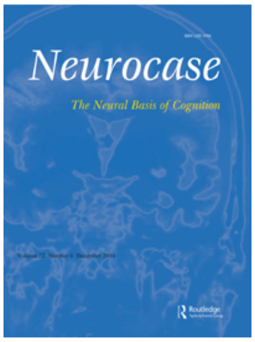

Neurocase

The Neural Basis of Cognition

ISSN: 1355-4794 (Print) 1465-3656 (Online) Journal homepage: http://www.tandfonline.com/loi/nncs20

Preserved processing of musical structure in a person with agrammatic aphasia

L. Robert Slevc, Yasmeen Faroqi-Shah, Sadhvi Saxena & Brooke M. Okada

To cite this article: L. Robert Slevc, Yasmeen Faroqi-Shah, Sadhvi Saxena & Brooke M. Okada (2016) Preserved processing of musical structure in a person with agrammatic aphasia, Neurocase, 22:6, 505-511, DOI: 10.1080/13554794.2016.1177090

To link to this article: http://dx.doi.org/10.1080/13554794.2016.1177090

Published online: 26 Apr 2016.

NEUROCASE, 2016
VOL. 22, NO. 6, 505–511
http://dx.doi.org/10.1080/13554794.2016.1177090

Routledge
Taylor & Francis Group

Preserved processing of musical structure in a person with agrammatic aphasia

L. Robert Slevc[a], Yasmeen Faroqi-Shah[b], Sadhvi Saxena[a] and Brooke M. Okada[a]

[a]Department of Psychology, University of Maryland, College Park, Maryland, USA; [b]Department of Hearing and Speech Sciences, University of Maryland, College Park, Maryland, USA

ABSTRACT

Evidence for shared processing of structure (or syntax) in language and in music conflicts with neuropsychological dissociations between the two. However, while harmonic structural processing can be impaired in patients with spared linguistic syntactic abilities (Peretz, I. (1993). Auditory atonalia for melodies. *Cognitive Neuropsychology, 10*, 21–56. doi:10.1080/02643299308253455), evidence for the opposite dissociation–preserved harmonic processing despite agrammatism–is largely lacking. Here, we report one such case: HV, a former musician with Broca's aphasia and agrammatic speech, was impaired in making linguistic, but not musical, acceptability judgments. Similarly, she showed no sensitivity to linguistic structure, but normal sensitivity to musical structure, in implicit priming tasks. To our knowledge, this is the first non-anecdotal report of a patient with agrammatic aphasia demonstrating preserved harmonic processing abilities, supporting claims that aspects of musical and linguistic structure rely on distinct neural mechanisms.

ARTICLE HISTORY
Received 17 November 2015
Accepted 5 April 2016

KEYWORDS
Language; music; syntax; agrammatism; atonalia

Does the processing of linguistic and musical structure rely on modular, domain-specific (e.g., Peretz & Coltheart, 2003), or on shared, domain-general mechanisms (e.g., Patel, 2003)? This question has attracted considerable interest, in part because it speaks to broad questions of modularity and because comparative research can inform the neurobiology of linguistic and musical abilities. Neuroimaging studies of musical structure often implicate areas associated with linguistic syntax (review: LaCroix, Diaz, & Rogalsky, 2015), and concurrent structural manipulations in language and music produce behavioral and electrophysiological interactions (review: Kunert & Slevc, 2015). However, the conclusion that linguistic and musical structure are closely related is tempered by neuropsychological dissociations between deficits of linguistic and musical structural processing (e.g., Peretz, 1993), which suggest that these processes rely on distinct neural mechanisms.

To reconcile evidence for shared processing with neuropsychological dissociations, Patel (2003, 2008, 2012) proposed the *shared syntactic integration resource hypothesis* (SSIRH), which suggests that structural processing in language and music rely on shared integration resources localized in frontal regions, but that these resources act on domain-specific representations based in the temporal lobes. By the SSIRH, evidence for shared structural processes in language and music reflect reliance on these shared integration resources (although the specific nature of these resources is debated; e.g., Slevc & Okada, 2015). In contrast, neurological dissociations reflect damage to language- or music-specific representation networks.

