ABSTRACT

Title of Thesis: AN EXAMINATION OF THE RELATIONSHIP BETWEEN PRIOR MUSICAL SOPHISTICATION AND LANGUAGE OUTCOMES IN PEOPLE WITH APHASIA

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Research suggests there is a neural relationship between music and language, such that higher levels of musical sophistication may be positively correlated with a person's linguistic and cognitive functioning. Though most of the research has focused on neurotypical individuals, the implication is that musical sophistication could benefit a person with a neurological impairment such as aphasia, perhaps by preserving linguistic abilities after the person has sustained a stroke. The study outlined here seeks to replicate and expand on the findings of Faroqi-Shah et al. (in prep) by looking at musical sophistication's influence on aphasia severity as well as on specific language and cognitive domains (e.g., syntax, auditory processing, memory, and cognitive control). Knowing what specific domains of language or cognition are involved could help

researchers better understand the neural location of musical and linguistic resources as well as the behavioral benefit of increased reserve in a neurologically impaired individual.

AN EXAMINATION OF THE RELATIONSHIP BETWEEN PRIOR MUSICAL SOPHISTICATION AND LANGUAGE OUTCOMES IN PEOPLE WITH APHASIA

by

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Table of Contents

Introduction

Lifestyle factors are external factors in a person's environment that can be modified or controlled. Examples of lifestyle factors include: socioeconomic status (SES), education, bilingualism, engagement in cognitive activities, physical exercise, and musical training. These are often discussed in scientific research in relation to their association with a person's health or quality-of-life. For instance, higher education, engagement in cognitive activities, physical activity, and musical training have been associated with better performance on cognitive domains such as episodic memory, working memory, semantic memory, perceptual speed, visuospatial abilities, executive control processes, and motor skill learning (Jefferson et al., 2011; Kramer & Erickson, 2007; Moreno et al., 2011; Ratey & Loehr, 2011; Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen, 2012; Wilson, Barnes, & Bennett, 2003). Lifestyle factors such as education, SES, and bilingualism have also been associated with less severe impairment in individuals with cognitive decline and cerebrovascular damage (Alladi et al., 2015; Bialystok, Craik, & Freedman, 2007; González-Fernández et al., 2011). The present study focuses on the relationship between musical sophistication (a lifestyle factor) and language outcomes in people with aphasia (PWA), which is a language impairment resulting from left-hemisphere cerebrovascular damage. Also, given that several lifestyle factors have been associated with positive cognitive or linguistic outcomes and that any individual may be engaged in multiple lifestyle enhancers, it will be important to tease apart possible correlations with musical sophistication versus those of other factors.

One way lifestyle factors promote change is through *neural plasticity*, which is defined as a person's ability to adapt to environmental stimuli, recover from injury or illness, or learn new information (Johnston, 2009) by generating neuronal or synaptic growth to re-organize previously established pathways and connections. In the upcoming sections, the following information will be presented and examined: the definitions of key terms, including musical sophistication; the neuroplastic changes associated with musical sophistication and training; theoretical perspectives and empirical findings on the association between music and language in healthy individuals and in PWA; the rationale and research questions (RQs) for the current study; and, finally, the methods, results, and discussion related to the current study.

Defining Musical Sophistication and Other Key Terms

There are a number of terms used to refer to a person's relationship with or exposure to music, including musical sophistication, expertise, training, aptitude, ability, skill, or potential. In this paper, only three terms will be used regularly. *Musical training* will be used when discussing background literature that equates training (i.e., years of lessons or intensity of practice) with musical skill or status (i.e., musicians vs. non-musicians). *Musical aptitude* will be used when discussing a person's natural musical ability (Swaminathan, Schellenberg, & Khalil, 2017), or their innate talents as they relate to music and regardless of training. Finally, *musical sophistication* will be the main term used in this paper and will be assessed for the participants in this study using questionnaires (see Methods section for details). Müllensiefen, Gingras, Musil, and Stewart (2014) explain that musical sophistication can be used to describe musicians and non-musicians alike since it is characterized by "a) higher frequencies of exerting musical skills or behaviors, b) greater ease, accuracy or effect of musical behaviors when executed, and c) a greater and more varied repertoire of musical behavior patterns" (p. 2).

Musical sophistication *can* include musical training and knowledge of musical theory, but Müllensiefen et al. (2014) also assert that a non-musician or a musician who is less proficient can still develop certain implicit skills—such as knowledge of musical structure or enhanced processing abilities—that lead to higher levels of musical sophistication through listening, emotions, general appreciation, and communication about music.

Neural Plasticity Associated with Musical Sophistication

Numerous studies in the past decade have discussed potential neuroplastic changes associated with musical sophistication and training. These are presented below, along with implications for the current study. Reported positive correlations with musical training, in particular, include greater efficiency in neural connections (Amer, Kalender, Hasher, Trehub, & Wong, 2013; Stern, 2009; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013) and greater activity in neural regions that subserve music and language (Kunert, Willems, Casasanto, Patel, & Hagoort, 2015; LaCroix, Diaz, & Rogalsky, 2015). Further, musicians who played string instruments since childhood had a more expansive cortical representation for their left-hand digits compared to their right hand and non-musicians, with the amount of change in the representation being correlated with the age the string musician began training (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). On the other hand, some studies suggest that the differences are due to something other than musical training, such as confounding variables (e.g., placebo effects or lack of random allocation of participants; Sala & Gobet, 2017) or musical aptitude (Swaminathan et al., 2017).

It has been proposed that the neuroplastic changes that are positively associated with music are the result of brain reserve, which refers to biological or genetic structural differences (such as increased brain size, number of synapses, or gray matter volume), or cognitive reserve, which refers to functional differences (such as the brain's ability to recruit alternative networks or process stimuli more efficiently) (Fauvel, Groussard, Eustache, Desgranges, & Platel, 2013; Jefferson et al., 2011; Stern, 2009). Brain and cognitive reserve could offer an advantage for musicians, in that they might be able to recover more quickly from a central nervous system injury when they have the possibility of cortical reorganization and growth (Elbert et al., 1995; Omigie & Samson, 2014). The implication for this study is that prior experience with music could be neuroprotective for a person with a neurological impairment such as aphasia, perhaps by mitigating changes in linguistic abilities after the person has sustained a stroke. This mitigation could be afforded by shared neural networks that are used for both music and language (e.g., Patel, 2003), or by a third (cognitive) mechanism that mediates both music and language (Slevc & Okada, 2015). However, before proposing the neuroprotective benefits of musical sophistication for language impairment, it is important to critically examine the empirical evidence for a relationship between music and language.

The Relationship Between Music and Language

Researchers do not all agree on *why* and *how* musical sophistication is associated with language performance, though many agree there is a relationship. In the literature, there seems to be two presiding theories: the same areas of the brain are recruited for features of music and language, either via neural overlap or neural sharing, so music influences language directly (Theory 1), or musical sophistication is related to cognition, which in turn influences language abilities (Theory 2). The first theory is represented by

Patel's (2003) Shared Syntactic Integration Resources Hypothesis (SSIRH), which proposes that the syntactic processing of music and language shares resources in the frontal lobe. Patel posits that language and music both have a hierarchical syntactic structure, such that the discrete elements (e.g., words or musical tones) can be rapidly organized into meaningful sequences (e.g., sentences or chord progressions). He suggests this structural integration is an important part of syntactic processing for both music and language, and he provides the SSIRH as an explanation of how resources are shared yet representations remain neurally distinct. Heffner and Slevc (2015) present another possibility, stating the parallels are actually between music and prosodic structure, which is also hierarchical. They argue that word segmentation, phonetic perception, and prosodic processing can all be influenced by musical training, again supporting the theory of shared resources that lead to improvements in language.

Some neuroimaging studies validate the idea of neural sharing for music and language, showing overlapping activation in the left inferior frontal gyrus in particular (Kunert et al., 2015; LaCroix et al., 2015). Other research, however, seems to support the idea that music and language are neurally distinct. Peretz, Vuvan, Lagrois, and Armony (2015) state that co-activation of brain regions on neuroimaging does not prove neural sharing. They suggest that music and language have adjacent, *distinct* neural networks although their neurons could be interspersed in what they refer to as "hubs" (p. 3), which are highly-connected integration centers in the brain that support efficient signal processing and connectivity. In response, Kunert and Slevc (2015) state that neuroimaging research can be equivocal and suggest the Peretz et al. (2015) review should have included behavioral evidence as well in order to measure functional outcomes. However, even with behavioral research included, outcomes are still conflicting. Two neuropsychological case studies report individuals with brain damage who have deficits in *either* linguistic (Slevc, Faroqi-Shah, Saxena, & Okada, 2016) or musical (Peretz, 1993) structure processing abilities (but not both), indicating neurally distinct regions for music and language. On the other hand, many studies have found improved performance on language assessments relative to prior musical sophistication, which seems to support the idea of overlap or sharing (Anvari, Trainor, Woodside, & Levy, 2002; Forgeard, Winner, Norton, & Schlaug, 2008; Hanna-Pladdy & Gajewski, 2012; Hanna-Pladdy & MacKay, 2011; Schlaug, Norton, Overy, & Winner, 2005). LaCroix et al. (2015) sought to explain this discrepancy by providing a task-dependent hypothesis, proposing that the degree of neural overlap for language and music is dependent on the type of processing required (i.e., what the brain is being asked to do).

This idea by LaCroix et al. (2015) also ties in with Theory 2, which indicates that the association between musical sophistication and language might be indirect, via mediating cognitive mechanisms such as memory (Martin, 2005; Talamini, Altoè, Carretti, & Grassi, 2017) or cognitive control (Novick, Trueswell, & Thompson-Schill, 2005; Pallesen et al., 2010; Slevc & Okada, 2015). For example, if a person has a high level of musical sophistication that leads to increased cognitive reserve in regions that involve memory and cognitive control, then it is possible that language performance might be benefitted if and when tasks recruit those overlapping or shared neural networks.

Much of the behavioral research investigating a *direct* (Theory 1) or *indirect* (Theory 2) relationship between music and language has focused on four main domains:

(1) syntax and (2) auditory processing for Theory 1 and (3) memory and (4) cognitive control for Theory 2. These four commonalities are discussed in further detail in the sections below and are investigated by the research questions of the current study.

Syntax

The research investigating the link between music and syntax is mixed, both in neurotypical individuals and in PWA. One convincing argument of shared processing of musical and linguistic syntax comes from the finding that listeners, regardless of their musical background, are delayed in reading sentences that have garden path ambiguities or syntactic violations when simultaneously presented with musical syntactic violations (Jung, Sontag, Park, & Loui, 2015; Slevc, Rosenberg, & Patel, 2009). The logic is that the increased response time for garden-path sentences when simultaneously presented with harmonically unexpected chords points to a shared pool of limited resources for syntactic processing (see the SSIRH, Patel, 2003; Slevc et al., 2009), rather than to non-competing distinct neural regions. Although there are no reports of interference paradigms with music and language in PWA specifically, two studies failed to find a correlation between performance on musical and linguistic syntactic judgments for that population (Faroqi-Shah, Slevc, Saxena, & Pifer, in prep; Patel, Iversen, Wassenaar, & Hagoort, 2008). In both studies, PWA and neurotypical adults performed two musical and two sentence processing tasks. The tasks either required explicit goodness judgments of music sequences/sentences or examined implicit priming of musical sequences/sentences. Patel et al.’s group of 12 agrammatic PWA showed impaired musical processing, while Faroqi-Shah et al.’s group of 23 PWA (and a subgroup of 12 agrammatic PWA) did not perform differently from neurotypical adults. PWA’s performance on musical and linguistic processing was not significantly correlated in either of the studies. Thus, while there is evidence of shared processing of music and linguistic syntax from interference paradigms in neurotypical adults, the current evidence from PWA does not show a strong association.

