults. Even though music is suggested as an intervention in enhancing cognition and counteracting the effects of deterioration due to aging, it is not clear as to how much and what intensity of musical training is needed to have a significant effect.

Another issue to be considered is the multitude of tests and constructs used under the umbrella term executive functions, and how this can make it more difficult to reach a consensus as to the effect of musical training on executive functions. In sum, it was found

that musical training tends to be positively related to enhanced executive function performance, but causality still needs to be addressed by longitudinal studies.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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Table 1.
Selected articles, what aspect of executive functioning was studied, with what task and outcome.

Article	Measured Executive Function	Behavioral Task	Task Outcome
Amer et al., 2013	Inhibitory control; working memory	Auditory Stroop task; Simon task; visuospatial span task; go/no-go paradigm; reading with distraction	Sustained music training or involvement is associated with improved aspects of cognitive functioning in older adults
Bialystok & Depape, 2009	Inhibitory control	Auditory Stroop task; Simon task	Extended musical experience enhances executive control
Clayton et al., 2016	Cognitive flexibility, inhibitory control, auditory working memory	Digit span backwards subtest of WAIS-IV; color-word interference subtest of DKEFS; design fluency subtest of the DKEFS	Musicians performed significantly better in the spatial hearing task and auditory working memory.
Cocchini et al., 2017	Dual task performance	Visual pattern test; music recognition task	Musical expertise has minimal impact on dual task performance
Franklin et al., 2006	Verbal working memory	Reading span; operation span	Musical training may influence verbal working memory
George & Coch, 2011	Working memory	Digits backward; letters backward	Long term music training is associated with improvements in working memory, in both auditory and visual domains
Hansen et al., 2013	Working memory	WAIS-III digit span and spatial span	There is an association between musical ability and enhancement of verbal WM storage capacity
Jentzsch et al., 2014	Conflict and post error adjustment	Auditory Stroop task; Simon task	The amount of musical practice was positively associated with response speed and better engagement of cognitive control processes.

Kaganovich et al., 2013	Complex sound encoding and inhibitory control	Auditory distraction paradigm	Musicians were overall more accurate at the temporal discrimination task and tended to be distracted less by irrelevant timbre change
Moradzadeh et al., 2015	Task switching and dual task performance	Quantity/identity task; Krantz paradigm	Long-term musical training is associated with advantages in task-switching ability and dual-task performance.
Moreno et al., 2014	Inhibitory control	Go/no-go paradigm	Musicians perhaps experience a lesser degree of conflict that require less subsequent inhibitory control to perform the task.
Moussard et al., 2016	Inhibitory control	Go/no-go paradigm	Music practice may have conferred na executive control advantage for musicians in later life
Oechslin et al., 2013	Working memory	Visual n-back letter task	Musicians showed an advantage in visual working memory
Pallesen et al., 2010	Working memory	Auditory n-back task	Auditory working memory is enhanced in musicians
Rodrigues et al., 2013	Inhibitory control	neuropsychological tests constructed by the authors	Long-term musical training may improve different forms of visual attention ability
Schroeder et al., 2016	Interference suppression	Simon Task	Enhanced interference suppression in musicians
Slater et al., 2017	Inhibitory control	Integrated visual and auditory plus continuous performance test	Percussionists outperformed the non-percussionists on inhibitory control
Slevc et al., 2016	Inhibitory control; updating; switching	Auditory Stroop task; Simon arrows task; n-back; auditory and visual switching tasks	Musical ability is associated (perhaps uniquely) with working memory updating abilities.
Talamini et al., 2016	Working memory	Digit span test	General advantage of musicians over non-musicians in verbal working memory tasks
Zuk et al., 2014	Cognitive flexibility; inhibitory control; verbal fluency; working memory	Trail making; verbal fluency; color word inference; design fluency - all subtests of the DKEFS	Musicians showed enhanced performance on measures of cognitive flexibility, working memory, and verbal fluency

The Effects of Music Training on Inhibitory Control and Working Memory

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Abstract

Executive functions are cognitive processes necessary to regulate and control behavior and can be divided into three cores: inhibitory control, working memory, and cognitive flexibility. Inhibitory control and working memory need each other to occur and can be considered the basis of executive functions, since cognitive flexibility builds on them both. These functions' performances can be enhanced through training, even though the training does not seem directly related to these functions. One activity said to improve executive function is musical practice. This research aimed to investigate a possible relationship of musical practice to inhibitory control and working memory. For this, 87 students from a teaching college were recruited and separated into four groups: musician seniors, musician freshmen, non-musician seniors, and non-musician freshmen. It was seen that musical practice in the context of this study was related to better performance of inhibitory control, but not of working memory. Only musician seniors showed improvements, not musician freshmen. We conclude that musical training leads to some cognitive benefits beyond the musical domain and that longitudinal studies are needed to assess causality.