However, there is not (as of yet) unambiguous evidence for a *double* dissociation between deficits involving musical and linguistic structure (*atonalia* and *agrammatism*). There is good evidence for atonalia without agrammatism: Peretz's (1993) patient GL regained language and pitch perception abilities following bilateral aneurysms, but remained insensitive to tonal structure (e.g., showing no ability to recognize melodic closure). However, we know of no cases that clearly show the opposite pattern: preserved processing of musical structure despite agrammatism. There are certainly suggestive cases; most famously, the composer Vissarion Shebalin suffered a series of strokes that left him with severe Wernicke's aphasia, yet continued to compose highly regarded music, including his fifth symphony (Luria, Tsvetkova, & Futer, 1965). Similarly, Basso and Capitani (1985) described a patient who could conduct complex music despite severe global aphasia (and ideomotor apraxia). It is difficult to imagine how one could successfully compose or conduct without an understanding of musical structure, however these patients' linguistic deficits may not have impacted their syntactic abilities per se, and so structural processing may have been preserved in both domains.

If no cases of preserved musical structure processing despite agrammatism exist, this could suggest that linguistic and musical representations are not, in fact, neurally distinct; instead, damage to the same neural structures may simply impact musical structure more than linguistic structure. If so, associations between agrammatism and musical structural processing (Patel, Iversen, Wassenaar, & Hagoort, 2008; Sammler, Koelsch, & Friederici, 2011) might reflect damage to shared representations (not just to shared processing resources). Here, however, we describe a patient exhibiting this previously undocumented dissociation–severe agrammatism despite normal processing of musical structure–lending clear support for a neural separation between aspects of musical and linguistic structural processing.

CONTACT L. Robert Slevc slevc@umd.edu

Table 1. Summary of HV's scores on the western aphasia battery revised (Kertesz, 2006).

Subtest	Score
Fluency	3/10
Information content	4/10
Auditory verbal comprehension	6.5/10
Repetition	1/10
Naming and word finding	2.4/10
Apraxia	55/60

Case history

At the time of testing, HV (identified by a subject code) was a 63-year-old right-handed native English speaking female. Approximately five months before testing, HV suffered a cerebrovascular accident (CVA) leading to right-side hemiplegia and aphasia. MRI at her initial diagnosis revealed an acute infarct in the area of the left middle cerebral artery, leading to damage to the left temporal and adjacent parietal lobe. Clinical assessment at the time of CVA led to a diagnosis of severe expressive aphasia, with a complete lack of functional speech. When tested five months later on the Western Aphasia Battery-Revised (Kertesz, 2006), HV showed a profile of Broca's aphasia, with an aphasia quotient of 33.6 (possible range = 0–100). She performed reasonably well on single word and simple sentence comprehension, but showed poor comprehension of complex sentences. Her language production was markedly impaired across multiple elicitation tasks, including picture description, naming, and repetition (see Table 1). Analysis of her narrative language (MacWhinney, Fromm, Forbes, & Holland, 2011) revealed an agrammatic pattern characterized by short utterances (mean length of utterance = 1.5), few grammatical utterances (8/185), paucity of verbs (15 verbs in a 287 word sample, noun:verb ratio = 1.7), and simplified verbal morphology. Most of her language consisted of pronouns and highly frequent words such as *okay*, *yeah*, and *no*, with almost no functional morphology. As with most English speaking agrammatic persons, she overused the progressive verb inflection, *ing*. A sample of HV's narrative language production is included in the Appendix.

Before her stroke, HV worked as a singer and entertainer, performing country, bluegrass, and gospel music. Although HV did not have formal musical training, she started playing music at the age of nine and remained continuously involved in musical activities throughout her life. On the Ollen Musical Sophistication Index (Ollen, 2006), she scored 954 of a possible 1000, indicating a very high (95%) probability that a music expert would categorize her as "musically sophisticated."

Below, we report a series of tests evaluating HV's linguistic and musical structural processing, as well as that of twelve older adult control participants, using matched "off-line" acceptability judgment tasks (Experiment 1) and "on-line" priming tasks (Experiment 2).

Experiment 1

In Experiment 1, participants were asked to make explicit acceptability judgments of linguistic and of musical structure, following Patel et al. (2008). If HV does, in fact, show preserved musical structural processing despite agrammatism, she should be impaired (relative to control participants) in linguistic grammaticality judgments but not in harmonic acceptability judgments.

Participants

HV and 16 control participants (three male) were recruited from the University of Maryland community. Control participants were neurologically healthy right-handed native English speaking adults with an average age of 60 (SD = 8.2, range = 44–74); this did not significantly differ from HV's age (of 63; t = 1.58, *n.s.*). These control participants were not matched to HV in terms of musical experience, however note that sensitivity to musical structure appears to result from normal exposure to music and does not tend to vary as a function of explicit musical training (Bigand & Poulin-Charronnat, 2006). HV and control participants were also not matched in education: HV had 13 years of formal education, whereas our control participants had an average of 16.5 years (SD = 2.7, range = 13–21).