Another way to examine the interaction between musical and linguistic syntax is to study the associations between musical sophistication and language performance. In studies with neurotypical individuals, musicians have superior abilities in learning artificial grammar (Brod & Opitz, 2012) and musically trained children have more robust neural responses to linguistic syntax (Jentschke & Koelsch, 2009). In a group of 23 PWA, Faroqi-Shah et al. (in prep) examined the association between a person's musical sophistication score (as measured by the Ollen Musical Sophistication Index [OMSI], Ollen, 2006) and narrative speech. For the narrative speech samples, they obtained the developmental sentence score (DSS), which Lee and Canter (1971) describe as the estimate of a person's ability to form sentences with a high grammatical load. Though DSS is based on how a child acquires syntax developmentally, Thorne and Faroqi-Shah (2016) found it was a reliable indicator of syntactic ability for PWA as well. The results of the Faroqi-Shah et al. study pointed to a correlation between prior musical sophistication (as measured by the OMSI) and the DSS, a syntactic measure. This association lends support to Theory 1, indicating that musical sophistication could influence shared syntactic processing and integration resources that, in turn, might influence language performance in PWA despite a lesion in primary language regions.

Auditory Processing

Auditory processing is another domain that has been used to examine the relationship between music and language, since both require listening to and interpreting sequences over time. Similar to the research on syntax, this is another area where the literature can be somewhat conflicting regarding neural overlap versus sharing. Also, although the available studies include neurotypical individuals with a wide range of musical skill, there is no known study investigating the relationship between music and auditory processing in PWA specifically.

In their neuroimaging study, Herdener et al. (2014) discovered that jazz drummers process rhythm in areas previously associated with language, such as the supramarginal gyrus in the left hemisphere. LaCroix et al. (2015) also found that speech and music have overlapping activity in Broca's area, a region in the inferior frontal gyrus that is associated with aphasia, for some tasks but not others. To help explain the overlap while still allowing for distinct processing regions, they theorized co-activation was task-dependent. Other neuroimaging studies approach the relationship from a different angle, directly investigating the effects of musical training on brain structure using voxel-based morphometry of MRI scans. In their 15-month longitudinal study, Hyde et al. (2009) related behavioral changes to structural neurological changes in children and found that increased performance on musical processing assessments predicted voxel size increases (i.e., increased gray or white matter) in the right primary auditory region, right precentral gyrus, and the corpus callosum. They concluded that the increases were a direct result of keyboard lessons, which could demonstrate that brain differences in musicians are a result of training rather than biological predictors of musical talent or proclivity. In adult musicians, Gaser and Schlaug (2003) noted additional structural changes. They found a linear correlation between musician status (professional, amateur, non-musicians) and gray matter volume in bilateral motor, visual-spatial, and auditory brain regions.

Two studies (Skoe & Kraus, 2012; White-Schwoch et al., 2013) used auditory brainstem responses to measure the long-term timing effects of musical training. Skoe and Kraus (2012) recruited 18–31-year-old participants who began musical training around the age of 9. Results indicated there was a positive correlation between the strength of the response and the existence of musical training. White-Schwoch et al. (2013) found that older adults who had a moderate amount of musical training (4–14 years) before the age of 25 exhibited less severe neural timing delays than those with no training. They explained that timing delays are a typical process of aging, but those people with musical training early in life processed synthesized speech sounds (i.e., the consonant-vowel transition "da") more efficiently in quiet and noise even decades later.

Finally, correlational behavioral studies have found improved auditory discrimination for melodies and rhythm in musicians (Forgeard et al., 2008; Schlaug et al., 2005), demonstrating near transfer changes associated with musical training. *Near transfer* associations[1] refer to those correlations that are seen in related domains (e.g., learning to play the drums vs. developing timing skills), and *far transfer* associations are those correlations that are in seemingly unrelated domains (e.g., learning to play the drums vs. improving literacy skills). For example, Anvari et al. (2002) found that music perception abilities seemed to predict early reading skills, which is a far transfer association. They proposed this is because music perception abilities share some unique auditory analysis skills with reading ability, even when phonological awareness was

[1] These associations are often referred to as *near transfer effects* and *far transfer effects* in the background literature. However, since correlation does not equate to causation, "effects" has been replaced with "associations" throughout this paper.

removed from the equation. Additionally, Schlaug et al. (2005) reasoned, “Phonemic awareness skills may be improved by music training because both music and language processing require the ability to segment streams of sound into small perceptual units” (p. 226). Though this seems logical, Forgeard et al. (2008) and Slater et al. (2014) did not find a significant correlation between musical training and phonemic or phonological awareness in their studies. Also, Schlaug et al. (2005) and Hyde et al. (2009) did not find significant correlations between musical training and auditory analysis tests that measured phonemic awareness, although Schlaug et al. (2005) did mention that they measured a small yet non-significant trend in that direction in their group of 9–11 year olds. A possible explanation for these findings is provided by Kraus and Chandrasekaran (2010), who mentioned that the neural plasticity and increased reserve associated with musical training seems to be dependent on four determinants: age of onset, number of years of continuous training, amount of practice, and aptitude. Based on these determinants, results might differ depending on duration of musical experience, intensity of experience, or even years since experience ceased. This could be why some studies with children (Forgeard et al., 2008; Hyde et al., 2009; Schlaug et al., 2005; Slater et al., 2014) show weaker or non-significant correlations as compared to the studies with adults.

In the current study, the PWA will be adults who may have had a lifetime accumulation of prior musical sophistication, so it is expected that they will show associations between music and auditory processing. However, there is no known research documenting an association between music and auditory comprehension/processing in PWA, so it is possible that the associations seen in neurotypical individuals do not generalize to this population.

To summarize the research indicating a direct relationship between music and language (Theory 1), musical and linguistic syntax might share processing resources that lead to increased cognitive reserve in relevant neural regions. For musical and linguistic auditory processing—neuroimaging, auditory brainstem response, and behavioral studies point to either an overlap in activation, decreased neural timing delays, or increased scores on auditory processing tasks based on musical sophistication and training, respectively. In addition to syntax and auditory processing, positive correlations and far transfer associations have been reported between musical training and the following language domains: vocabulary (Forgeard et al., 2008; Schlaug et al., 2005), naming (Hanna-Pladdy & MacKay, 2011), and phonemic fluency (Hanna-Pladdy & Gajewski, 2012). However, since these areas are not widely discussed in the available literature, they have not been covered at length in this paper. The cognitive domains of memory and cognitive control will be discussed next. These are related to Theory 2, which states that a possible link between music and language is cognition.

Memory

Several studies point to a relationship among music, memory, and language, since musical sophistication has been shown to correlate with memory and since receptive and expressive language involve components of storage, manipulation, and recall (George & Coch, 2011; Hanna-Pladdy & Gajewski, 2012; Ho, Cheung, & Chan, 2003). However, as with other language and cognitive domains, the findings are mixed and there are no known studies specifically investigating musical sophistication, memory, and language in PWA.

George and Coch (2011) provide both behavioral and event-related potential results to show that neurotypical, undergraduate musicians outperformed non-musicians on tasks that measure visual, phonological, and executive memory. Musicians also had shorter latency and higher amplitude P300s, demonstrating faster updating and a larger allocation of neural resources for auditory and visual working memory. Several other behavioral studies report similar results. Musical training has been found to correlate with increases in verbal memory (Hanna-Pladdy & Gajewski, 2012; Ho et al., 2003), working memory (Hanna-Pladdy & Gajewski, 2012; Schellenberg, 2006), and non-verbal memory (Hanna-Pladdy & MacKay, 2011). Schellenberg (2006) also found a positive correlation between music lessons and IQ. The correlations were weaker but still significant for the young adults as compared to children, causing Schellenberg (2006) to note that there might be long-term changes associated with musical training even years after lessons had ended. This could be significant for PWA, if they no longer interact with music or if their exposure or training ceased years prior. For Hanna-Pladdy and MacKay (2011), the difference in performance between three groups (high-activity, low-activity, and non-musicians) did not always reach significance, but the researchers noted there was a linear trend to the relationship between years of musical training and cognitive functioning in older adults. The primary musical sophistication index that will be used in this study (Goldsmiths Musical Sophistication Index [Gold-MSI], Müllensiefen et al., 2014) will address these possibilities, since it asks about years and intensity of training.

There are also behavioral studies that show non-significant outcomes for memory assessments. In her experiment, Rauscher (2002) did not find significant increases on a pictorial memory task for children who received keyboard lessons. Additionally, Ho et al. (2003) failed to find correlations between musical training and visual memory, and Strait, Kraus, Parbery-Clark, and Ashley (2010) did not find differences between musicians and non-musicians on an auditory working memory task (memory for reversed digits).

In PWA, there are no known studies looking at the association between musical sophistication and memory, so the relevant literature primarily investigates the influence of memory on language tasks. In a neuropsychological and neuroimaging study, Martin (2005) noted that brain-damaged individuals often have limited memory spans and recall, which could lead to problems with language comprehension or naming. Martin suggests that this is dependent on the type of task and the specific neurological source of the memory deficit, finding that people with inferior frontal gyrus lesions show impairments in semantic short-term memory (STM)—perhaps as a result of a difficulty inhibiting irrelevant, competing semantic information. Verhaegan, Piertot, and Poncelet (2013) provided case studies that showed two PWA with "word production impairments," which they explain are characterized by "production of paraphasias, circumlocutions, nonresponses, the use of indefinite terms (e.g., 'thing'), abnormally long response latencies, and inappropriate pauses (e.g., in the middle of a sentence)" (p. 546). Based on the participants' performance on short-term memory assessments, the researchers discovered that the patients presented with two different types of STM impairment—phonological vs. lexical–semantic. They suggested that since both are associated with language, both can significantly influence a PWA's language profile after a stroke. This could, in turn, affect performance on language measures, which helps to provide data to show the link between cognition and language. Cognitive control is another cognitive domain that has been described as inherent in some tasks, so this will be addressed next.

Cognitive Control

Cognitive control is often needed in language tasks and refers to a person's ability to shift attention by revising previous interpretations or dampening competing representations in order to prevent/correct errors (Novick et al., 2005). There is no single agreed-upon neural correlate for cognitive control, though several regions have shown activation for cognitive control tasks in neuroimaging studies. These include, among others, the left fronto-temporal-parietal cortex (for propositional spoken language tasks; Geranmayeh, Wise, Mehta, & Leech, 2014), the left inferior frontal gyrus (LaCroix et al., 2015; Novick et al., 2005), and the lateral prefrontal cortex and parietal regions (Pallesen et al., 2010). As suggested previously (LaCroix et al., 2015; Martin, 2005), it seems that the activation is task-dependent and so could benefit various components of language—perhaps even after a person has sustained a stroke. Slevc and Okada (2015) suggest that the shared neural resources for music and language actually have to do with cognitive control. This could explain why some skills are linked in music and language, but not others. They propose that the overlap occurs when the brain is actively processing stimuli, such as encountering an unexpected element or revising a previous interpretation—both situations when cognitive control is needed.

The research surrounding music and cognitive control reports mixed findings and includes neuroimaging data as well as participants' performance on behavioral measures. Neuroimaging studies generally report increased activation for musicians as compared to non-musicians. For example, Pallesen et al. (2010) and Sachs, Kaplan, Der Sarkissian, and Habibi (2017) found that participants with musical training had increased blood oxygenation-level dependent responses, as shown by fMRI, in areas related to cognitive control. However, Sachs et al. and Moussard, Bermudez, Alain, Tays, and Moreno (2016) did not find improvements on behavioral tasks for those with musical training, noting that they performed the same as controls on behavioral measures of task switching, working memory, and response inhibition. To explain the seemingly disparate findings in the Sachs et al. study, the researchers proposed that neuroimaging might help clarify the relationship between music and executive functions (such as cognitive control) in instances where changes are not or cannot be captured by behavioral assessments. Still, there are also behavioral studies that show increased performance on cognitive control measures. Amer et al. (2013) looked at the near and far transfer associations with long-term musical training and found that the professional musicians had stronger performance on visuospatial span, cognitive control tasks, and on some auditory processing tasks (e.g., pitch identification). Additionally, Schroeder, Marian, Shook, and Bartolotti (2016) found that both bilinguals and musicians performed better on a Simon task, which measures a person's ability to ignore distracting cues (i.e., interference suppression).

