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Cognitive Reserve: Building a Healthy Brain

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Abstract

Previous research has shown that lifelong experiences with complex sensory-motor activities, such as multilingualism and musicianship, contribute to a neuroprotective effect that delays the symptoms of dementia. This effect is called cognitive reserve, and it differs from neurological brain reserve, as it is developed through behavior rather than genetic or biological factors. However, synthesis across multiple fields of inquiry is necessary to characterize the neural mechanisms behind cognitive reserve as created by multilingualism and musicianship. This review intends to integrate previous results, while advocating for a greater understanding of cultural diversity in neuroscience studies of language and music. Research in this field has the potential to promote healthy aging through lifestyle changes, decreasing the social, emotional, and financial burden of dementia, while creating a more culturally connected world.

What is Cognitive Reserve?

Behavioral brain reserve, also known as cognitive reserve, is described by Valenzuela & Sachdev as "complex mental activity across the lifespan [allowing] flexible cognitive repertoires to be deployed in the face of underlying neural dysfunction" (2006: 441). Cognitive reserve differs from neurological brain reserve because rather than relying on biological factors, such as brain volume, it is generated through a lifetime of actions. This means that lifelong experiences of mentally stimulating activities can enable the brain to rewire itself, finding ways to maintain healthy function despite the presence of atrophy due to aging or pathology. Valenzuela & Sachdev demonstrated that high cognitive reserve, as indexed by education, occupation, and mentally stimulating leisure activities, was associated with a 46% decrease in dementia risk

(447). The most robust results came from studies of leisure activities, suggesting that cognitive brain reserve is largely built through lifestyle (Valenzuela & Sachdev 2006: 449).

As Kees de Bot explains, by 2050, the elderly population will outnumber the young (2010: 425). Finding healthy ways to age is necessary to improve quality of life, delay a loss of autonomy, and decrease the financial burden caused by cognitive decline in the older adult population. One of the reasons for cognitive decline is a shift in communication with younger generations (de Bot 2010: 428). Since older adults are often assumed to have declining cognitive abilities, younger generations interact with them in a way that is simpler and easier to understand. This decreases the opportunities for older individuals to challenge themselves and forces them into more simple language use, causing them to lose their complex language skills. This ends up leading to a decline in these cognitive abilities, confirming the expectations of this stereotyped perception (de Bot 2010: 428). Sharing information about cognitive reserve has the potential to deconstruct the essentialist view of aging. An aging brain does not need to be an unhealthy one. Rather, the function of an individual's brain is based on a lifetime of experiences.

The Multilingual Advantage

Bialystock et al. displayed that multilingualism provides a cognitive reserve that delays the symptoms of dementia by 4.1 years (2007: 462). One possible behavioral mechanism is that when using one language, multilinguals must inhibit their other languages, improving their ability for attentional control. Abutalebi et al. explained that aging bilinguals perform better than aging monolinguals on the Flanker task (2015b: 209). This task is designed to measure inhibitory control and requires selective attention to a central target that is flanked by either congruent, incongruent, or neutral distractor stimuli. The ability to selectively attend to target stimuli may improve cognitive abilities in older multilinguals, as selective attention is important for many other cognitive functions, including encoding of memories and communication.

Another hypothesis is that multilinguals have an improved cognitive flexibility that allows them to take advantage of neural pathways that remain intact. Kovács & Mehler demonstrated that cognitive flexibility for bilinguals begins in infancy. Bilingual infants were able to learn two linguistic structures at once, whereas monolingual infants were only able to learn one linguistic structure at a time (2009: 611-612). This ability to adjust cognitive processing to reflect changing tasks may be what allows older multilinguals to continue to exhibit high cognitive functioning despite aging.

There are also structural changes in the brain that may drive cognitive reserve in multilinguals. For example, Abutalebi et al. provided evidence that gray matter volume in the right inferior parietal lobule decreases for aging monolinguals, but it stays the same for aging bilinguals (2015a: 11). There is also evidence that bilinguals have increased gray matter in the anterior cingulate cortex (Abutalebi et al. 2015b: 209) and caudate nucleus of the basal ganglia (Wong et al. 2016: 4). All regions mentioned are associated with cognitive control, perhaps relating to multilinguals' improved performance on the Flanker task. Further research is needed to determine whether there is a causative effect between these neural and behavioral mechanisms; however, this suggests that multilingualism not only provides a cognitive benefit, but it may also maintain the biological structure of the brain.

There has also been evidence to suggest that bilingualism increases white matter integrity in the left superior longitudinal fasciculus, as measured by axial diffusivity (Anderson et al. 2018: 148). This white matter fiber tract connects the pars opercularis, important for language production, with the language-receptive areas in the temporal lobes (Anderson et al. 2018: 149).

Increased white matter integrity in this fiber tract is likely due to the increased task demands of language use for bilinguals, as bilinguals must adjust their phonology to match the language currently in use. A decrease in the white matter integrity of this fiber tract has been associated with the progression of Alzheimer's Disease, providing further evidence that this pathway is important to cognitive functioning (Anderson et al. 2018: 143).