Keywords: executive functions; musical training; neuroplasticity

Executive functions are a set of cognitive processes that are necessary to regulate and control behavior (Clayton et al., 2016; Diamond, 2013, 2014; Slevc, Davey, Buschkuehl, & Jaeggi, 2016; Zuk, Benjamin, Kenyon, & Gaab, 2014). Because of executive functions, humans have the ability to concentrate, to go against instincts when these are ill advised, to flexibly adjust to new information (Diamond, 2014), to execute plans (Jentzsch, Mkrtchian, & Kansal, 2014; Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014), solve problems (Dumke, 2017), form analogies, obey social rules, multitask (Grafman & Litvian, 1999), and perform several other actions.

There are three closely related, but separable core executive functions: inhibitory control, working memory, and cognitive flexibility (Diamond, 2013; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Slevc et al, 2016). Inhibition is the ability to control attention, behavior and thoughts (Slevc et al., 2016). Because of it, competing inputs or actions can be suppressed (Slater, Ashley, Tierney, & Kraus, 2017). Working memory allows one to hold and manipulate information in the mind that is no longer perceptually present (Diamond, 2014; Dumke, 2017; George & Coch, 2011). These two cores support each other and cooccur (Diamond, 2013).

Cognitive flexibility is understood to be the capacity to switch between mental processes to better adjust and respond to the changing task demands (Diamond, 2013, 2014; Moradzadeh, Blumenthal, & Wiseheart, 2015; Slevc et al., 2016; Zuk et al., 2014). It builds on the other two functions, in the sense that inhibition is necessary to deactivate a previous perspective and working memory to load in a new one (Diamond, 2013).

The performance of these functions can be improved by skill training and experience, which do not have to necessarily target executive functions (Moradzadeh et al., 2015; Moreno et al., 2014). As displayed by Millner, Jaroszewski, Chamarthi, and Pizzagalli (2012), even brief training can improve cognitive control and transfer to a similar but

untrained task. One experience that researchers consider is musical training, since it requires hours of practice and involves skills associated with executive functions, such as attention (Duke, Cash, & Allen, 2011), monitoring, switching, and updating (Bialystok & Depape, 2009; Moradzadeh et al., 2015).

Literature suggests enhanced inhibitory control (Jentzsch et al., 2014; Kaganovich et al., 2013; Moussard, Bermudez, Alain, Tays, & Moreno, 2016; Rodrigues, Loureiro, & Caramelli, 2013; Schroeder, Marian, Shook, & Bartolotti, 2016) and working memory (Amer, Kalender, Hasher, Trehub, & Wong, 2013; George & Coch, 2011; Pallesen et al., 2010; Slevc et al., 2016; Zuk et al., 2014) in musicians compared to non-musicians. Recently, few researchers have assessed the influence of musical training on aspects of cognitive flexibility, and even less reported a positive correlation (Moradzadeh et al., 2015; Zuk et al., 2014).

Little is known as to how much musical training is necessary to impact executive functions. The aforementioned research had either professional, formally trained, or almost lifelong musicians as participants that started practicing at an early age. Only Jentzsch et al. (2014) created a scale to compare beginner musicians to more seasoned ones. Other authors attempted to create a scale of musical ability by self-report (Franklin et al., 2008; Moradzadeh et al., 2015) or a combination of music tests and self-report (Slevc et al., 2016).

To better understand the effect of musical training in executive function, it is also necessary to investigate if a smaller amount and less intense practice could also lead to enhancements. It is not clear if these musical advantages will be limited to the auditory modality, since musical performance gives auditory feedback (Carey et al., 2015; Hansen, Wallentin, & Vuust, 2013) or if it will relate to non-auditory executive function tasks as well (Bialystok & Depape, 2009; Oechslin, Van De Ville, Lazeyras, Hauert, & James, 2013).