Behavioral studies that specifically focused on PWA report that performance on cognitive control tasks can be lower in PWA as compared to controls (see, e.g., Kuzmina & Weekes, 2017; Noonan, Jefferies, Corbett, & Lambon Ralph, 2010). However, Fedorenko and Varley (2016) also reported that some PWA can still engage in complex reasoning tasks that involve executive functions, indicating that the language system is not critical for the person to perform those functions. For this reason, they suggest that cognitive control and language are nearby yet distinct in the left frontal cortex. This could be a significant finding for PWA, because it suggests that shared resources can remain intact post-stroke. Also, though there are no known studies that discuss a correlation between musical processing and cognitive control in PWA, it is possible that prior musical sophistication could be associated with increased performance on a cognitive control task even after a person has sustained neurological damage.

To summarize the relationship between music and cognitive domains (Theory 2), musical sophistication and training can lead to increased activation in neuroimaging studies and increased performance on behavioral tasks for both memory and cognitive control. Nevertheless, as is the case with all the domains discussed so far, much of the research offers correlational data only. This means that results can suggest an association, but they cannot prove causality. Furthermore, most of the studies were conducted with healthy participants. There is no guarantee that the correlations will be the same for a person who has sustained neurological damage, although the current study aims to investigate the relationships in further detail.

The Relationship Between Music and Language in Aphasia

As described in the previous sections, very little research has examined musical processing in PWA (Faroqi-Shah et al., in prep; Patel et al., 2008; Peretz, 1993; Slevc et al., 2016). And, to our knowledge, only one study has examined the influence of musical sophistication in PWA (Faroqi-Shah et al., in prep). For the 23 PWA in their study, Faroqi-Shah et al. (in prep) administered the *Western Aphasia Battery-Revised* (WAB-R; Kertesz, 2007) Aphasia Quotient (AQ) sections, elicited narrative language samples, and asked participants to fill out a self-report questionnaire about their musical sophistication (i.e., the OMSI, Ollen, 2006). The overall results of the study, as they relate to the current experiment, showed that the PWAs' musical sophistication scores correlated with both linguistic and musical syntactic processing tasks. Years of music lessons also correlated positively with the PWAs' DSS scores and the overall severity of aphasia (as measured by the WAB-R AQ), though the latter correlation did not meet the conservative *p* value threshold of .01. For the agrammatic PWA subgroup, OMSI scores correlated with linguistic syntactic processing but not musical syntactic processing. Also, there was no positive correlation between years of music lessons and DSS scores and the WAB-R AQ for that subgroup. Faroqi-Shah et al. (in prep) concluded that the positive correlations found in their main group of PWA could be due to cognitive reserve afforded by past musical sophistication and training.

Since language impairment in aphasia is associated with a multitude of factors—including lesion volume and location (Kertesz, 1988), education (González-Fernández et al., 2011), and engagement in language therapy—it is crucial to try to replicate the findings of Faroqi-Shah et al. (in prep) to show an association with musical sophistication as well. Replicability is important in behavioral research to show that findings are *likely* rather than just *possible* (Open Science Collaboration, 2015), and it increases confidence in outcomes and helps to build a stronger foundation for future research. Also, although a correlation was found for narrative syntax and aphasia severity, additional information on associations with specific components of language (e.g., auditory processing) is lacking. The study outlined in this paper seeks to replicate the available research by Faroqi-Shah et al. (in prep) and also analyze specific language and cognitive domains more closely.

Given that musical sophistication could co-occur with other lifestyle factors as well, it is important to tease out the whether the findings in PWA are specifically driven by musical sophistication or the types of individuals who are likely to engage in multiple cognitive activities in general. Hanna-Pladdy and Gajewski (2012) investigated this possibility in neurotypical individuals by using a measure of general activity level (the Adelaide Activities Profile) in their follow-up study to Hanna-Pladdy and MacKay (2011). Similarly, for each research question in this study (see next section), the influence of general cognitive reserve is controlled for by the Cognitive Reserve Index Questionnaire (CRIq; Nucci, Mapelli, & Mondini, 2012a)—an assessment that aims to quantify the cognitive reserve that has been accumulated by each person throughout his/her lifetime. That way, if prior musical sophistication is associated with aphasia severity, specific language domains, or specific cognitive domains but general measures of cognitive reserve are not, then one can presume that musical sophistication—rather than the sum of a person's lifetime cognitive activities—is responsible for the outcomes.

The correlation between musical sophistication and aphasia (Faroqi-Shah et al., in prep) is an important finding, because the implication is that music—a lifestyle factor that is available to many—could potentially alter a person's functional communication abilities. That is, the benefits of prior musical sophistication might continue even after an acquired neurological impairment. Further, the study's finding adds to the existing body of research on the neuroprotective changes associated with musical training in other populations (see, e.g., Verghese et al., 2003). However, these results need replication, particularly because Faroqi-Shah et al. did not control for other cognitive reserve factors that may co-occur with musical sophistication. Knowing what specific domains of language are correlated with musical sophistication could also help researchers better understand the brain–behavior relationship in PWA. If musical sophistication is related to language performance but not cognitive performance, then the benefits of music would point to far transfer associations for domain-specific tasks. On the other hand, if cognitive domains show a relationship with music but language domains do not, then it could be that musical sophistication is only associated with those activities that recruit a certain cognitive skill (e.g., STM or cognitive control). The RQs proposed below investigate these possibilities. Additionally, the results of the study will help to investigate the likelihood of particular hypotheses (e.g., the SSIRH), explore the potential behavioral benefits of increased reserve in a neurologically impaired individual, and clarify the neural interactions between musical and linguistic representations and resources.

Research Questions and Hypotheses

The primary aim of this study is to examine the relationship between prior musical sophistication and language and cognitive performance in PWA. The secondary aim of this study is to replicate and expand on the findings of Faroqi-Shah et al. (in prep). To help achieve these goals, this study poses the following RQs in persons with aphasia:

- RQ 1: Is prior musical sophistication associated with the overall severity of language impairment in individuals with aphasia when the influence of general cognitive reserve has been accounted for?
- RQ 2: Is prior musical sophistication associated with increased performance on specific language domains (i.e., syntax and auditory processing) when the influence of general cognitive reserve has been accounted for?
- RQ 3: Is prior musical sophistication associated with increased performance on specific cognitive domains (i.e., memory and cognitive control) when the influence of general cognitive reserve has been accounted for?

The existing music–language research in neurotypical adults (e.g., Hanna-Pladdy & MacKay, 2011; Herdener et al., 2014; Slevc et al., 2009; White-Schwoch et al., 2013) and the findings of Faroqi-Shah et al. (in prep) in PWA suggest that musical sophistication will be positively correlated with overall language performance in PWA (Hypothesis 1), even after controlling for the cognitive reserve that results from general lifetime cognitive activities. The literature also suggests there will be a positive correlation between musical sophistication and specific language or cognitive components (Hypotheses 2 and 3), such as syntax, auditory processing, memory, and cognitive control. Alternatively, there might not be a correlation between musical sophistication and any (or some) of the assessment results. Since the research that showed the correlations were mostly found with healthy individuals, the same correlations might not apply to a person who has sustained a brain lesion—especially if music and language share the same neural regions (which is one theory of the relationship between the two). Age of onset of musical training, intensity and duration of practice, and aptitude could also play a role in outcomes (Kraus & Chandrasekaran, 2010).

Methods

Study Design

This study utilized a within-group design, in which a single group of PWA was recruited. The study analyzed performance on measures of musical sophistication, overall cognitive reserve, language, and cognition to investigate the relationship between music and language in PWA. The independent variable for RQs 1–3 was participants' scores on a measure of musical sophistication: the Gold-MSI (Müllensiefen et al., 2014). The GOLD-MSI was used instead of the OMSI (Ollen, 2006) because it is more extensive (39 items vs. 10 items) and was created to assess musical sophistication in the general population rather than in musicians. Also, although some studies have dichotomously divided participants into musicians and non-musicians (e.g., Gaser & Schlaug, 2003; George & Coch, 2011), the independent variable in this study will be modeled from Faroqi-Shah et al. (in prep) and will be used as a continuous variable.

The CRIq (Nucci et al., 2012a) was included as a covariate for RQs 1–3 to control for participation in general lifestyle factors that promote cognitive reserve. The dependent variables for the study included the following: (1) For RQ 1, percentage of errors (hereafter, % Errors; Dependent Variable 1-1 [DV 1-1]) on the WAB-R (Kertesz, 2007) was used to measure overall language severity.[2] % Errors was calculated for all WAB-R AQ tasks that were considered objectively scored (i.e., all items that had a clear correct or incorrect response), which included all AQ test items except for the Spontaneous Speech subtest and the Word Fluency task. One point was assigned for each item in the Yes/No Questions, Auditory Word Recognition, Object Naming, Sentence Completion, and Responsive Speech tasks to make sure all items were evenly weighted. For those items that consisted of multiple scoring components (e.g., items on the Sequential Commands and Repetition task), each component within the item was scored as 1 point. (2) For RQ 2, the number of verbs per utterance (DV 2-1; MacWhinney, 2000) for three narrative language samples was used to measure syntax, and % Errors (DV 2-2) on the Auditory Comprehension WAB-R subtest was used to measure auditory processing. (3) For RQ 3, scores on the digit pointing span task (DV 3-1), a non-verbal memory task by De Renzi and Nichelli (1975), was used to measure STM. Performance on the Stroop task (Stroop, 1935) was used to assess cognitive control, and this was calculated as a Stroop effect for

[2] The current study will include % Errors for the WAB-R (Kertesz, 2007) instead of raw scores since this is considered a direct measure of performance and since it helps to enable comparison with other findings of correlation with aphasia severity in the literature (e.g., education in González-Fernández et al., 2011).

response time (DV 3-2)—that is, the difference between the response times of the incongruent and congruent trials.

The OMSI (Ollen, 2006) and Years of Training were used as independent variables in secondary analyses to maintain replicability with Faroqi-Shah et al.'s (in prep) findings. The dependent variables in these analyses included scores on the WAB-R AQ (Kertesz, 2007) and the number of verbs per utterance (which roughly corresponds to the number of clauses per utterance, MacWhinney, 2000). Though DSS was also collected to enable comparison, the results were considered unreliable since only four participants had enough utterances that were considered appropriate for the DSS analysis.[3] This prohibits comparison with the Faroqi-Shah et al. (in prep) study, which found a correlation between the OMSI (Ollen, 2006) and the DSS for their participants with aphasia.

Participants

Eighteen participants were recruited via telephone and email through the Aphasia Research Center at the University of Maryland. Forty-seven emails were also sent to speech-language pathologists throughout the region, though no additional participants were recruited as a result. One participant out of the original 18 did not complete the assessments due to confusion regarding the online questionnaires. Paper copies were mailed with return postage included, but these were not received by the examiner by the time data analysis was run. As a result, 17 participants were included in the present sample.

[3] An utterance was considered appropriate if it had a subject and predicate or was an imperative, was different from all prior utterances, and so on (see MacWhinney, 2000, p. 80, for a complete list of criteria).