Bilinguals also benefit from increased functional connectivity. There is evidence to suggest that bilinguals have a greater functional connectivity than monolinguals in a network comprising the insula, superior temporal gyrus, pars triangularis, pars opercularis, and medial superior frontal gyrus (Wong et al. 2016: 7). The proposed function of this network is to control interference between languages (Wong et al. 2016: 7). A second network has also showed increased functional connectivity for bilinguals, comprising the right superior frontal gyrus, left superior occipital gyrus, right superior frontal gyrus, left superior parietal gyrus, left superior temporal pole, and left angular gyrus (Wong et al. 2016: 7). The proposed function of this network is to facilitate reading and identification of visual morphemes (Wong et al. 2016: 7). The increased connectivity between these regions may also support other cognitive processes, as the brain should be viewed as multimodal rather than modular.

Music and the Mind

Pladdy & MacKay explained that musical training throughout the life span has been associated with improved non-verbal memory performance, naming, and executive processes in aging individuals (2011: Abstract). Musicianship also provides many benefits in the auditory domain. Aging musicians are better at listening in noisy conditions (Kraus 2021: 234). This may suggest a similar behavioral mechanism to multilingualism, as listening in noisy conditions requires selective attention.

Another effect of musicianship is evident in studies of the frequency-following response, a neural response to sound believed to originate mainly from the brainstem. Healthy aging in non-musicians is typically associated with a decrease in the fidelity of this response, but this decline is attenuated in musicians (Kraus 2021: 234). This suggests that the encoding of sound remains intact in aging musicians at the level of the brainstem.

One possible neural mechanism for this cognitive reserve provided by lifelong musicianship is gray matter volume. Gaser & Schlaug found that professional musicians had increased gray matter volume in primary motor areas, somatosensory areas, premotor regions, superior parietal regions, and the inferior temporal gyrus bilaterally (2006: 516). These regions are part of networks proposed to facilitate motor skill learning and translation from visual musical notation to motor commands (2006: 516).

Another possible neural mechanism is white matter integrity. Andrews et al. displayed a trend towards an increase in white matter integrity in the bilateral superior longitudinal fasciculi and bilateral uncinate fasciculi in aging musicians as compared to young musicians (2021: 5). This suggests that musicianship may reverse the loss of integrity of white matter fiber tracts typically seen in aging. There is also evidence to suggest that in lifelong musicians, average connectivity between resting-state networks, including the default mode, auditory, visual, and sensorimotor networks, increases with age, while in non-musicians, network connectivity decreases with age (Eierud et al. 2023: 4). Therefore, lifelong musicians may receive a cognitive benefit from maintaining the connections between different networks in the brain. This may be built by music's tendency to recruit multiple networks simultaneously. Playing a musical instrument involves many sensory, motor, and executive control functions. Engaging these functions simultaneously may strengthen the connections between these networks.

The Speech Act and the Musical Utterance

There are many similarities between the speech act and the musical utterance. According to Roman Jakobson, all speech acts have six factors and six functions, and meaning emerges through the re-hierarchization of these functions (1990: 73, 77). The six factors are contact (the connection between at least two individuals), context (the physical and cultural environment in which the act is embedded and to which the act refers), addresser (the person speaking), addressee (the person or people hearing), code (the language), and message (the information communicated between at least two individuals) (Jakobson 1990: 73). Each of these factors map onto distinct functions: phatic (opening the channel), referential (expressing the context), emotive (sharing intentions of the addresser), conative (sparking action in the addressee), metalingual (commenting on the code), and poetic (the aesthetic beauty with which the message is presented) (Jakobson 1990: 77). Speech acts are always plural, have histories, and are embedded in speech communities. As Jakobson explains, "…language is THE necessary and substantial foundation of human culture" (1985: 107).

Bruno Nettl explains that music is also strongly connected to culture. He describes music as having social units, like speech communities (2019: 465). These social units often claim specific musics as their own, just as members of a speech community share rules for the conduct and interpretation of language. Nettl shares that music is used in most cultures to mark the importance of an event, and it likely helped coordinate early communities in ritualistic movement due to its strong sense of rhythm (2019: 472). However, he argues that language is more universal in human culture, as those without language are not seen as participants in human culture, whereas those without music may still be cultural beings (2019: 467).

The musical utterance is also similar to the speech act in that all musical utterances have histories. Even in improvisation, musicians constantly draw inspiration from previous performances in what are called musical "quotations" and follow conventions established by centuries of musical utterances. Jakobson stated that "Language is overcoming of isolation in space and time" (1985: 101). This also holds true for music. Performing music written in or inspired by another time or cultural space deconstructs this isolation.