To accomplish this, students from a teaching college in Brazil were recruited to perform auditory and visual tasks: the musician group was studying to become music teachers, the non-musician group was studying to become physics, chemistry, or computing teachers. To assess if more study could yield more benefits, musician freshmen were compared to musician seniors, non-musicians were also separated into freshmen and senior groups for control purposes.

It was expected that musicians in general would outperform non-musicians, and that senior musicians would outperform the other three groups, perhaps because they experienced more structured and more intense musical study.

Method

Participants

There were 87 participants (42.5% women), all students at the Instituto Federal do Sertão Pernambucano in Brazil, ranging from 18 to 55 years of age ($M = 26.24$, $SD = 8.37$). Musicians consisted of 19 freshmen and 17 seniors enrolled in an undergraduate course to become music teachers, and reported playing at least one of 14 instruments (guitar, violin, cello, electric guitar, trumpet, electric keyboard, organ, drums, euphonium, saxophone, clarinet, trombone, electric organ, and piano). Non-musicians were 28 freshmen and 23 seniors enrolled in undergraduate courses to become teachers in physics, chemistry, and computing. All non-musicians reported having minimal (less than 2 months) to no musical training. Volunteers provided written informed consent to participate in the study, and all experimental protocols were reviewed and approved by a local ethics committee.

Using an ANOVA (Tukey post hoc), it was verified that average age per group was significantly different for the musician seniors ($M = 35.24$, $SD = 9.74$) when compared to

musician freshmen (M = 26.74, SD = 9.20), to non-musician seniors (M = 24.96, SD = 4.00), and to non-musician freshmen (M = 21.50, SD = 4.64) [$F(3,83) = 14.25$; $p < .001$]. No significant differences were found when comparing the other three groups to each other. 20 participants (8 musicians) reported playing over an hour of videogame per week. All participants reported being in good health and there were no significant differences across groups as to socioeconomic status. 7 participants (4 musicians) reported having already graduated from another course. Only 3 participants (2 musicians) professed being fluent in a second language.

The freshman musicians reported having had an average of 11.89 years of music study, and the musician seniors an average of 16.76, not necessarily formal. The reported average hours of daily study were 2.62 and 2.90, respectively. There was a positive correlation between age and years of practice [$r = .703$; $p < .001$].

Instead of measuring cognitive abilities, the Brazilian standardized college entrance test (Enem) scores were taken into consideration. This exam aims to prioritize evaluating students' reasoning skills instead of content memorization (Brasil, 2009). Since the average score to get into each course was similar, it was inferred that the groups would not differ enough to affect executive function measures.

Procedure

Participants completed a questionnaire detailing their age, gender, socioeconomic status, total years of education, language use, general health, and music experience. Musicians specified their primary instrument, the number of weekly hours they spend practicing, and the amount of years they have been playing their instrument. Three computerized tests made available by Stoet (2010, 2017) were adapted to Portuguese and used, two assessing inhibitory control and one working memory.

Auditory Stroop task. The applied auditory Stroop task was a measure of auditory inhibition control and an adaptation of Hamers and Lambert's (1972) task. Participants heard in Portuguese, through headphones, the words "man" (*homem*) or "woman" (*mulher*) and had to indicate whether the voice heard was that of a man or woman by pressing either the "H" key or "M" key. The stimuli were randomized and across trials had a mean of 50% display of each condition. They received immediate feedback as to their answer being correct or not and had 2s to respond to each of the 96 trials. Reaction time and response accuracy were recorded, and error trials were excluded from the response time analysis. Responses faster than 250ms were also excluded. The Stroop Effect is measured by subtracting the reaction time of congruent trials (woman says "woman", man says "man") from the incongruent trials (woman says "man", man says "woman").

Visual Simon task. This task is a measure of visual inhibitory control and was adapted from Simon and Rudell (1967). Participants were required to answer if the word that appeared on a computer screen was "left" or "right", no matter if the word appeared on the left or right side of the screen. On some trials the correct response key was on the same side as the stimulus (congruent condition), on others it was not (incongruent condition). This was randomized and across trials had a mean of 50% display of each condition. Each of the 96 trials began with a 250ms fixation cross at the center of the screen, followed by the word stimulus displayed until the response occurred or 2s had elapsed. Just as the Stroop task reaction time and response accuracy were recorded, error trials and responses faster than 250ms were excluded from the response time analysis. The Simon Effect is the increase in response time needed for incongruent trials, and therefore calculated by subtracting the average reaction time in congruent trials from the incongruent average.