In the group of 17 participants, there were 10 females and 7 males. The mean age (SD) was 62.8 (12.3) years, with a range of 41 to 87, and the mean years of education (SD) was 16.5 (2.4) years, with a range of 12–20. Sixteen participants were right-handed and one was left-handed. All participants had a diagnosis of aphasia, resulting from one or more left-hemisphere cerebrovascular accident(s) at least 6 months prior. All participants were monolingual speakers of English, which, for this study, meant they were native speakers of English who did not learn a second language before the age of 12. Participants had at least a high school education and were accompanied by a close informant (e.g., family member), when necessary, who could provide detailed historical information. Other exclusionary criteria included uncorrected visual or hearing deficits or a history of psychiatric conditions, and assessments for each are described in detail in the Background Tests section below.

Procedure

Testing was initiated after obtaining informed consent from the participants (or their legal representative if the PWA needed assistance). Prior to obtaining consent, full details of the study were provided and participants had an opportunity to ask questions. For all assessments, total administration time ranged from 2 to 3 hours and scoring was based on the standard procedures mentioned in the test manuals.

Background tests. Screening measures were administered before the full language, cognition, and musical sophistication assessments to rule out exclusionary criteria and to help determine which tests were appropriate to use for each participant. The measures included screeners for hearing and visual deficits, cognitive status, apraxia of speech and limb apraxia, depression, and reading.

To screen for vision/hearing deficits, the participant needed to pass a color blindness test (pass/fail), a vision screening (20/40 line on Snellen chart from 6 feet away), a test for visual neglect (the Symbols Cancellation subtest of the *Cognitive Linguistic Quick Test* [Helm-Estabrooks, 2001]), and a hearing screening (40dB at 500, 1000, and 2000 Hz). Since the Symbols Cancellation subtest was used as a test of visual neglect and not for attention, a participant was given a passing score if they marked symbols in all four quadrants. If the participant self-reported previously diagnosed hearing or vision impairments, he/she was required to use corrective aids during the testing (e.g., hearing aids or glasses). Information regarding a history of psychiatric conditions was gathered by participant or caregiver report.

The Diadochokinetic Rate subtest from the *Apraxia Battery for Adults-Second Edition* (ABA-2; Dabul, 2000) was used to make sure the client had no more than mild apraxia of speech (acceptable score = ≥7). Also, although the ABA-2 is primarily geared toward apraxia of speech, Subtest 3 was also used to measure limb apraxia (acceptable scores = ≥37) since some memory tasks used in this study (De Renzi & Nichelli, 1975) required pointing. If a participant had more than mild apraxia of speech, only their receptive measures were included in the analyses. However, for those with no or mild apraxia of speech, receptive and expressive measures were included. If a participant had more than mild limb apraxia, the results for the short-term memory tasks (De Renzi & Nichelli, 1975) were not used. The Geriatric Depression Scale-15 (GDS; Sheikh & Yesavage, 1986) was used to screen for depression, with scores >5 being suggestive of depression. Since the subjects were people with aphasia and it was expected that scores might be higher than those of neurotypical adults, this was not considered exclusionary criteria but instead was collected to help describe the sample. In total, five participants received a score >5. Finally, participants needed to score at least 5/6 on Subtests D and E of the Supplemental Reading test of the WAB-R (Kertesz, 2007). If participants failed this screening task, results from the Stroop task were not included in the analyses.

Study assessments.

Goldsmith Musical Sophistication Index. Version 1.0 of the GOLD-MSI (Müllensiefen et al., 2014) was used in this study, and it includes 39 items in the following categories and with the range of possible scores listed in parentheses: Active Engagement (9–63), Perceptual Abilities (9–63), Musical Training (7–49), Singing Abilities (7–49), and Emotions (6–42). It also includes an overall factor for General Sophistication (18–126), which incorporates aspects from each of the five categories. Each item on the questionnaire is scored on the same 7-point scale (1 = *completely disagree* to 7 = *completely agree*), and the items are equally weighted (Müllensiefen et al., 2014). Percentiles are provided by the authors for each individual subtest as well as the overall score, with the mean General Sophistication score listed as 82 out of a possible 126 (Müllensiefen, Gingras, Stewart, & Musil, 2013). The Gold-MSI is a self-report measure, although in some instances the caregivers of the PWA were asked to answer the information to the best of their knowledge. When necessary, either due to time constraints or participant fatigue, the questionnaire was completed online outside of the session.

Cognitive Reserve Index Questionnaire. The CRIq (Nucci et al., 2012a, 2012b) covers three separate topics that are commonly used proxies for cognitive reserve in the literature: CRI-Education, CRI-Working Activity, and CRI-Leisure Time. CRI-Education includes years of education and time spent in vocational training; CRI-Working Activity includes several options for type of work, ranging from "low skilled manual work" to "highly responsible or intellectual occupation," and the participant enters years worked for each; and CRI-Leisure Time section includes 16 questions total, relating to social activities (e.g., going to the cinema), intellectual activities (e.g., reading a book), or physical activities (e.g., sports). There are only two items related to music on the questionnaire: "Artistic activities (music, singing, performance, painting, writing, etc.)" and attending "exhibitions, concerts, conferences" (Nucci et al., 2012a). Neither of the questions relate to musical sophistication directly, so the CRIq was considered to include different, non-overlapping items from the GOLD-MSI (Müllensiefen et al., 2014). In the current study, participants were asked to complete the questionnaire based on their cognitive experiences prior to sustaining a stroke.

Though there are no published norms in English for the CRIq (Nucci et al., 2012b), this questionnaire was still used because it covers a wide variety of lifetime activities without focusing too heavily on music. Also, the authors provide a convincing defense of the published reliability (α = 0.62, 95% CI [0.56, 0.97]), explaining that social, economic, and historical reasons at least partially explain why some parts of the test did not seem to correlate with others for the Italian population sample (see p. 221 in Nucci et al., 2012b, for the full explanation).

Western Aphasia Battery-Revised. The WAB-R (Kertesz, 2007) was used to provide information relevant to RQ 1 (% Errors on WAB-R tests described previously) and RQ 2 (% Errors on the Auditory Comprehension subtest). Also, scores on the WAB-R AQ provided overall severity information (maximum score: 100) for a secondary analysis as well as the type of aphasia.

Narrative language samples. Three narrative language samples were used to help assess participants' syntax for RQ 2: a personal narrative sample (in response to the prompt "Tell me about an important event in your life") and two picture scene descriptions (the Cookie Theft picture from the Boston Diagnostic Aphasia Examination [Goodglass, Kaplan, & Barresi, 2001] and the picture description from the Spontaneous Speech subtest of the WAB-R [Kertesz, 2007]). Since some of the PWA had limited spontaneous speech, the samples from the three tasks were combined in one transcript to increase the number of utterances for each participant. The narrative samples were transcribed with a software called Computerized Language Analysis (CLAN; MacWhinney, 2000), and two utilities—KIDEVAL and EVAL—from CLAN were run to analyze the sample. These utilities provided information on the number of verbs per utterance and the DSS.

Non-verbal memory task. Complete administration and scoring details for the digit pointing span task, used to assess STM for RQ 3, as well as norms for brain-damaged individuals are available in De Renzi and Nichelli (1975). For this task, the examiner read strings of numbers of increasing length (e.g., 2-7 to 3-9-5 to 1-7-3-8, etc.) and the participant was asked to point, in order, to blocks with the corresponding numbers on them. The maximum score on the task was 10.5 points, and the non-verbal response for the task was designed by De Renzi and Nichelli to ensure that testing modality did not interfere with the examinees' performance.

Stroop task. For RQ 3, an inhibitory control task (taken from Faroqi-Shah, Sampson, Baughman, & Pranger, 2014), referred to as the Stroop color-word task (Stroop, 1935), was used to assess cognitive control. In this Stroop task, a word was presented visually to each participant and the person was asked to push a button on a computer keyboard that matched the ink color of the word. For example, three keyboard arrow keys had stickers that were either yellow, red, or green and the participant was asked to push the yellow button when a yellow word showed on the computer screen. In congruent trials, the word and the color of the ink matched; in neutral trials, the word was unrelated ("plan"); and in incongruent trials, the ink color did not match the word (i.e., the word was red but the ink color was green). Each participant had to pass the color blindness and reading screeners in order for the results of this task to be considered valid. On all tasks, cognitive control was indicated by the Stroop effect for response time.

Additional measure for the secondary analyses: Ollen Musical Sophistication Index. The OMSI (Ollen, 2006) is a 10-item questionnaire that returns a score between 0 and 1000, with a higher score indicating higher musical sophistication. A score of 750, for example, would indicate that there is a 75% probability that the participant would be deemed "musically sophisticated" by an expert. Similar to the Gold-MSI, the OMSI is a self-report measure that could be completed by the participant or a caregiver during the testing session or online after the session.

Data Analysis

Five simple linear regression analyses were run to examine potential correlations between scores on the Gold-MSI (Müllensiefen et al., 2014) and the linguistic and cognitive dependent variables (DV 1-1, DV 2-1, DV 2-2, DV 3-1, and DV 3-2), after controlling for other lifestyle factors with the CRIq (Nucci et al., 2012b). Four additional simple linear regression analyses were run for the secondary analysis to compare this study with results from a prior study (i.e., Faroqi-Shah et al., in prep), using the OMSI and Years of Training as independent variables. All analyses are outlined in detail in the Results section below. A conservative *p* value of .01 was adopted for all analyses to minimize the chances of Type 1 error.

Results

Primary Analyses

The number of participants whose scores were included in the primary regression analyses, reasons for exclusion of other participants, and means and standard deviations for all primary measures are provided in Table 1. For all participants in this study, the range of musical sophistication scores on the Gold-MSI (Müllensiefen et al., 2014) was 30 to 81, with a mean of 58.24. According to Müllensiefen et al. (2014), the mean score was 81.58 (out of a possible 126) for their large sample of 147,633 people. This means that all 17 participants in this study scored below the mean. For the WAB-R, the range of participant scores was 33.3 to 97, with 0–25 considered very severe, 26–50 considered severe, 51–75 considered moderate, and 76+ considered mild (Kertesz, 2007). Three participants were above the 93.8 cut-off score for aphasia, according to Kertesz (2007). However, these participants were still included due to their diagnoses of aphasia and their

Table 1

The Number of Participants and Descriptive Statistics for the Measures Used in the Primary Regression Analyses.

Assessment	*N*	Reason for Participant Exclusion	Maximum Possible Score	Mean (SD)
Gold-MSI	17	N/A	126	58.2 (16.99)
CRIq	17	N/A	N/A	131.4 (22.1)
DV 1-1: % Errors on WAB-R	11	Failed apraxia screening	100%	20.6 (21.6)
DV 2-1: Verbs/Utterance for Narrative Samples	11	Failed apraxia screening	N/A	1.3 (.5)
DV 2-2: % Errors on WAB-R Auditory Comprehension Subtest	16	Lack of access to original test form, since this participant's WAB results were from another recent study	100%	17.8 (19.02)
DV 3-1: Digit Pointing Span Memory Task	16	One person failed the trial/screening criteria associated with this individual task so the task was not administered	10.5	2.9 (2.9)
DV 3-2: Stroop Task for Response Time	14	Failed reading screen, incomplete test data, and disregard for task instructions (either due to fatigue or confusion)	N/A	0.2 (0.3)

Note. N: Total number of participants; SD: Standard deviation; Gold-MSI: Goldsmiths Musical Sophistication Index; N/A: Not applicable; CRIq: Cognitive Reserve Index Questionnaire; DV: Dependent variable; WAB-R: Western Aphasia Battery-Revised. See the Study Design section for a thorough description of each DV mentioned in Column 1.

descriptions of language difficulties in daily communication (Fromm et al., 2017). The mean score on the WAB-R AQ for the 11 participants who passed the apraxia screener was 75.5 with a standard deviation of 22.03, suggesting the participants in this study generally had milder aphasia. Even with all 17 participants included, the mean was still within the mild range at 69.5 with an SD of 20.5.