Method

Linguistic acceptability judgments

Sentences for the linguistic acceptability judgments (from Faroqi-Shah & Dickey, 2009) consisted of 40 sentences with morphosyntactic errors, and 60 filler sentences (40 syntactically accurate and 20 with semantic anomalies). The morphosyntactic errors all involved violations of verb morphology, including auxiliary-verb inflection mismatches (e.g., *The baby is spill the milk*) and incorrect tense (e.g., *Tomorrow the tourist stayed at a motel*) because processing of verb morphology is most challenging for persons with agramamtic aphasia relative to other syntactic constraints such as subject-verb agreement (Friedmann & Grodzinsky, 1997). These sentences were recorded by a male native speaker of English and were presented in a pre-determined random sequence.

Participants were instructed to listen to each sentence and to decide if it was an acceptable sentence or if it was ungrammatical or did not make sense. Participants pressed a key to begin each trial and indicated their decision by pressing one of two colored keys (yellow for acceptable or blue for unacceptable) with their left hand (left hand responses were used to account for HV's right hemiplegia). After five practice trials with feedback, participants proceeded to judge the 100 test sentences.

Musical acceptability judgments

Stimuli for the musical acceptability judgment task were 36 chord sequences (from Patel, Gibson, Ratner, Besson, & Holcomb, 1998) that ranged from 7 to 12 chords in length, were played in a piano timbre, and clearly established a musical key (three sequences in each of the 12 major musical keys). Each sequence occurred in two forms: one "acceptable" form with all harmonically expected (in-key) chords, and one "unacceptable" form where one chord (the fifth or later) was replaced with a chord from a distant key (see Patel et al., 1998, for details). Items were presented in a fixed pseudorandom order, constrained such that the acceptable and unacceptable versions of each sequence occurred in different halves of the task and at least six trials apart. The first two items were used for practice and were excluded from analysis.

Participants were instructed to listen to each sequence and to press yellow if the tones fit together, or blue if some tones don't belong, using their left hand. After four practice trials with feedback (in-key and out-of-key versions of two items), participants proceeded to judge the remaining 68 sequences, with a break halfway through.

Results and discussion

Performance on both linguistic and musical acceptability judgment tasks was evaluated with *d-prime* (discriminability) scores, and HV's performance was compared to that of the control group using Crawford and Howell's (1998) modified *t*-test. As can be seen in the left side of Figure 1, control participants were highly accurate on linguistic judgments (with discrimination performance significantly above chance; t = 17.21, p < .001). In contrast, HV was unable to accurately discriminate grammatical from ungrammatical sentences, which differed significantly from control participants' performance (Crawford's t = −3.98, p < .01).

Control participants also discriminated between sequences with in-key and out-of-key chords above chance (Figure 1, right; t = 6.18, p < .001). In contrast to her performance with linguistic judgments, HV discriminated between these musical sequences just as well as controls (Crawford's t = −0.62). HV thus showed a classical dissociation between accuracy on linguistic and musical acceptability judgments (assessed with Crawford & Garthwaite's, 2005, *Revised Standardized Difference Test;* t = 2.62, p < .05), demonstrating agrammatism without atonalia. This, along with findings of the opposite dissociation (Peretz, 1993), support claims for neural separation between aspects of structural processing in language and music.

These acceptability judgment tasks, however, have some limitations. For one, syntactic acceptability is likely a graded, not binary quality (perhaps especially in music, where harmonic structure is not so much a set of *rules* as a collection of *norms* that are constantly challenged and changing; e.g., de Clercq & Temperley, 2011). A second limitation is that the

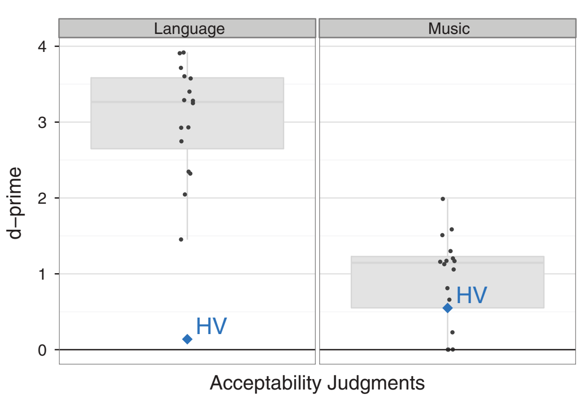

Figure 1. Acceptability judgment performance (d-prime) on linguistic (left) and musical (right) acceptability judgment tasks for control participants (boxplots indicate group-level data and black circles indicate individual control participants) and for HV (labeled diamond).