The emergence of meaning in music can also be described by the Jakobsonian speech act model. In the musical utterance, there is also a need to open the channel (phatic), to refer to the culture in which it is embedded (referential), to share the intentions of the performer (emotive), to inspire action in the audience (conative), to comment on and bend the rules of the code (metalingual), and to provide a sense of aesthetic beauty (poetic). The dominant function in a musical utterance is constantly shifting and can be interpreted differently by different participants in the act within different cultural spaces and times. Andrews et al. suggests modeling of musical acts that includes signification and communication, drawing parallels with linguistic models and expanding past simply referential meaning (Forthcoming, Abstract). All musical utterances have multiple meanings.

Another similarity between languages and musics are that they are learned. As Dwight Bolinger explains in his example of the word *lemon*, once the connection between a form and its meaning is learned, the sign becomes just as real as the sensory experience of its referent (1965: 233). Language is learned through language. Therefore, the connection between forms and meanings is learned. However, this connection is not arbitrary, as meanings affect forms and forms affect meanings.

This process may explain the assumption that musical intervals are innate. Patel explains that although certain intervals may sound natural based on their frequency in a specific culture's music, pitch intervals are learned sound categories (2008: 22). He also explains that musicians perceive pitch intervals categorically, whereas non-musicians do not (2008: 25). This provides further support for the notion that musical pitch intervals are learned.

The All-Purpose Auditory System

The processing of music and speech also share neural correlates. Schirmer et al. found that the temporal lobes serve as a bilateral all-purpose auditory system that is shaped by auditory experiences (2012: 146). This suggests that the processing of both music and language relies on the same system. Further evidence for this cross-modal processing comes from Weiss & Bidelman's study of the frequency-following response (FFR) in musicians as compared to non-musicians. In this study, naive listeners classified sonifications of brainstem-evoked potentials from individuals with extensive musical training faster and more categorically than potentials from non-musicians (Weiss & Bidelman 2015: 1687). This suggests musicians' encoding of speech in the brainstem is clearer and contains more behaviorally relevant speech cues than that of non-musicians (Weiss & Bidelman 2015: 1687).

The behavioral and neural similarities between linguistic and musical processing suggest that similar mechanisms may support the development of cognitive reserve in multilinguals and musicians. As mentioned above, both aging multilinguals and aging musicians have improved executive control processes, specifically selective attention and inhibitory control. These processes are constantly employed by multilinguals to inhibit other languages and attend to the most appropriate language for a given situation. Musicians also employ these processes flexibly and in real time. For example, in a large ensemble, it is crucial that a musician can selectively attend to other musicians on their instrumental part for tuning purposes and ignore a noisy audience. The role of a conductor also requires extreme flexibility in attention, hearing at once the individual parts and the overall sound.

There are also similarities in the possible neural mechanisms of cognitive reserve in multilinguals and musicians. Both aging multilinguals and aging musicians have exhibited increased white matter integrity in the superior longitudinal fasciculi. These white matter fiber tracts connect the parietal, occipital, and temporal lobes with the frontal cortices (Kamali et al. 2014: 269). These tracts are an important part of networks that support attention, memory, emotions, and language (Kamali et al. 2014: 269). This displays a clear connection to the proposed behavioral mechanism of improved selective attention.

Multilinguals and musicians also exhibit increased functional connectivity in networks that include the superior temporal gyrus and superior occipital gyrus. This reflects the employment of both auditory and visual sensory regions in the processing of music and language. Most musicians trained in Western classical music learn how to read music visually as well as listen. It is important for these musicians to connect visual symbols with sounds and motor programs. Learning a language is very similar. Most first languages are learned through the oral-aural channel; however, reading is a crucial skill for contributing to and learning from human culture. Bolinger argues for the existence of visual morphemes, describing three types: those that exist independently of auditory morphemes, those that supplement auditory morphemes, and those that supplant auditory morphemes (1965: 269). This elucidates a possible reason for increased connectivity between auditory and visual networks and the rest of the brain in multilinguals and musicians.

Conclusions and Future Directions

Evidence has been presented to suggest that multilingualism and musicianship provide a cognitive reserve that protects cognitive functioning in older adults. A possible behavioral mechanism for this effect is an increased ability for selective attention and inhibitory control, constructed by a lifetime of speech acts and musical utterances. This may be supported by increased white matter integrity in the superior longitudinal fasciculi and increased functional connectivity with the auditory and visual networks. Further research is needed to determine whether these differences improve cognitive ability in older adults. It is also important to determine whether musicianship and multilingualism cause these changes rather than people with these structural and behavioral differences being more likely to become musicians and multilinguals.

Another future possibility in this field is the study of multi-musicality. People are members of multiple and changing speech communities. This is the same with music. Nettl explains that there are no musical universals, and multiple musics can exist in a single cultural space (2019: 465). To understand how music impacts neural function, it is crucial to study the musics of many different cultures and acknowledge that all musicians interact with multiple musical "languages".

Further research on cognitive reserve as constructed by multilingualism and (multi) musicality has the potential to advocate for more wide-spread second language and musical education in primary and secondary schools to change the way we age. This will not only create a more cognitively resilient population, but it will also increase cultural diversity and deconstruct the essentialist view of aging. With these lifestyle changes, we can build a healthy brain.

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