The mean CRIq score and standard deviation for this sample was 131.4 (22.1), with three participants scoring in the "medium" range (85–114) for their Cognitive Index, six scoring in the medium-high range (115–130), and seven scoring in the high range (≥130). Overall, the mean of all participants falls within the "high" range. The mean (SD) reported in Nucci et al. (2012b) is 100 (15), showing that our sample outperformed the normative sample by a wide margin. In fact, the highest score in the current study was 193, which is almost double the mean reported in the original study. The correlation between the CRIq and the Gold-MSI for all 17 participants was .187, which is not considered significant.

The results of the primary regression analyses as well as correlations between

Table 2

Results for the Primary Regression Analyses (Gold-MSI as Independent Variable) and Pearson Correlations Between Measures.

Regression/ Dependent Variable	Results of Regression	Pearson Correlations
DV 1-1: % Errors on WAB-R	$R^2 = 0.14$, $F(2,8) = 1.8$, $p > .01$	WAB % Errors & Gold-MSI: -0.463; WAB % Errors & CRIq: 0.19; Gold-MSI & CRIq: 0.247
DV 2-1: Verbs/Utterance for Narrative Samples	$R^2 = –0.15$, $F(2,8) = 0.3$, $p > .01$	Verbs/Utt & Gold-MSI: -0.213; Verbs/Utt & CRIq: -0.229; Gold-MSI & CRIq: 0.247
DV 2-2: % Errors on WAB-R Auditory Comprehension Subtest	$R^2 = 0.08$, $F(2,13) = 1.7$, $p > .01$	WAB_AC % Errors & Gold-MSI: -0.413; WAB_AC % Errors & CRIq: 0.069; Gold-MSI & CRIq: 0.253

DV 3-1: Digit Pointing Span Memory Task	R^2 = –0.06, *F*(2,13) = 0.6, *p* > .01	STM DPS & Gold-MSI: 0.161; STM DPS & CRIq: 0.274; Gold-MSI & CRIq: 0.305
DV 3-2: Stroop Task for Response Time	R^2 = –0.18, *F*(2,11) = 0.006, *p* > .01	Stroop RT & Gold-MSI: 0.011; Stroop RT & CRIq: -0.027; Gold-MSI & CRIq: 0.267

Note. The Results of Regression column reports the following for each analysis: adjusted R^2, degrees of freedom (df1), residual, *F* value, and *p* value (significance). DV: Dependent variable; WAB-R: Western Aphasia Battery-Revised; % Errors: Percentage of errors; Gold-MSI: Goldsmiths Musical Sophistication Index; CRIq: Cognitive Reserve Index Questionnaire; Verbs/Utt: Verbs per utterance; WAB_AC: WAB-R Auditory Comprehension Subtest; DPS: Digit pointing span; RT: Response time. See the Study Design section for a thorough description of each DV mentioned in Column 1.

various predictors are provided in Table 2. Since the correlations between predictors vary based on the performance of a fluctuating number of participants, this information is reported for each individual analysis. As can be seen from Table 2, scores on the Gold-MSI (Müllensiefen et al., 2014) did not significantly predict performance on overall language severity (measured by % Errors on the WAB-R; Kertesz, 2007) or performance on specific language and cognitive domains for any regression analysis. There were also moderate (i.e., ranging from .3–.5) but non-significant negative correlations between the Gold-MSI and WAB % Errors (ρ = –.46, *p* > .01), which was used to measure overall aphasia severity, and the Gold-MSI and % Errors on the WAB-R Auditory Comprehension subtest (ρ = –.41, *p* > .01). The direction of the correlations was expected, as a lower percentage of errors indicates better performance on the measures.

Secondary Analyses

Table 3 reports the number of participants included for the secondary measures, the reason for exclusion of other participants, and means and standard deviations. Table 4 reports the results of the secondary regression analyses and the Pearson correlations between the predictors.

Table 3

The Number of Participants and Descriptive Statistics for the Measures Used in the Secondary Regression Analyses.

Assessment	*N*	Reason for Participant Exclusion	Maximum Possible Score	Mean (SD)
OMSI	17	N/A	1000	127.2 (99.4)
Years of Training	17	N/A	N/A	0.7 (1.3)
Scores on the WAB-R Aphasia Quotient	11	Failed apraxia screening	100	75.5 (22.03)
Verbs/Utterance for Narrative Samples	11	Failed apraxia screening	N/A	1.3 (.5)

Note. N: Total number of participants; SD: Standard deviation; OMSI: Ollen Musical Sophistication Index; N/A: Not applicable; WAB-R: Western Aphasia Battery-Revised.

Table 4

Results for the Secondary Regression Analyses and Pearson Correlations Between Measures.

Independent Variable	Regression/ Dependent Variable	Results of Regression	Pearson Correlations
OMSI	Scores on the WAB-R Aphasia Quotient	$R^2 = -0.08$, $F(1,9) = 0.3$, $p > .01$	WAB-R AQ & OMSI: 0.172
	Verbs/Utterance for Narrative Samples	$R^2 = -0.09$, $F(1,9) = 0.2$, $p > .01$	Verbs/Utt & OMSI: 0.141
Years of Training	Scores on the WAB-R Aphasia Quotient	$R^2 = 0.09$, $F(1,9) = 2.0$, $p > .01$	Years of Training and WAB-R AQ: 0.426
	Verbs/Utterance for Narrative Samples	$R^2 = 0.12$, $F(1,9) = 2.3$, $p > .01$	Years of Training and Verbs/Utt: 0.454

Note. The Results of Regression column reports the following for each analysis: adjusted R^2, degrees of freedom (df1), residual, *F* value, and *p* value (significance). OMSI: Ollen Musical Sophistication Index; WAB-R: Western Aphasia Battery-Revised; AQ: Aphasia Quotient; Verbs/Utt: Verbs per utterance.

As shown in Table 4, scores on the WAB-R AQ (Kertesz, 2007) and number of verbs per utterance were not predicted by scores on the OMSI (Ollen, 2006) or years of training. There were moderate but also non-significant positive correlations between years of training and WAB-R AQ scores ($\rho = .43$, $p > .01$) and years of training and Verbs/Utterance ($\rho = .45$, $p > .01$), which was used as a substitute measure for syntax in place of the DSS. (In the current study, the results for DSS were unreliable since there were only four participants with 50 DSS-appropriate utterances.) These correlations are very similar to those found by Faroqi-Shah et al. (in prep), who reported a positive correlation between years of lessons and the overall severity of aphasia ($\rho = .45$, $p < .05$; although non-significant since it did not meet the conservative *p*-value of 0.01) and between years of lessons and DSS ($\rho = .6$, $p < .01$).

Post-Hoc Analyses

Kraus and Chandrasekaran (2010) suggested that age of onset of musical training, intensity and duration of practice, and aptitude could all play a role in language and cognition outcomes, so post-hoc analyses were run for all dependent variables (DV 1-1 through DV 3-2) with age of onset, years of training, duration of experience, and intensity of practice as the independent variables. Additional analyses were also run with the five categories that make up the Gold-MSI (Active Engagement, Perceptual Abilities, Musical Training, Singing Abilities, and Emotions; Müllensiefen et al., 2014) as the independent variables and DV 1-1 through DV 3-2 as the dependent variables. The intention of all post-hoc analyses was to investigate the relationship between musical sophistication and language in closer detail, to see if certain musical factors are more highly correlated than others with measures of language and cognition.

The only significantly predictive relationship ($p = .01$) for the regression analyses for the four Kraus and Chandrasekaran (2010) determinants was between Intensity of

Training and Stroop Response Time, which could be interpreted as higher amounts of daily performance leading to increased cognitive reserve in areas that are used for cognitive control. This could be attributed to musicians continuously making revisions as they practice (e.g., if they play a wrong note), which would be one example where cognitive control is involved. However, since there were several regressions run for this post-hoc analyses, it is also important to note that significance could have been met by chance. There were also several moderate to strong correlations between several measures, which are as follows: (1) Years of training was moderately correlated with % Errors on the WAB-R (ρ = –.43), Verbs/Utterance (ρ = .45), % Errors on the WAB-R Auditory Comprehension subtest (ρ = –.35), the Digit Pointing Span STM task (ρ = .48), the Stroop effect for response time (ρ = .34), and the WAB-R AQ (ρ = .43). None of these correlations was found to be significant. (2) Age of onset was moderately to strongly correlated with % Errors on the WAB-R (ρ = .86, *p* = .01), % Errors on the WAB Auditory Comprehension subtest (ρ = .65), the Digit Pointing Span task (ρ = –.48), and the WAB-R AQ (ρ = –.73). Note that the expected positive and negative correlations are switched for Age of Onset, since a higher % Errors indicates worse performance and a higher Age of Onset means a person learned an instrument later in life than those with a low age of onset. One of these correlation values reached significance (*p* = .01), though it is important to note that the *n* value for this regression was only 6 participants since only people with a history of musical training had an age of onset listed. (3) Duration of training did not have moderate or strong correlations with any dependent variables. (4) Finally, intensity of training was moderately correlated with % Errors on the WAB-R (ρ = –.42), Verbs/Utterance (ρ = .57), % Errors on the WAB-R Auditory Comprehension subtest ($\rho = -.36$), and the Stroop effect for response time ($\rho = .66$, $p = .004$). The correlation and regression between intensity of training and the Stroop effect are both significant. This data lends support to Kraus and Chandrasekaran's (2010) proposition that these four factors can help to determine the neural plasticity and increased reserve associated with musical training, as shown by performance on behavioral measures in this study. There were several significant correlations and even more that might have reached significance given a larger sample of participants.

When the five Gold-MSI (Müllensiefen et al., 2014) categories were run as the independent variables with DV 1-1 through DV 3-2 as the dependent variables, there were no significantly predictive relationships (i.e., $p > .01$ for all). However, there were several moderate to strong correlations. None of them reached significance in the current study, although one of them trended toward significance with a directional probability of .015. This information is added after the correlation value where appropriate. (1) Active Engagement was moderately correlated with Verbs/Utterance ($\rho = -.31$). (2) Perceptual Abilities were moderately correlated with % Errors on the WAB-R ($\rho = -.50$) and % Errors on the WAB-R Auditory Comprehension subtest ($\rho = -.40$). (3) Musical Training was moderately to strongly correlated with % Errors on the WAB-R ($\rho = -.52$), % Errors on the WAB-R Auditory Comprehension subtest ($\rho = -.43$), and the Stroop effect for response time ($\rho = .42$). (4) Singing Abilities were moderately to strongly correlated with % Errors on the WAB-R ($\rho = -.48$) and % Errors on the WAB-R Auditory Comprehension subtest ($\rho = -.54$, $p = .015$). (5) Finally, Emotions were moderately correlated with % Errors on the WAB-R ($\rho = -.39$) and % Errors on the WAB-R Auditory Comprehension subtest ($\rho = -.32$).

The results from the post-hoc analyses are not discussed at length throughout the rest of the paper since they do not directly relate to the three research questions, but they are reported here to provide additional information about the sample, assist with interpretation, and inform future studies. It is possible that certain components of a person's musical sophistication (e.g., age of onset or intensity of training) are more predictive of their skills on language and cognition measures than others. This might help to tease out what it is about musical sophistication and musical training that makes them influential on language. A discussion of all results is included below.