Visual n-back letter task. A sequence of letters was presented on a computer screen, one at a time for only 2s. Participants had to answer if they had seen the same letter three

appearances ago by pressing the “M” key, if not, they were to press the “N” key. This activity was used to assess working memory, since the letters had to be continuously memorized and compared. Immediate feedback was given so that participants could know if they answered correctly or not to each of the 60 appearances. An n-back score was created from the results by subtracting undetected n-back items from correctly identified n-back items.

Data analysis

To investigate group differences on task performance, one-way ANOVAs and Tukey post hocs were conducted regarding response times, accuracy, Simon Effect, Stroop Effect, and n-back score. The between group factor was: being musician or non-musician, being freshman or senior. Correlations between the performance of musicians in tests, age, years of music study and weekly study hours were performed using Pearson’s correlation test.

Accuracy is shown in percentage, using the amount of correct trials in relation to the total amount of trials of each individual’s test.

Since groups had significantly different ages, initially one-way ANCOVAs were conducted to determine group differences regarding the variables mentioned above controlling for age. However, it was seen that age was not a significant covariate.

The significance level was set to 5% ($p < 0.05$) for all tests. Statistics were computed using IBM SPSS Statistics, version 21.

Results

Inhibitory Control

Two tests were administered to assess inhibitory control. Since musicianship relies heavily on auditory input, it was considered interesting to also evaluate inhibitory control using an auditory version of the Stroop test.

Auditory Stroop. The auditory Stroop test was designed to measure auditory inhibition control and provides two types of data: accuracy and response time. No significant correlation was found between these variables, years of study, and hours of weekly practice. However, age showed a significant positive weak correlation with accuracy [$r = .253$; $p = .018$].

The four groups: musician seniors or freshmen and non-musician seniors or freshmen, showed no significant differences regarding Stroop accuracy. The mean response times for congruent and incongruent trials showed no difference between these groups. For measuring the Stroop Effect, the mean response time in congruent trials (1,016.80 ms) was subtracted by that of incongruent trials (1,065.30 ms). Musician seniors (20.49 ms) had a significantly smaller Stroop Effect [$F(3,83) = 3.43$; $p = .021$, $\eta_p^2 = .110$] than non-musician seniors (84.21 ms), as shown in Figure 1.