linguistic acceptability judgment task looked only at morphosyntactic violations. Although agrammatic aphasia is most strongly associated with difficulties with verb morphology (e.g., Friedmann & Grodzinsky, 1997), this is nevertheless not a comprehensive test of linguistic structural processing. In addition, the metacognitive nature of these tasks likely places considerable demands on attention and memory (Caplan & Waters, 1999), so task performance could reflect various cognitive processes. Indeed, there is evidence that amusic individuals can show sensitivity to musical structure in implicit measures despite poor performance on explicit tasks (Omigie, Pearce, & Stewart, 2012; Tillmann, Gosselin, Bigand, & Peretz, 2012; Tillmann, Peretz, Bigand, & Gosselin, 2007). Similarly, agrammatic aphasic persons can show sensitivity to linguistic structure in online measures despite poor performance in explicit comprehension measures (e.g., Dickey, Choy, & Thompson, 2007). Thus, Experiment 2 was designed to circumvent these concerns by assessing HV's sensitivity to linguistic and musical structure using implicit "online" tasks.

Experiment 2

In Experiment 2, participants completed priming tasks designed to implicitly assess sensitivity to linguistic and musical structure. If HV's impaired linguistic but preserved musical judgments in Experiment 1 truly reflect preserved harmonic processing ability despite agrammatism, she should exhibit the same pattern of performance-impaired sensitivity to linguistic structure but normal sensitivity to musical structure on these "online" tasks.

Participants

HV and the same 16 control participants from Experiment 1 participated in Experiment 2.

Method

Word monitoring task

In order to implicitly evaluate processing of linguistic syntax, we used a word monitoring paradigm (Marslen-Wilson & Tyler, 1980) modeled after Peelle, Cooke, Moore, Vesely, and Grossman (2007). In this task, participants were instructed to simply monitor spoken sentences for a specific target word, and press the spacebar as quickly as possible when that word occurred. When target words follow grammatical errors, participants are typically slow to respond (relative to words in grammatical contexts), and this slowing can be taken as evidence for sensitivity to that grammatical error (Peelle et al., 2007).

In the 45 critical sentences, the target word (indicated by * in the following examples) occurred shortly after a grammatical violation, allowing us to measure delay in word monitoring caused by sensitivity to the violation. In fillers and correct sentences, the word to be monitored occurred at different sentence positions to preclude participants from predicting word location. Following Friederici (1995) and Peelle et al. (2007), grammatical violations were of three types (N = 15 each): *thematic violations* in which the verb's arguments violated selectional restrictions which constrain the meaning of the verb (e.g., *The teacher trimmed the *students to do well in class*), *morphosyntatic violations* which were errors with functional morphology (e.g., *The woman will removing her *shoes in the front porch*), and *word class substitutions* in which the sentence main verb was substituted by a noun (*The driver will folder the *roses to the new office*). Filler sentences were 30 semantically anomalous and 75 accurate sentences. Stimuli were recorded by a female native speaker of English and were presented in a pre-determined random sequence, following five practice trials. Participants pressed a key to start each trial, then heard the word to be monitored followed by a beep and, 1000 ms later, the sentence.

Harmonic priming task

To evaluate online processing of musical structure, we relied on a harmonic priming paradigm (Bharucha & Stoeckig, 1986; Tillmann, Bigand, Escoffier, & Lalitte, 2006), where participants' judgments about a nonharmonic feature of a target chord (here, of the chord's timbre) are influenced by that chord's harmonic function. Stimuli were 24 eight-chord sequences (see Figure 2 for an example): the first seven chords were played with a harpsichord timbre and the final chord was played either with a trumpet or a vocal (choir) timbre. The sequences ended either with an authentic cadence, where the last (tonic) chord is highly expected (V–I), or a less-expected subdominant chord (I–IV). Sequences were yoked such that the same final two chords occurred in each tonal context, thus the comparison of harmonic conditions involved acoustically identical chords. Items were presented in a fixed pseudorandom order such that the trumpet- and choir-endings of each sequence occurred in different halves of the task and at least five trials apart.

Participants were instructed to listen to each sequence and quickly press the yellow button if the final chord was played by a trumpet or the blue button if it was sung by a choir (using their left hand). Line drawings of a trumpet and of a choir appeared on the screen over the appropriate response buttons during the onset of the final chord. After examples of the two timbres and two practice trials (one ending with each timbre), participants heard and categorized 48 sequences with a short break halfway through.