Discussion

Music is thought to influence language outcomes by causing neuroplastic changes that lead to increased levels of cognitive reserve. If a person has higher musical sophistication, then the idea is that the region of the brain associated with music will have higher levels of reserve that might benefit other domains that utilize the same area. Researchers have posited several theories regarding these neural correlates between music and language. For example, researchers that support Theory 1 (Heffner & Slevc, 2015; Kunert et al., 2015; LaCroix et al., 2015; Patel, 2003; Peretz et al., 2015; Slevc et al., 2009) either suggest that the representations for music and language directly overlap in the brain or that the two at least share certain processing resources. Supporters for Theory 2 (Martin, 2005; Novick, Trueswell, & Thompson-Schill, 2005; Pallesen et al., 2010; Slevc & Okada, 2015; Talamini, Altoè, Carretti, & Grassi, 2017) indicate that the relationship is more indirect, such that music affects cognitive domains (e.g., memory or cognitive control), which, in turn, affect language.

The current study was intended to further explore the relationship between music and language. It investigated associations between musical sophistication and overall aphasia severity, specific language domains (syntax and auditory processing), and specific cognitive domains (memory and cognitive control). Results show that musical sophistication was not significantly correlated with any language or cognitive measures in this group of persons with aphasia. An interpretation of the findings is presented below, which includes a summary of past relevant research, a discussion of the theoretical implications, a direct comparison with Faroqi-Shah et al. (in prep), and then potential explanations for the outcomes noted in this study. Finally, directions for future research will be summarized.

Comparison with Background Literature

The lack of significant associations in this study is consistent with other studies that failed to find a correlation between musical training/tasks and linguistic and cognitive tasks in neurotypical individuals, including on measures of syntax, auditory comprehension, memory, and cognitive control (Forgeard et al., 2008; Ho et al., 2003; Hyde et al., 2009; Moussard et al., 2016; Patel et al., 2008; Rauscher, 2002; Sachs et al., 2017; Schlaug et al., 2005; Slater et al., 2014; Strait et al., 2010). Nevertheless, there are even more studies that point to an association between music and language. However, many of these studies look at musicians or individuals who have undergone a period of intense practice, so it is possible that the measurable increases in cognitive and brain reserve or the increased performance on behavioral measures do not consistently apply to people with a more casual approach to musical training or practice.

In PWA, the literature is limited and results are also mixed. Though Faroqi-Shah et al. (in prep) found some correlations with musical measures, they also failed to find a correlation between performance on musical and linguistic syntactic judgments for that population, as did Patel et al. (2008). This is an important finding because it is one example where the evidence from PWA does not support that of the findings with neurotypical individuals (Jung et al., 2015; Slevc et al., 2009). Additionally, Slevc et al. (2016) and Peretz (1993) found PWA that showed a dissociation between music and language (i.e., the PWA had either linguistic OR musical structure processing deficits), indicating there are instances where the two do not overlap and where the *far transfer* associations for one might not extend to the other.

Theoretical Implications

The original hypotheses of this study are not supported by the final results, so implications of the findings are discussed as they relate to previous research and theories surrounding the relationship between music and language. Hypotheses 1, 2, and 3 suggested that musical sophistication would be significantly associated with overall language performance and specific language and cognitive components in PWA. These hypotheses were based on the extensive literature in neurotypical individuals as well as promising studies that showed music (Faroqi-Shah et al., in prep) and other lifestyle factors (Alladi et al., 2015; Bialystok, Craik, & Freedman, 2007; González-Fernández et al., 2011) can have a positive correlation with language even in people with neurological impairment. The results of this study did show moderate correlations between (1) scores on the Gold-MSI (Müllensiefen et al., 2014) and (a) overall severity of language as well as (b) measures of Auditory Comprehension, and between (2) years of training and (a) a measure of Syntax and (b) overall aphasia severity. However, none of these correlations reached significance so the results of this study do not point to a strong relationship between music and language in PWA for any of the three research questions.

One possible implication of these findings is that musical sophistication has a positive and significant association with cognition and language in neurotypical individuals only. Since the literature specifically investigating associations between musical sophistication and language measures in PWA is limited (Faroqi-Shah et al., in prep), it is possible that the many benefits musical training and sophistication afford to neurotypical individuals do not consistently extend to PWA. This could be because music and language share the same neural regions, which is one idea that was presented in Theory 1, and these neural regions are damaged when a person sustains a left-hemisphere stroke. That is, the cognitive and brain reserve that is accumulated by a person with high levels of musical sophistication might be in the very region of the brain that is damaged in PWA.

An alternate approach in Theory 1 suggested that music and specific linguistic and cognitive domains might be related via neural sharing rather than neural overlap (Heffner & Slevc, 2015; Patel, 2003; Peretz et al., 2015; Slevc et al., 2009). Several studies support this idea and suggest that music and language share neural resources for some tasks but not others (LaCroix et al., 2015; Martin, 2005). It is possible that the measures of language and cognition used in this study did not use the right kind of tasks for syntax, auditory processing, memory, and cognitive control, and this is why there were no significant behavioral associations noted.

Theory 2 in the literature presumes that the link between music and language is cognition. However, scores on the Gold-MSI were not correlated with performance on the digit pointing span task for STM (De Renzi & Nichelli, 1975) or the Stroop color-word task (Faroqi-Shah et al., 2014). Once again, this could be a task effect or it might mean that musical sophistication has little influence on a PWA's STM or cognitive control.

Comparison with Faroqi-Shah et al. (in prep)

Though much of the demographic data was comparable between the two studies, there are some variations that might explain why this study did not replicate the significant findings of Faroqi-Shah et al. (in prep). Demographic information and measures used in both studies are presented in Table 5 in order to facilitate a direct comparison of results.

Table 5

Comparison of Demographics and Assessments Between the Current Study and Faroqi-Shah et al. (in prep).

	Current Study	Faroqi-Shah et al. (in prep)
Demographic Information:		
N	17 for receptive measures, 11 for expressive	23
Gender	10 female, 7 male	15 female, 8 male
Primary Language	English	English
Minimum Education	High school	High school
Age	62.8 (12.3), 41–87	59.8 (10.1), 40–81
Years of Education	16.5 (2.4), 12–20	16.7 (4.2), 13–25
n with unaided hearing loss	0	0
n with prior speech-language difficulties	0	0

n with prior history of substance abuse	0	0
n with prior history of psychiatric conditions or neurological disorders	0	1 (prior diagnosis of bipolar disorder)
Possible depression, according to GDS	5	0
Prior CVAs	13 with 1 CVA, two with 2 CVAs, two with 3 CVAs	All with 1 CVA
Type of Aphasia	Broca's: 6, Anomic: 3, Conduction: 2, Wernicke's: 2, Transcortical motor: 1, NAWAB: 3	Broca's: 12, Anomic: 7, Conduction: 1, NAWAB: 3
Measures:		
WAB-R	75.5 (22.03), 33.3–97	72.8 (20.0), 30.8–99.6
OMSI scores	127.2 (99.4), 18–359	170.3 (221.5), 18–931
Narrative Language Samples	Verbs/Utterance: 1.3 (.5)	DSS: 15.4 (13.7)
Years of Training	0.71 (1.3), 0–5	1.7 (2.3), 0–7

Note. N: Total number of participants; SD: Standard deviation; *n:* Number of participants; CVA: Cerebrovascular accident; NAWAB: Not aphasic according to WAB-R (cut-off score of 93.8; Fromm et al., 2017); WAB-R: Western Aphasia Battery-Revised; OMSI: Ollen Musical Sophistication Index; DSS: Developmental syntax score. The information reported for age, years of education, and years of training is formatted as Mean in Years (SD), Range.

Gender; primary language; age; minimum education and years of education; and results for screening measures of unaided hearing loss or prior history of speech or language impairments, substance abuse, and psychiatric conditions or neurological disorders were all comparable between the two studies. In this study, five people scored >5 on the GDS, though none did in Faroqi-Shah et al. (in prep). Pohjasvaara, Vataja, Leppävuori, Kaste, and Erkinjuntti (2001) report that participant depression could affect long-term functional outcomes for people who have had a stroke, so it is possible this was a factor during testing. In Faroqi-Shah et al. (in prep), all 23 PWA had a history of a single left-hemisphere cerebrovascular accident (CVA). In the present study, attempts were made to find people with a single CVA, though it was determined this criterion would limit the sample pool too greatly based on the time frame available. For those participants with two and three CVAs, it is possible there are multiple lesion sites that could each contribute to language outcomes so there is not a clear 1:1 relationship. Type of aphasia also varied between the two studies. Faroqi-Shah reported fewer types of aphasia, with Broca's aphasia being the most frequent. The current sample was more varied as far as type of aphasia, as two additional types (Wernicke's and transcortical motor) were present. This, also, might have had an effect on outcomes seen, since dominant language characteristics vary among the different diagnoses.

Performance on some study measures differed between these two studies. Participants in both studies had comparable scores on the WAB-R AQ (Kertesz, 2007), but Faroqi-Shah et al.'s (in prep) participants had higher OMSI (Ollen, 2006) scores on average: Mean (SD) = 170.3 (221.5), Range = 18–931, compared to the PWA in this study: 127.2 (99.4), 18–359.[4] This study's OMSI scores mirror those of the Gold-MSI (Müllensiefen et al., 2014), reported earlier in the Results section, in that they show a limited range of musical sophistication for the participants. No participants scored higher than 359, meaning there is only a 35.9% chance that any of these participants would be deemed "musically sophisticated" by an expert (based solely on OMSI scores). The decreased heterogeneity for musical training and sophistication for the current sample might be one reason why significant findings from Faroqi-Shah et al. (in prep) were not

[4] The CRIq was not included as a covariate in the secondary analyses' regressions in order to maintain replicability with the Faroqi-Shah et al. (in prep) design.

replicated in the current study. Another reason might be the smaller sample size in this study, as some correlations between variables were very similar (e.g., ρ = .43 versus .45 for Years of Training and WAB-R AQ) but only reached significance for Faroqi-Shah et al. Alternately, the results of this study might have been influenced by other considerations, which are described below.

Potential Explanations for Outcomes

Lesion volume and location, medical intervention, post-stroke activities and compensatory strategies, scoring considerations, reliability of the measures used in this study, and the lack of correlation between the Gold-MSI (Müllensiefen et al., 2014) and the OMSI (Ollen, 2006) could all have played a role in outcomes. These are addressed in detail below and are followed by considerations and recommendations for future research.

Important determinants of aphasia severity and recovery after stroke are the volume and location of a lesion (Basso, 1992; Kertesz, Lau, & Polk, 1993; Kertesz & McCabe, 1977; Selnes, Knopman, Niccum, Rubens, & Larson, 1983) and whether a person received post-stroke medical intervention. The 17 participants in this study were categorized as having Broca's (6), anomic (3), conduction (2), Wernicke's (2), or transcortical motor (1) aphasia and no aphasia (3) as per the WAB-R (Kertesz, 2007) cutoff scores (Fromm et al., 2017). Though PWA have impairments in all modalities, the participants' linguistic profiles varied based on the type of aphasia (e.g., comprehension is more impaired in Wernicke's aphasia than in anomic aphasia), and type of aphasia is impacted by lesion size and location since neural regions have various responsibilities—for example, auditory comprehension vs. semantics. This could have led to different outcomes than if all participants had the same lesion site or size. With relation to medical intervention, in two of the narrative responses to the prompt "Tell me about an important event in your life," people explained that they received a drug at the hospital that was intended to help limit the damage caused by the stroke. Tissue plasminogen activator (tPA) can be administered for an acute ischemic stroke within 3 hours of the onset of stroke symptoms (Zivin, 2009), and it works to dissolve a clot and improve blood flow to the affected area of the brain. Since tPA is intended to alter the effects of a stroke, it is probable that the language and cognition outcomes would look different for people that did not receive the treatment. Unfortunately, lesion size, lesion location, and medical intervention could not be controlled in this study because brain imaging data and medical records were not available for all participants. In future research, this should be accounted for whenever possible since these determinants impact both the severity of aphasia and scores on particular tasks.