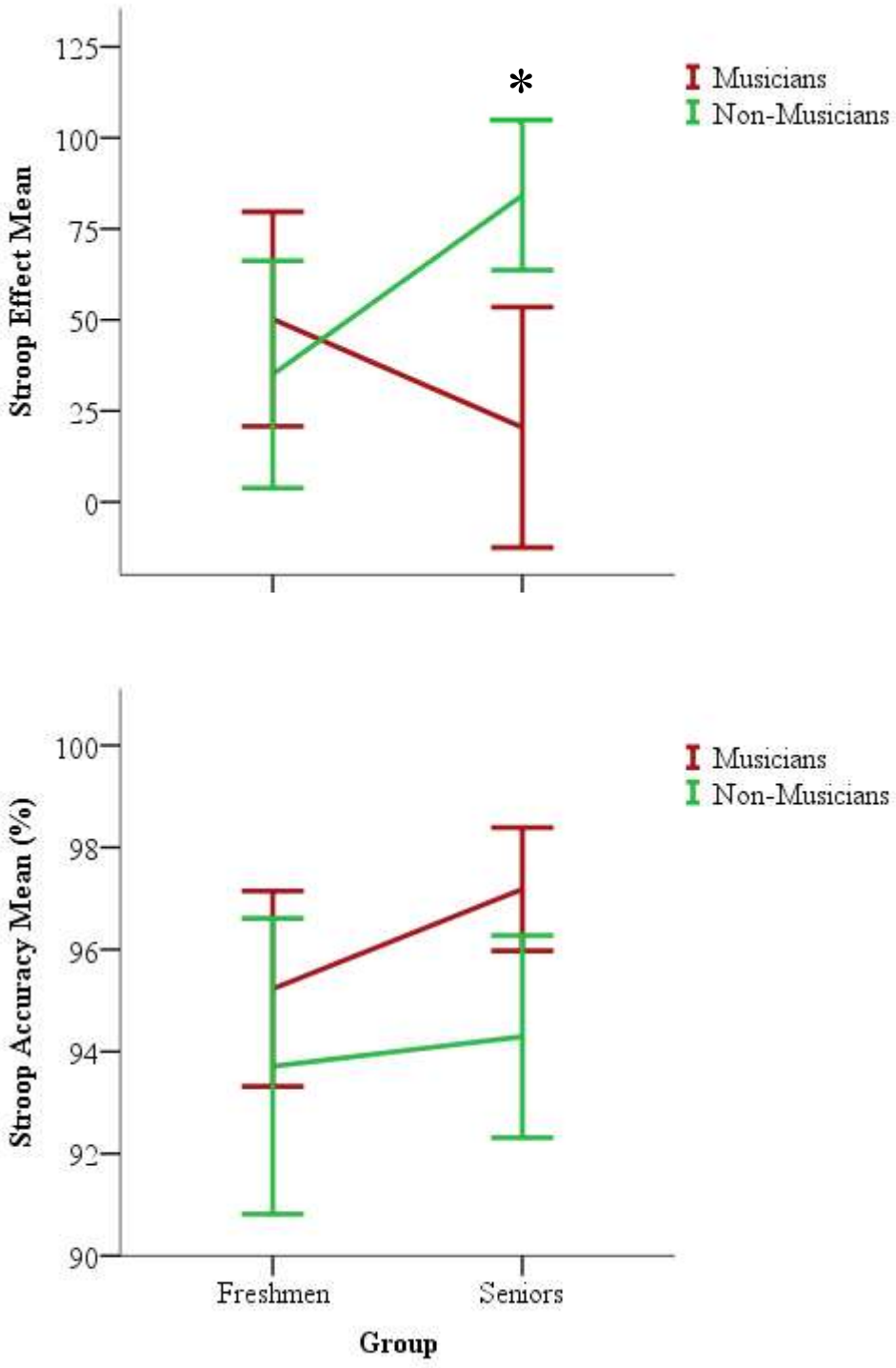

Figure 1. Musician seniors showed a significantly smaller Stroop Effect than non-musician seniors. Means and standard errors of Stroop Effect and Stroop accuracy for freshmen and seniors are shown. The red line represents musicians and the green line represents non-musicians. *Represents a significant difference between musician seniors and non-musician seniors ($p<0.05$). No significant difference was found for Stroop accuracy.

Simon task. The Simon task sought to measure visual inhibitory control. Just as the auditory Stroop, it provided data as to accuracy and response time, the latter transformed into a measure of Simon Effect. No significant correlation was found between these variables, years of study, and hours of weekly practice.

Overall mean accuracy rate was 96.18% and showed significant differences among some groups. Musician seniors (97.67%) and non-musician seniors (97.06%) had a significantly better [$F(3,83) = 4.34$; $p = .007$, $\eta_p^2 = .135$] accuracy than non-musician freshmen (94.94%) but no difference was seen for musician freshmen (95.61%), as shown in Figure 2. Age showed a positive correlation with accuracy [$r = .303$; $p = .004$], meaning that the older the participant, the more likely they were to have shown better accuracy on the Simon task. It is important to note that musician seniors were significantly older than participants of other groups and that age and years of practice were positively and significantly correlated.