Results and discussion

HV responded more slowly than control participants on both tasks: her mean word monitoring time was 732 ms, compared to controls' mean of 398 ms (SD = 128 ms) and her mean harmonic priming time was 1880 ms, compared to controls' mean of 1089 ms (SD = 494 ms). Because we are interested in differences between conditions rather than task latency per se, accurate response times on both tasks were standardized (z-scored) for each participant (following Tillmann et al., 2012). Sensitivity to structural manipulations was calculated as the difference between standardized RTs in the two conditions, and HV's difference score was compared to the control participants' scores using Crawford and Howell (1998) modified *t*-test.

Control participants were significantly slower to respond to words that followed grammatical violations compared to words in grammatical contexts ($t = 11.32$, $p < .001$), but HV showed no such sensitivity to grammatical errors and her difference score differed significantly from control participants' scores (Figure 3, left; Crawford's $t = -3.83$, $p < .01$). Control participants also showed sensitivity to harmonic structure by categorizing timbres significantly faster on subdominant than on tonic chords ($t = 2.19$, $p < .05$) and HV's harmonic priming effect did not differ from that of the control participants (Figure 3, right; Crawford's $t = 1.45$).

Taken together, and mirroring the results of Experiment 1, HV showed a classical dissociation between performance on implicit measures of linguistic and musical syntactic processing (Revised Standardized Difference Test: $t = 3.47$, $p < .01$).

Surprisingly, the harmonic priming effect observed here was the reverse of the typical pattern, where responses are faster on sequences ending on the tonic than on the

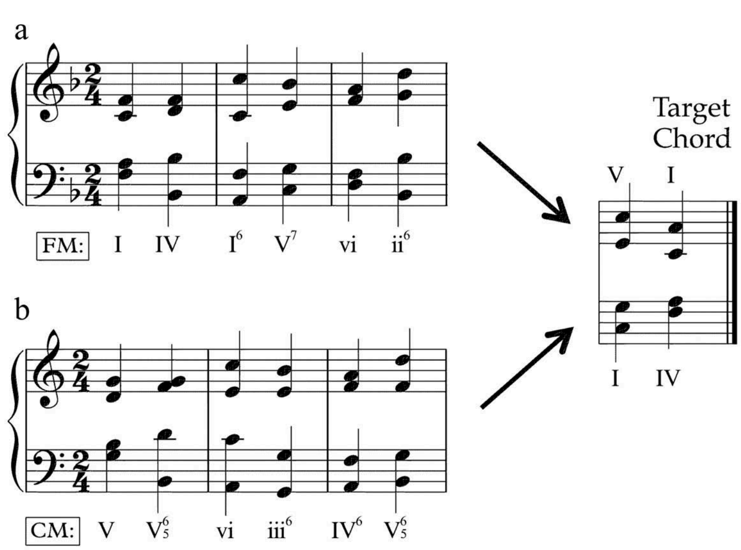

Figure 2. Example stimuli from the harmonic priming task. The final two chords (here, C and F) act as V–I (an authentic cadence) following the F-major context in (A) or as a less-expected I–IV following the C-major context in (B).

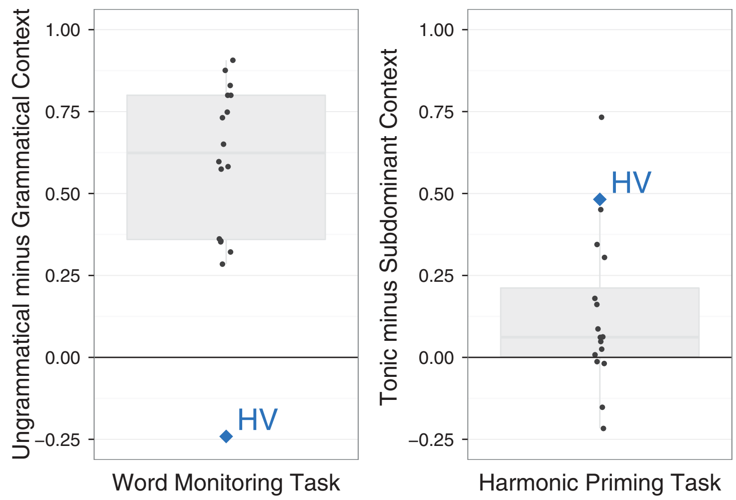

Figure 3. Performance on implicit measures of linguistic and musical structure for control participants (boxplots represent group-level data and black circles represent individual participants) and for HV (labeled diamond). The Y-axis represents standardized difference scores for the linguistic word-monitoring task (mean z-scored RT for words following ungrammaticalities minus mean z-scored RT for words in grammatical sentences) and for the musical harmonic priming task (mean z-scored RT for timbre judgments on tonic (I) chords minus mean z-scored RT for timbre judgments on subdominant (IV) chords).