A person's involvement in therapy or other activities post-stroke could also influence performance on the measures. All participants in this study worked with a speech pathologist after their stroke, ranging from 1 month to 6 years (per report on a Participant History Questionnaire). Presumably, via speech therapy or independently, the participants have also adopted several strategies to compensate for receptive or expressive impairments (e.g., circumlocution for word-finding difficulties). These compensatory strategies might affect performance on tasks or correlations between measures in this study, since the participants' language capabilities are continuously changing. Additionally, seven of 17 participants had at least tried a speech app on their phone or tablet since the time of their stroke, two participants listened to music more often since their stroke (seven others listened less often and eight listened to the same amount), and two participants participated in musical activities more often since their stroke (four participated less often and nine participated the same amount).

Another possibility for the lack of significant correlations found in this study is that the influence of musical sophistication is so great that highly musically sophisticated people show no language deficits at all after having a stroke or their aphasia is so mild that they are not diagnosed and would not be included in the sample. This possibility is unlikely based on the modest gains that are typically reported on behavioral assessments for neurotypical individuals, although it is worth consideration. Within this study alone, the support is mixed. Comparing the WAB-R AQ (Kertesz, 2007) scores of the participants with the highest and lowest Gold-MSI scores, it was noted that the participant with the lowest musical sophistication score had a higher AQ than the person with the highest score. The person with the lowest Gold-MSI score was also one of the two that reported receiving the tPA drug, however, so this could have complicated the outcomes. On the other hand, the range of scores for the participants in this study on the Gold-MSI was 30 to 81 (mean = 58.24), meaning that all participants in this study scored below Müllensiefen et al. (2014)'s reported mean of 81.58. This could lend support to the theory that highly musically sophisticated people do not have aphasia. However, more likely is that this is just how this particular sample trended since the participants in Faroqi-Shah et al. (in prep) had a much wider range of musical sophistication scores (18–931), as measured by the OMSI. Alternatively, the Gold-MSI mean in this study might also seem low since it is being directly compared to the mean reported by Müllensiefen et al. (2014). Their data is taken from a large internet sample of 147,633 individuals.

Considering that people who are musically inclined or stronger appreciators of music are more likely to gravitate toward an online survey about music, it is possible that the mean of 81.58 is not reflective of the general population.

Although the results for this sample were below average for the Gold-MSI (Müllensiefen et al., 2014), they were well above average for the CRIq (Nucci et al., 2012a). This could have altered the outcome since this study controlled for cognitive reserve; however, rerunning the analyses without the CRIq still did not predict significant variations in performance. The mean CRIq score for this sample was 131.35, versus the mean of 100 reported in Nucci et al. (2012b). Possible reasons for this include the fact that caregivers or PWA could not remember the total amount of time, so they rounded up; they did not know the answer in the first place so they guessed (for caregivers); or they exaggerated their responses. Alternately, the higher scores could be because the study was conducted in a major metropolitan area, and participants' education averaged 16.47 years—the equivalent of an undergraduate college degree. Also, all participants in this study were middle-aged to older adults (age range: 41–87, mean age: 62.82) so they had a longer time to accumulate cognitive reserve. However, in the norms reports in Nucci et al. (2012b), the age ranges tested (18–44, 45–69, 70–102) never differ by more than 9 points for the mean of each category so the advanced age alone should not explain the variance.

The low scores of the Gold-MSI (Müllensiefen et al., 2014) and the high scores of the CRIq (Nucci et al., 2012a) could also be due to the fact that these questionnaires were not originally intended for use with PWA. For all questionnaires, the PWA and their caregivers were provided with instructions to fill out the information based on the person with aphasia's premorbid musical habits (for the Gold-MSI) or cognitive activities (for the CRIq). This could be confusing since the person needed to remember to respond to questions based on habits from years prior. Also, some of the participants or caregivers filled out the information independently online without the examiner nearby. In these instances, the examiner could not provide a reminder that the information was based on pre-morbid activities, nor were the people able to ask clarification questions for any items that might be confusing.

In many instances, the PWA was not able to fill out the questionnaires so a caregiver did so on their behalf. A limitation to this is that the caregiver might not have known the PWA's past musical history (e.g., if they received a year of lessons in childhood) and so their responses were estimates or guesses. For the instances when the PWA filled out the questionnaires independently, Martin (2005) explained that brain-damaged individuals sometimes have problems with recall, so it could be that memory deficits affected a person's response to the questions on the indices. The participants in this study were also somewhat older (mean age: 62.8) and these questionnaires asked the participants to report on activities or employment throughout their lifespan. This could be challenging even for neurotypical adults, since some of the activities are decades old. This potential issue is reflected in the responses of three of the 17 participants, where the responses for Years of training differed between the Gold-MSI and the OMSI (Ollen, 2006). Presumably, this was because the PWA's training was in their childhood and they had difficulty remembering the exact number of years.

Discrepancies between the Gold-MSI (Müllensiefen et al., 2014) and the OMSI (Ollen, 2006) were not limited to years of training. For the 17 participants in this study, the Pearson correlation between the two measures was –0.156. This was unexpected, since both are a measure of musical sophistication and they even have some overlap in questioning. It is the examiner's opinion that the Gold-MSI seemed to rate people appropriately according to their responses and their level of expertise. However, there were some responses or scores on the OMSI that did not seem to match the person's skills. For example, one participant played six instruments and was the only person to rate themselves as a musician (specifically, an amateur musician). This participant had one of the highest ratings on the Gold-MSI but one of the lowest on the OMSI, possibly because he was a self-taught musician and never received formal training. Three other participants matched on all responses on the OMSI except for two—age (early 40s, late 50s, and early 80s) and title (music-loving non-musician vs. non-musician). The older (early 80s) music-loving non-musician scored 58 points lower than the younger non-musician (early 40s) but two points higher than the younger music-loving non-musician (late 50s). These results make it clear that age does not explain the difference, nor does it make sense that a person claiming to be a non-musician would rank 58 points higher than someone claiming to be a music-loving non-musician. These discrepancies are beyond the scope of the present study, though they might contribute to the lack of correlations found with OMSI scores.

Future Recommendations and Considerations

Some possible changes for future studies include: (1) controlling for lesion volume and location, (2) increasing the sample size, (3) attempting to recruit participants with a wider range of musical sophistication and language scores, and (4) including additional measures of syntax. A larger sample would have been ideal and might have led to different results, but these were all participants that responded to recruitment attempts during the time frame of this study. Also, another limitation to this study was that all participants were below the mean for musical sophistication scores (Müllensiefen et al., 2014), and their scores were often similar to others in the sample pool. A larger point gap between each participant will lead to clearer results. For syntax, it is possible that another measure might have better reflected the language skills in this particular sample (e.g., Percent Grammatical Utterances, Mean Length of Utterance, or Verb Morphology Index). Since much of the background literature points to a relationship between music and syntax, both in neurotypical individuals and in PWA (Faroqi-Shah et al., in prep), this is an area that should be explored more closely.

In future studies, even if significant positive correlations are discovered, researchers should be careful when attributing this to musical sophistication only as there are several other factors that could be at play. In this study, cognitive reserve was controlled for since there are many other lifestyle factors that have been shown to increase performance on measures of language and cognition (e.g., education, SES, or bilingualism; Alladi et al., 2015; Bialystok et al., 2007; González-Fernández et al., 2011). Aptitude or genetic predisposition is another factor that could be involved in outcomes. For example, Amer et al. (2013) found that musicians were better at pitch perception, but it could be that a person became a musician because they already had these innate skills. It is possible that the people that decide to pursue musically-related activities are those with higher overall IQ (Schellenberg, 2006) or better auditory comprehension already, or that musicians that continue with training are the same type of people that push to do well in school. There are other studies that seek to address the possibility of pre-existing factors (e.g., Hanna-Pladdy & Gajewski, 2012, or Hyde et al., 2009), and this should continue to be a consideration for studies going forward.

Conclusion

This study did not find significant associations between musical sophistication scores on the Gold-MSI and severity of aphasia, individual language domains, or individual cognitive domains. Thus, we can conclude that the increased cognitive reserve afforded by musical sophistication does not consistently show behavioral benefits. Much of the literature with neurotypical individuals supports a relationship between music and language. Theory 1 suggested the relationship is direct, through neural overlap of musical and linguistic representations or through neural sharing of resources. Theory 2 suggested that the relationship is indirect, via mediating cognitive mechanisms like memory and cognitive control. In this study, neither theory is directly indicated, although moderate but non-significant correlations between variables (Gold-MSI and % Errors on the WAB-R, Gold-MSI and % Errors on the Auditory Comprehension subtest, Years of Training and Verbs/Utterance, and Years of Training and WAB AQ) provide more support for Theory 1 than Theory 2. It is possible that the relationships are blurred due to the neurological impairment in PWA, since findings do differ from those that are present in studies with neurotypical individuals.

Based on the background literature, the suggestion that musical sophistication benefits language performance still seems plausible, so future research should continue to investigate this question while accounting for considerations such as lesion volume and location, sample size, and the range of musical sophistication and language scores among participants.

References

Alladi, S., Bak, T. H., Mekala, S., Rajan, A., Chaudhuri, J. R., Mioshi, E., … Kaul, S. (2016). Impact of bilingualism on cognitive outcome after stroke. *Stroke, 47*, 258–261.

Amer, T., Kalender, B., Hasher, L., Trehub, S. E., & Wong, Y. (2013). Do older professional musicians have cognitive advantages? *PLOS ONE, 8*(8), e71630.

Anvari, S. H., Trainor, L. J., Woodside, J., & Levy, B. A. (2002). Relations among musical skills, phonological processing, and early reading ability in preschool children. *Journal of Experimental Child Psychology, 83*, 111–130.

Basso, A. (1992). Prognostic factors in aphasia. *Aphasiology, 6*, 337–348.

Bialystok, E., Craik, F. I. M., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia, 45*, 459–464.

Brod, G., & Opitz, B. (2012). Does it really matter? Separating the effects of musical training on syntax acquisition. *Frontiers in Psychology, 3*, 543.

Dabul, B. (2000). *Apraxia Battery for Adults-Second Edition.* Austin, TX: Pro-Ed.

De Renzi, E., & Nichelli, P. (1975). Verbal and non-verbal short-term memory impairment following hemispheric damage. *Cortex, 11*, 341–354.

Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270*, 305–307.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non- search task. *Perception and Psychophysics, 16*, 143–149.

Faroqi-Shah, Y., Sampson, M., Baughman, S., & Pranger, M. (2014). Inhibitory control, word retrieval and bilingual aphasia: Is there a relationship? *Frontiers in Psychology*. doi: 10.3389/conf.fpsyg.2014.64.00049

Faroqi-Shah, Y., Slevc, L. R., Saxena, S., & Pifer, M. (in preparation). *Structural processing of language and music in post-stroke aphasia.* Manuscript in preparation.

Fauvel, B., Groussard, M., Eustache, F., Desgranges, B., & Platel, H. (2013). Neural implementation of musical expertise and cognitive transfers: Could they be promising in the framework of normal cognitive aging? *Frontiers in Human Neuroscience, 7,* 693.

Fedorenko, E., & Varley, R. (2016). Language and thought are not the same thing: Evidence from neuroimaging and neurological patients. *Annals of the New York Academy of Sciences, 1369*(1), 132–153.

Forgeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *PLoS ONE, 3*(10), e3566.

Fromm, D., Forbes, M., Holland, A., Dalton, S. G., Richardson, J., & MacWhinney, B. (2017). Discourse characteristics in aphasia beyond the western aphasia battery cutoff. *American Journal of Speech-Language Pathology, 26*(3), 762–768.

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *Journal of Neuroscience, 23*(27), 9240–9245.

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia, 49*(5), 1083–1094.