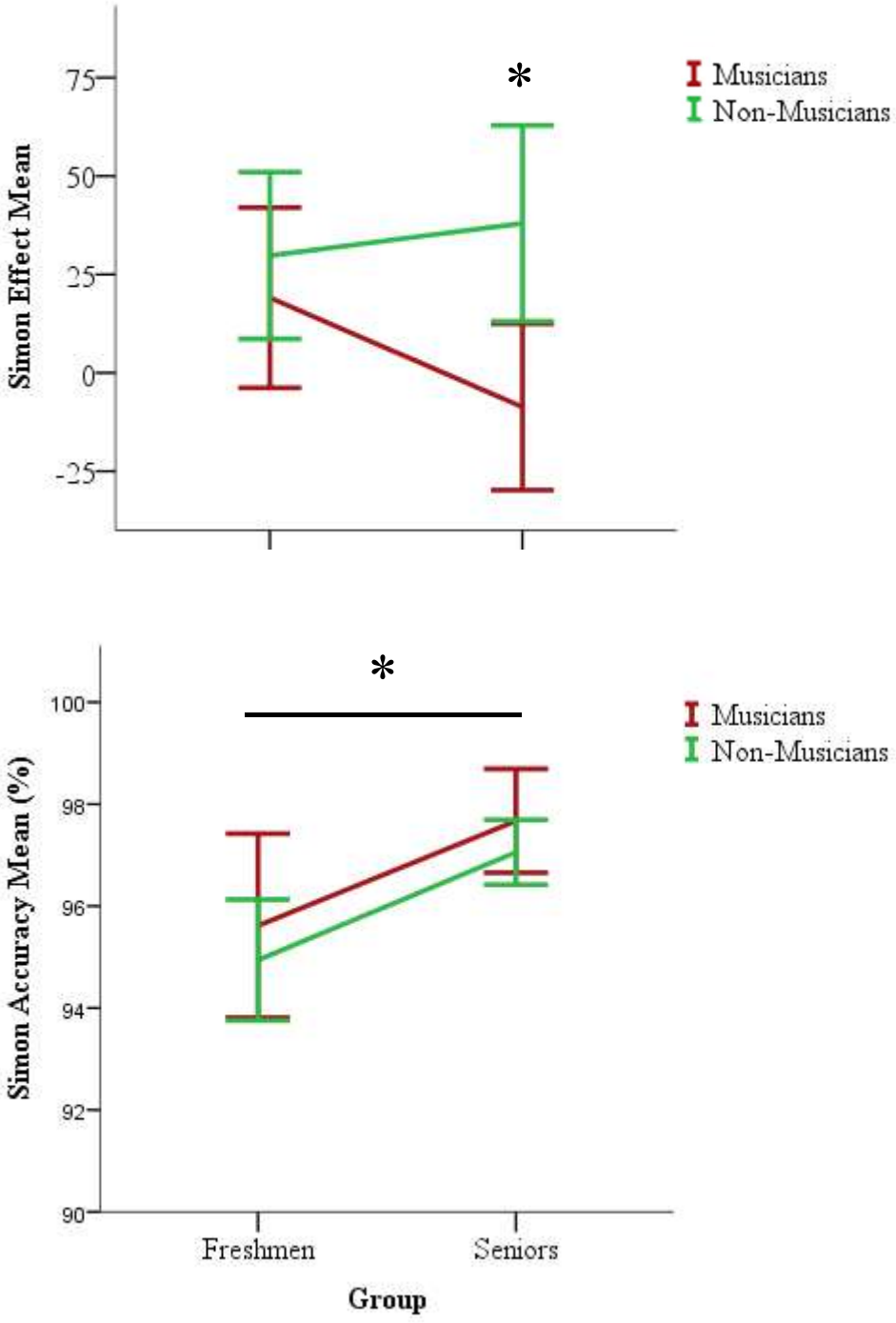

Figure 2. Musicians seniors perform better than non-musician seniors on a Simon task. Means and standard errors of Simon Effect and Simon accuracy for freshmen and seniors are shown. The red line represents musicians and the green line represents non-musicians. *Musician seniors had a significantly smaller Simon Effect than non-musician seniors ($p<0.05$). Musician seniors and non-musician seniors had a significantly higher accuracy ($p<0.05$) than non-musician freshmen.

The mean response time for congruent and incongruent trials yielded no significant difference between the four groups. The mean response time for all participants on congruent trials (697.02 ms) was smaller than on incongruent trials (742.03 ms). A Tukey post hoc revealed that musician seniors (-8.66 ms) had a significantly better Simon Effect [$F(3,83) = 2.76$; $p = .048$, $\eta_p^2 = .091$] than non-musician seniors (37.98 ms), but not when compared to musician freshmen (19.08 ms) nor non-musician freshmen (29.81 ms) (see Figure 2).

Working Memory

N-back. The n-back task was used to assess working memory, having as output response time, correctly identified n-back items, false alarms, misses, and an n-back score created by subtracting misses from correctly identified n-back items. The data for one of the participants had to be discarded since there was no response throughout the test. The data for 8 participants were not used in the n-back score due to technical error (1 music freshman, 2 music seniors, 2 non-musician freshmen, and 3 non-musician seniors).

The devised n-back score and response times were evaluated, and no significant differences were found between the four groups. A significant positive correlation was found between years of practice and n-back response time [$r = .377$; $p = .025$], also between age and response time [$r = .332$; $p = .002$]. In other words, the more years of practice a participant had, or the older they were, the more likely to have a larger response time.