subdominant (e.g., Bharucha & Stoeckig, 1986; Tillmann et al., 2012). This is not problematic for the conclusion that HV is sensitive to harmonic structure because the target chords were identical except for their harmonic function, and so any difference presumably reflects sensitivity to musical structure. Further suggesting this "reverse" effect indeed reflects normal sensitivity to harmonic structure, we replicated this pattern using these same stimuli in a group of 24 University of Maryland undergraduates, who were also faster on subdominant compared to tonic trials (t = 3.82, p < 0.001).

Nevertheless, it is surprising that responses to a subdominant chord were faster, not slower, than those to a tonic chord. This likely reflects two aspects of our task and stimuli: first, the subdominant chord in the "unexpected" condition always followed an authentic cadence (V–I–IV), and second, all trials were different-timbre trials (to make the task easier for aphasic participants; most paradigms contrast same vs. different timbre). It might be relatively unsurprising to hear a new instrument (timbre) play a subdominant (IV) right after an authentic cadence, which signals the conclusion of a musical phrase (as in the V–I–IV condition), but might be somewhat more surprising to hear a new instrument suddenly finish a nearly complete phrase (as in the V–I condition). Listeners are certainly sensitive to cadential expectancies (e.g., Sears, Caplin, & McAdams, 2014), and harmonic priming paradigms often only find tonic facilitation when the timbre does *not* change and small or "reverse" effects (at least numerically) like those shown here when timbre does change (e.g., Marmel & Tillmann, 2009). An (admittedly unanticipated) advantage of this "reverse" effect is that it is unlikely to be attributable to sensory mechanisms (cf. Collins, Tillmann, Barrett, Delbé, & Janata, 2014) and is instead likely to reflect cognitively based harmonic structure.

General discussion

The idea that structural processing in language and music rely on shared cognitive and neural mechanisms has attracted increasing interest and debate, in part because this issue speaks to larger issues of domain specificity of linguistic syntax and of music (e.g., Patel, 2003, 2008; Peretz, 2006; Peretz, Vuvan, Lagrois, & Armony, 2015). It is generally acknowledged that at least some aspects of musical and linguistic structure rely on distinct neural mechanisms given neuropsychological dissociations between aphasia and amusia. However, while the literature includes clear cases with spared grammatical processing despite atonalia (Peretz, 1993), there has been a surprising lack of unambiguous evidence for the opposite dissociation.

Here, we reported one such case: HV is an agrammatic former musician who was unable to distinguish grammatical from ungrammatical sentences but could discriminate between chord sequences that did and did not contain a chord from a distant key. Similarly, she showed no sensitivity to linguistic structure in an implicit word-monitoring task, but showed normal sensitivity to musical structure in a harmonic priming task. Although there have been several previously documented patients with spared musical processing despite linguistic deficits (e.g., Basso & Capitani, 1985; Luria et al., 1965; see also Peretz, 2006), this is (to our knowledge) the first nonanecdotal report of a patient with agrammatic aphasia demonstrating preserved harmonic processing abilities.

A double dissociation between agrammatism and atonalia is consistent with two general conclusions regarding linguistic and musical syntax. One possibility is that structural processing across these domains relies on neurally distinct processes, and so similarities between structures across domains are largely coincidental. This conclusion seems unlikely, however, given a variety of findings showing behavioral and electrophysiologial interactions across domains (Kunert & Slevc, 2015) and similar patterns of activation in neuroimaging studies (LaCroix et al., 2015; but see Peretz et al., 2015). Instead, we take these data as support for the separable representations component of Patel's (2003, 2008) influential shared syntactic integration resources hypothesis, where shared frontal regions mediate syntactic processing in both language and music (cf. Kunert, Willems, Casasanto, Patel, & Hagoort, 2015), but interact with separable linguistic and musical syntactic representations based in temporal regions (cf., Norman-Haignere, Kanwisher, & McDermott, 2015; Rogalsky, Rong, Saberi, & Hickok, 2011). HV is indeed consistent with this framework, assuming that her left temporo-parietal damage impacted language-specific syntactic representations while leaving musical representations and shared frontal processes intact. More generally, patients like HV illustrate the complexity of musical processing and its relationship to language, and highlight the continued ability of neuropsychological research to inform our understanding of these distinctively human abilities.