Geranmayeh, F., Wise, R. J. S., Mehta, A., & Leech, R. (2014). Overlapping networks engaged during spoken language production and its cognitive control. *Journal of Neuroscience, 34*(26), 8728–8740.

Golden, C. J. (1978). *The Stroop color and word test.* Chicago, IL: Stoelting Company.

González-Fernández, M., Davis, C., Molitoris, J. J., Newhart, M., Leigh, R., & Hillis, A. E. (2011). Formal education, socioeconomic status, and the severity of aphasia after stroke. *Archives of Physical Medicine and Rehabilitation, 92*, 1809–1813.

Goodglass, H., Kaplan, E., & Barresi, B. (2001). Boston Diagnostic Aphasia Examination (3rd ed.). Austin, TX: Pro-Ed.

Hanna-Pladdy, B., & Gajewski, B. (2012). Recent and past musical activity predicts cognitive aging variability: Direct comparison with general lifestyle activities. *Frontiers in Human Neuroscience, 6*, 198.

Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology, 25*(3), 378–386.

Helm-Estabrooks, N. (2001). *Cognitive Linguistic Quick Test.* San Antonio, TX: Pearson.

Herdener, M., Humbel, T., Esposito, F., Habermeyer, B., Cattapan-Ludewig, K., & Seifritz, E. (2014). Jazz drummers recruit language-specific areas for the processing of rhythmic structure. *Cerebral Cortex, 24*(3), 836–843.

Ho, Y.-C., Cheung, M.-C., & Chan, A. S. (2003). Music training improves verbal but not visual memory: Cross-sectional and longitudinal explorations in children. *Neuropsychology, 17*(3), 439-450.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience, 29*(10), 3019–3025.

Jefferson, A. L., Gibbons, L. E., Rentz, D. M., Carvalho, J. O., Manly, J., Bennett, D. A., & Jones, R. N. (2011). A life course model of cognitive activities, socioeconomic status, education, reading ability, and cognition. *Journal of the American Geriatrics Society, 59*, 1403–1411.

Jentschke, S., & Koelsch, S. (2009). Musical training modulates the development of syntax processing in children. *Neuroimage, 47*(2), 735–744.

Johnston, M. V. (2009). Plasticity in the developing brain: Implications for rehabilitation. *Developmental Disabilities Research Reviews*, *15*, 94–101.

Jung, H., Sontag, S., Park, Y. S., & Loui, P. (2015). Rhythmic effects of syntax processing in music and language. *Frontiers in Psychology, 6,* 1762.

Kertesz, A. (1988). Lesion size and location in recovery from aphasia. *Journal of Neurolinguistics, 3*(1), 49–61.

Kertesz, A. (2007). *Western Aphasia Battery-Revised.* San Antonio, TX: Harcourt Assessment.

Kertesz, A., Lau, W. P., & Polk, M. (1993). The structural determinants of recovery in Wernicke's aphasia. *Brain and Language*, *44,* 153–164.

Kertesz, A., & McCabe, P. (1977). Recovery patterns and prognosis in aphasia. *Brain, 100,* 1–18.

Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: Influence of physical activity on cognition and brain function. *TRENDS in Cognitive Sciences,* *11*(8), 342–348.

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews: Neuroscience, 11*, 599–605.

Kunert, R., Willems, R. M., Casasanto, D., Patel, A. D., & Hagoort, P. (2015). Music and language syntax interact in Broca's area: An fMRI study. *PLoS ONE, 10*(11), *e0141069.*

Kuzmina, E., & Weekes, B. S., (2017). Role of cognitive control in language deficits in different types of aphasia. *Aphasiology, 31*(7), 765–792.

LaCroix, A. N., Diaz, A. F., & Rogalsky, C. (2015). The relationship between the neural computations for speech and music perception is context-dependent: An activation likelihood estimate study. *Frontiers in Psychology, 6*, 1138.

Lee, L. L., & Canter, S. M. (1971). Developmental sentence scoring: A clinical procedure for estimating syntactic development in children's spontaneous speech. *Journal of Speech and Hearing Disorders, 36*, 315–340.

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Martin, R. C. (2005). Components of short-term memory and their relation to language processing: Evidence from neuropsychology and neuroimaging. *Current Directions in Psychological Science, 14*(4), 204–208.

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science, 22*(11), 1425–1433.

Moussard, A., Bermudez, P., Alain, C., Tays, W., & Moreno, S. (2016). Life-long music practice and executive control in older adults: An event-related potential study. *Brain Research, 1642,* 146–153.

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLOS ONE, 9*(6), e101091.

Müllensiefen, D., Gingras, B., Stewart, L., & Musil, J. J. (2013). *Goldsmiths Musical Sophistication Index (Gold-MSI) v1.0: Technical report and documentation, Revision 0.3.* Retrieved from http://www.gold.ac.uk/media/documents-by-section/departments/psychology/Gold-MSIv10_Documentation-1.pdf

Noonan, K. A., Jefferies, E., Corbett, F., & Lambon Ralph, M. A. (2010). Elucidating the nature of deregulated semantic cognition in semantic aphasia: Evidence for the roles of prefrontal and temporo-parietal cortices. *Journal of Cognitive Neuroscience, 22*(7), 1597–1613.

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective, & Behavioral Neuroscience, 5*(3), 263–281.

Nucci, M., Mapelli, D., & Mondini, S. (2012a). *Cognitive Reserve Index questionnaire (CRIq).* Retrieved from http://www.cognitivereserveindex.org/CRI_2.0_EN.pdf

Nucci, M., Mapelli, D., & Mondini, S. (2012b). Cognitive Reserve Index questionnaire (CRIq): A new instrument for measuring cognitive reserve. *Aging Clinical and Experimental Research, 24*(3), 218–226.

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical* *sophistication using expert ratings*. Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=osu1161705351

Omigie, D., & Samson, S. (2014). A protective effect of musical expertise on cognitive outcome following brain damage? *Neuropsychology Review*, *24*, 445–460.

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science, 349*(6251), aac4716.

Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PLoS ONE*, *5*(6), e11120.

Patel, A. D. (2003). Language, music, syntax and the brain. *Nature Neuroscience*, *6*(7), 674–681.

Patel, A. D., Iversen, J. R., Wassenaar, M., & Hagoort, P. (2008). Musical syntactic processing in agrammatic Broca's aphasia. *Aphasiology*, *22*(7–8), 776–789.

Peretz, I. (1993). Auditory atonalia for melodies. *Cognitive Neuropsychology, 10*, 21–56.

Peretz, I., Vuvan, D., Lagrois, M.-E., & Armony, J. L. (2015). Neural overlap in processing music and speech. *Philosophical Transactions of the Royal Society B, 370, 20140090.*

Pohjasvaara, T., Vataja, R., Leppävuori, A., Kaste, M., & Erkinjuntti, T. (2001). Depression is an independent predictor of poor long-term functional outcome post-stroke. *European Journal of Neurology*, *8*(4), 315–319.

Ratey, J. J., & Loehr, J. E. (2011). The positive impact of physical activity on cognition during adulthood: A review of underlying mechanisms, evidence and recommendations. *Reviews in the Neurosciences, 22*(2), 171–185.

Rauscher, F. H. (2002). Mozart and the mind: Factual and fictional effects of musical enrichment. In J. Aronson (Ed.*), Improving academic achievement: Impact of psychological factors on education* (pp. 269–278). New York, NY: Academic Press.

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., & Nielsen, J. B. (2012). A single bout of exercise improves motor memory. *PLOS ONE, 7*(9), e44594.

Sachs, M., Kaplan, J., Der Sarkissian, A., & Habibi, A. (2017). Increased engagement of the cognitive control network associated with music training in children during an fMRI Stroop task. *PLoS ONE, 12*(10), e0187254.

Sala, G., & Gobet, F. (2017). When the music's over. Does music skill transfer to children's and young adolescents' cognitive and academic skills? A meta-analysis. *Educational Research Review, 20*, 55–67.

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98*(2), 457–468.

Schlaug, G., Norton, A., Overy, K., & Winner, E. (2005). Effects of music training on the child's brain and cognitive development. *Annals of the New York Academy of Sciences, 1060*, 219–230.

Schroeder, S. R., Marian, V., Shook, A., & Bartolotti, J. (2016). Bilingualism and musicianship enhance cognitive control. *Neural Plasticity, 2016,* 4058620.

Selnes, O. A., Knopman, D. S., Niccum, N., Rubens, A. B., & Larson, D. (1983). Computed tomographic scan correlates of auditory comprehension deficits in aphasia: A prospective recovery study. *Annals of Neurology, 5,* 558–566.

Sheikh, J. I., & Yesavage, J. A. (1986). Geriatric Depression Scale (GDS): Recent evidence and development of a shorter version. In T. L. Brink (Ed.*), Clinical gerontology: A guide to assessment and intervention* (pp. 165–173). New York, NY: Haworth Press.

Skoe, E., & Kraus, N. (2012). A little goes a long way: How the adult brain is shaped by musical training in childhood. *Journal of Neuroscience, 32*(34), 11507–11510.

Slater, J., Strait, D. L., Skoe, E., O'Connell, S., Thompson, E., & Kraus, N. (2014). Longitudinal effects of group music instruction on literacy skills in low-income children. *PLoS ONE, 9*(11), e113383.

Slevc, L. R., Faroqi-Shah, Y., Saxena, S., & Okada, B. M. (2016). Preserved processing of musical structure in a person with agrammatic aphasia. *Neurocase, 22*(6), 505–511.

Slevc, L. R., & Okada, B. M. (2015). Processing structure in language and music: A case for shared reliance on cognitive control. *Psychonomic Bulletin & Review, 22*, 637–652.

Slevc, L. R., Rosenberg, J. C., & Patel, A. D. (2009). Making psycholinguistics musical: Self-paced reading time evidence for shared processing of linguistic and musical syntax. *Psychonomic Bulletin & Review, 16*(2), 374–381.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47,* 2015–2028.

Strait, D. L., Kraus, N., Parbery-Clark, A., & Ashley, R. (2010). Musical experience shapes top-down auditory mechanisms: Evidence from masking and auditory attention performance. *Hearing Research, 261*, 22–29.

Stroop, J. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643–662.

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence, 62*, 119–124.

Talamini, F., Altoè, G., Carretti, B., & Grassi, M. (2017). Musicians have better memory than nonmusicians: A meta-analysis. *PLoS ONE, 12*(10), e0186773.

Thorne, J., & Faroqi-Shah, Y. (2016). Verb production in aphasia: Testing the division of labor between syntax and semantics. *Seminars in Speech and Language, 37*(1), 23–33.

Verghese, J., Lipton, R. B., Katz, M. J., Hall, C. B., Derby, C. A., Kuslansky, G., … Buschke, H. (2003). Leisure activities and the risk of dementia in the elderly. *The New England Journal of Medicine, 348*(25), 2508–2516.

Verhaegan, C., Piertot, F., & Poncelet, M. (2013). Dissociable components of phonological and lexical–semantic short-term memory and their relation to impaired word production in aphasia. *Cognitive Neuropsychology, 30*(7–8), 544–563.

White-Schwoch, T., Carr, K. W., Anderson, S., Strait, D. L., & Kraus, N. (2013). Older adults benefit from music training early in life: Biological evidence for long-term training-driven plasticity. *Journal of Neuroscience, 33*(45), 17667–17674.

Wilson, R. S., Barnes, L. L., & Bennett, D. A. (2003). Assessment of lifetime participation in cognitively stimulating activities. *Journal of Clinical and Experimental Neuropsychology*, *25*(5), 634–642.

Zivin, J. A. (2009). Acute stroke therapy with tissue plasminogen activator (tPA) since it was approved by the U.S. Food and Drug Administration (FDA). *Annals of Neurology*, *66*, 6–10.