Discussion

To sum up differences of performance, musician seniors had a better Stroop and Simon Effect than non-musician seniors and were more accurate in the Simon task than non-

musician freshmen and non-musician seniors. The latter were more accurate than non-musician freshmen. No differences were found for the working memory task.

It was seen that musical practice in the context of this study led to cognitive benefits, but not as seen in research in which musicians were professionals and had logged several hours of daily music study for at least half their lives. Compared to other studies, it seems that the amount of musical practice is one of the strongest factors in musical expertise (Bialystok & Depape, 2009; Ericsson, Krampe, & Tesch-Roemer, 1993; Jaencke, 2009; Moradzadeh et al., 2015).

In the Ericsson et al. (1993) study, it was reported that while professional pianists and violinists had practiced 7,500 hours before reaching the age of 18, music teachers could only account for 3,500. In this study, the mean reported years of study was 11.89 and current daily hours was 2.62 for musician freshmen and 16.76 and 2.90 for musician seniors. The fact that 14,85 was the average age for when the musician freshmen started learning an instrument and 18.76 for seniors was considered ideal for this study, since it could have indicated that they have not practiced music as much as in the research mentioned in the beginning of this paper. Participants in other research were either professional, formally trained, or almost lifelong musicians as participants that started practicing at an early age, leaving question as to what impact would less training have on executive functions.

Stroop Effect was significantly smaller, therefore better, for musician seniors compared to non-musician seniors but showed no advantages for musician freshmen. Even though for Slevc et al. (2016) this was not the case, Amer et al. (2013), Bialystok and Depape (2009), and Slater et al. (2017) demonstrated enhanced auditory inhibitory control for musicians as one group, making no distinctions between who had less or more experience.

Musician seniors showed, overall, the best performance in visual inhibitory task, especially when compared with non-musician seniors. It is necessary to be aware of

congruent facilitation that happens in the Simon test, which is the reduction of interference after the conflict in the previous trial (Jentzsch et al., 2014; Schroeder et al., 2016). This could reflect a better ability to utilize or worse ability to ignore the irrelevant but informative stimulus location on the previous trial (Schroeder et al., 2016) and could explain why there were negative values in many senior musicians' Simon Effects.

Overall tendency for inhibitory control is that musician and non-musician freshmen showed very similar performance, which improved for musician seniors and worsened for non-musician seniors no matter if the stimuli were visual or auditory. It is important to note that age showed a positive correlation to Stroop and Simon accuracy, and that musician seniors were a significantly older group. This could lead to wonder if accuracy was better due to age, or if it was better due to being a musician senior. However, ANCOVAs on Stroop and Simon accuracy ruled out age as a significant covariate.

Studies point to older participants having poorer inhibition performance when compared to younger participants (Nielson, Langenecker, & Garavan, 2002; Sweeney, Rosano, Berman, & Luna, 2001; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). In this study, senior musicians were significantly older and yet had better inhibitory performance. Because of this, it is possible to infer that their better performance is due to musical training and not older age. It could also be considered that music training attenuates age related decline in inhibitory control.

One reason that could have rendered similar inhibitory results for groups was the low difficulty of the tasks. According to Moreno et al. (2014), while very easy tasks may not show behavioral differences, in the neural level different event related potential patterns emerge. This could also be the case and points to the importance of investigating neural correlates.

Although the Stroop Effect and the Simon Effect seemed to have a similar pattern across groups, they showed no correlation. This is foreseeable, for although they both measure inhibitory control, it would seem that individual response patterns differ for both (Pratte & Rouder, 2010). It could be argued that, despite being a measure of inhibitory control, they both could be attributable to different mechanisms. This difference is due to the Stroop test's conflict being stimulus based (difference between word said and voice in which it is said) and the Simon's being response based (position of answer key in relation with stimulus on screen) (Scerrati, Lugli, Nicoletti & Umiltà, 2017).

Even though the main consensus in literature is improved working memory for musicians, none was seen here (Amer et al., 2013; Clayton et al., 2016; Hansen et al., 2013; Oechslin et al., 2013; Pallesen et al., 2010; Slevc et al., 2016; Talamini, Carretti, & Grassi, 2016; Zuk et al., 2014). It is wondered if the lack of training trials could have made, at least the first trials, more about understanding what was asked instead of assessing working memory. It could also be argued that there was not enough musical practice to render advantages to this cognitive function.