Acknowledgments

This research was supported by a Dean's Research Initiative grant from the University of Maryland's College of Behavioral and Social Sciences. We thank Aniruddh Patel for helpful feedback, and Polina Altskan, Viraj Desai, Hana Fudala, Rebecca McDaniels, and Anjana Rao for assistance with task development and data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by a Dean's Research Initiative grant from the University of Maryland's College of Behavioral and Social Sciences.

ORCID

L. Robert Slevc http://orcid.org/0000-0002-5183-6786
Yasmeen Faroqi-Shah http://orcid.org/0000-0002-4634-7857

References

Basso, A., & Capitani, E. (1985). Spared musical abilities in a conductor with global aphasia and ideomotor apraxia. *Journal of the Neurological Sciences*, *48*, 407–412. doi:10.1136/jnnp.48.5.407

Bharucha, J. J., & Stoeckig, K. (1986). Reaction time and musical expectancy: Priming of chords. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 403–410. doi:10.1037/0096-1523.12.4.403

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, *100*, 100–130. doi:10.1016/j.cognition.2005.11.007

Caplan, D., & Waters, G. S. (1999). Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences*, *22*, 77–94. doi:10.1017/S0140525X99001788

Collins, T., Tillmann, B., Barrett, F., Delbé, C., & Janata, P. (2014). A combined model of sensory and cognitive representations underlying tonal expectations in music: From audio signals to behavior. *Psychological Review*, *121*, 33–65. doi:10.1037/a0034695

Crawford, J. R., & Garthwaite, P. H. (2005). Testing for suspected impairments and dissociations in single-case studies in neuropsychology: Evaluation of alternatives using Monte Carlo simulations and revised tests for dissociations. *Neuropsychology*, *19*, 318–331. doi:10.1037/0894-4105.19.3.318

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist (Neuropsychology, Development and Cognition: Section D)*, *12*, 482–486. doi:10.1076/clin.12.4.482.7241

de Clercq, T., & Temperley, D. (2011). A corpus analysis of rock harmony. *Popular Music*, *30*, 47–70. doi:10.1017/S026114301000067X

Dickey, M. W., Choy, J. J., & Thompson, C. K. (2007). Real-time comprehension of wh-movement in aphasia: Evidence from eyetracking while listening. *Brain and Language*, *100*, 1–22. doi:10.1016/j.bandl.2006.06.004

Faroqi-Shah, Y., & Dickey, M. W. (2009). On-line processing of tense and temporality in agrammatic aphasia. *Brain and Language*, *108*, 97–111. doi:10.1016/j.bandl.2008.10.003

Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language*, *50*, 259–281. doi:10.1006/brln.1995.1048

Friedmann, N., & Grodzinsky, Y. (1997). Tense and agreement in agrammatic production: Pruning the syntactic tree. *Brain & Language*, *56*, 397–425. doi:10.1006/brln.1997.1795

Kertesz, A. (2006). *Western aphasia battery-revised (WAB-R)*. Austin, TX: Pro-Ed.

Kunert, R., & Slevc, L. R. (2015). A commentary on: "Neural overlap in processing music and speech". *Frontiers in Human Neuroscience*, *9*, 330. doi:10.3389/fnhum.2015.00330

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*, e0141069. doi:10.1371/journal.pone.0141069

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. doi:10.3389/fpsyg.2015.01138

Luria, A. R., Tsvetkova, L. S., & Futer, D. S. (1965). Aphasia in a composer. *Journal of the Neurological Sciences*, *2*, 288–292. doi:10.1016/0022-510X(65)90113-9

MacWhinney, B., Fromm, D., Forbes, M., & Holland, A. (2011). AphasiaBank: Methods for studying discourse. *Aphasiology*, *25*, 1286–1307. doi:10.1080/02687038.2011.589893

Marmel, F., & Tillmann, B. (2009). Tonal priming beyond tonics. *Music Perception: An Interdisciplinary Journal*, *26*, 211–221. doi:10.1525/mp.2009.26.3.211

Marslen-Wilson, W. D., & Tyler, L. (1980). The temporal structure of spoken language understanding. *Cognition*, *8*, 1–71. doi:10.1016/0010-0277(80)90015-3

Norman-Haignere, S., Kanwisher, N. G., & McDermott, J. H. (2015). Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition. *Neuron*, *88*, 1281–1296. doi:10.1016/j.neuron.2015.11.035

Ollen, J. E. (2006). *A criterion-related validity test of selected indicators of musical sophistication using expert ratings*. Columbus: Ohio State University.