Another finding was that musician seniors had slower response times in the working memory task and were significantly older than other groups. Bialystok et al. (2004) and Sweeney et al. (2001) found a reduction in working memory performance in older participants. They concluded that this reduction could be lessened by musical training, which was not the case for this research. Enhancements in working memory could be somewhat more resistant than in inhibitory control.

More studies are necessary to address the direction of causality, since it is not certain if group differences are due to musical training or other factors, such as personality or motivation that led people to persistently study music. Other studies report this same issue

but argue that causality could be inferred since participants were cognitively matched (Franklin et al, 2008; Schroeder et al, 2016).

Conclusion

It could be argued that musical training leads to some cognitive benefits beyond the musical domain. However, the extent of these benefits could be related to characteristics of the musical training, leading to significant enhancements seen for musician seniors but not for musician freshmen, even though they showed no significant difference as to time and years of musical practice. To see more enhancements as demonstrated by other research, perhaps it would have been necessary to have participants that are professionals, have more years of formal music study, and practice more daily. This might not be the reality for most who study an instrument, making it important to study those who are not as engaged in practicing as professionals, especially when considering music as some form of intervention.

The main issue that arose in other research, and in this one, is that only longitudinal studies could assess causality. For the future, it would be interesting to accompany participants such as these from the beginning until the end of their college course.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Considerações Finais

A revisão de literatura incluiu 20 artigos que estudaram o efeito de treino musical em funções executivas. Esses estudos apontam para uma relação entre intenso treino musical e performance melhorada em funções executivas que vão além do domínio musical. Embora o treino musical aparenta melhorar cognição, não se pode confirmar causalidade sem o uso de estudos longitudinais. Alguns autores inferem causalidade, porém, pouco se entende de como é esse processo e quanto treino já seria suficiente para se observar efeitos positivos sobre as funções executivas.

O artigo experimental buscou entender a relação entre treino musical, controle inibitório e memória de trabalho em músicos que não tinham extensivas horas de treino, portanto estudou alunos de licenciatura em música. Até o momento não se tem o conhecimento de outro estudo que fez isso. Esse treino foi associado a melhoras cognitivas, mas não tão fortes quanto demonstrado em estudos em que os participantes foram músicos profissionais que tinham estudado por pelo menos metade de sua vida.

Inicialmente se considerou importante analisar os três núcleos de funções executivas, inclusive foi aplicado testes nesse intuito, porém na hora da análise dos dados foi encontrada uma falha no teste aplicado para mensurar flexibilidade cognitiva, o Teste Wisconsin de Classificação de Cartas (WCST). Sendo assim, esse teste foi descartado na escrita final do artigo.

Nesse teste, algumas cartas são apresentadas ao participante com a instrução de serem combinadas utilizando o mouse, porém não é informado o critério que deve ser usado para atingir a combinação correta. Ao final de cada apresentação, é revelado ao participante se ele fez a combinação correta ou não. Com o passar das apresentações, são utilizadas novas regras, cabe ao participante perceber isso e se adaptar. O correto para o WCST é que a mudança de regra ocorra, sem conhecimento do participante, a cada dez acertos. O que

ocorreu no teste aplicado foi que essa mudança ocorreu a cada dez apresentações, independente de erro ou acerto. Acreditou-se que isso tenha interferido nos resultados ao ponto de invalidar o teste.

Ficou o aprendizado de ter mais cuidado na programação e aplicação dos testes, e a importância de se ter mais de um teste avaliando o mesmo construto, como foi o caso para controle inibitório (avaliado através do Teste Stroop e do Teste Simon). Considerando a quantidade de pessoas que tocam algum instrumento mesmo não sendo profissionais, foi importante poder constatar que houve melhoras cognitivas em uma amostra de músicos que não se encaixavam no perfil de profissionais como nos estudos já realizados.

Para o futuro, seria interessante poder realizar um estudo longitudinal com os alunos de licenciatura em música ao longo do curso, ou outra população de músicos que não praticam de forma tão intensa. Além disso, sugere-se a importância de incluir um grupo de participantes com características semelhantes aos que fizeram parte desse estudo, ou seja, de músicos que não tenham extensivas horas de treino, em projetos que objetivam demonstrar os efeitos do treino musical em funções executivas.

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