Omigie, D., Pearce, M. T., & Stewart, L. (2012). Tracking of pitch probabilities in congenital amusia. *Neuropsychologia*, *50*, 1483–1493. doi:10.1016/j.neuropsychologia.2012.02.034

Patel, A. D. (2003). Language, music, syntax and the brain. *Nature Neuroscience*, *6*, 674–681. doi:10.1038/nn1082

Patel, A. D. (2008). *Music, language, and the brain*. New York, NY: Oxford University Press.

Patel, A. D. (2012). Language, music, and the brain: A resource-sharing framework. In P. Rebuschat, M. Rohrmeier, J. Hawkins, & I. Cross (Eds.), *Language and music as cognitive systems* (pp. 204–223). New York, NY: Oxford University Press.

Patel, A. D., Gibson, E., Ratner, J., Besson, M., & Holcomb, P. J. (1998). Processing syntactic relations in language and music: An event-related potential study. *Journal of Cognitive Neuroscience*, *10*, 717–733. doi:10.1162/089892998563121

Patel, A. D., Iversen, J. R., Wassenaar, M., & Hagoort, P. (2008). Musical syntactic processing in agrammatic Broca's aphasia. *Aphasiology*, *22*, 776–789. doi:10.1080/02687030701803804

Peelle, J. E., Cooke, A., Moore, P., Vesely, L., & Grossman, M. (2007). Syntactic and thematic components of sentence processing in progressive nonfluent aphasia and nonaphasic frontotemporal dementia. *Journal of Neurolinguistics*, *20*, 482–494. doi:10.1016/j.jneuroling.2007.04.002

Peretz, I. (1993). Auditory atonalia for melodies. *Cognitive Neuropsychology*, *10*, 21–56. doi:10.1080/02643299308253455

Peretz, I. (2006). The nature of music from a biological perspective. *Cognition*, *100*, 1–32. doi:10.1016/j.cognition.2005.11.004

Peretz, I., & Coltheart, M. (2003). Modularity of music processing. *Nature Neuroscience*, *6*, 688–691. doi:10.1038/nn1083

Peretz, I., Vuvan, D., Lagrois, M., & Armony, J. (2015). Neural overlap in processing music and speech. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*, 20140090. doi:10.1098/rstb.2014.0090

Rogalsky, C., Rong, F., Saberi, K., & Hickok, G. (2011). Functional anatomy of language and music perception: Temporal and structural factors investigated using functional magnetic resonance imaging. *The Journal of Neuroscience*, *31*, 3843–3852. doi:10.1523/JNEUROSCI.4515-10.2011

Sammler, D., Koelsch, S., & Friederici, A. D. (2011). Are left fronto-temporal brain areas a prerequisite for normal music-syntactic processing? *Cortex*, *47*, 659–673. doi:10.1016/j.cortex.2010.04.007

Sears, D., Caplin, W. E., & McAdams, S. (2014). Perceiving the classical cadence. *Music Perception: An Interdisciplinary Journal*, *31*, 397–417. doi:10.1525/mp.2014.31.5.397

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. doi:10.3758/s13423-014-0712-4

Tillmann, B., Bigand, E., Escoffier, N., & Lalitte, P. (2006). The influence of musical relatedness on timbre discrimination. *European Journal of Cognitive Psychology*, *18*, 343–358. doi:10.1080/09541440500269548

Tillmann, B., Gosselin, N., Bigand, E., & Peretz, I. (2012). Priming paradigm reveals harmonic structure processing in congenital amusia. *Cortex*, *48*, 1073–1078. doi:10.1016/j.cortex.2012.01.001

Tillmann, B., Peretz, I., Bigand, E., & Gosselin, N. (2007). Harmonic priming in an amusic patient: The power of implicit tasks. *Cognitive Neuropsychology*, *24*, 603–622. doi:10.1080/02643290701609527

Appendix

Narrative language sample from HV (telling the story *Cinderella*)

Examiner: I would like you to tell me the story of Cinderella. Here is a picture book to remind you about the story. Take a look at the pictures and then I will put the book away.

HV: umm…I want to xxx…a story…I…umm…I want…tell umm… once one…umm…once…once…once…

once…umm…

Examiner: Did Cinderella go to the ball and meet the prince?

KV: Yes…yeah…umm…once…one…umm…come…umm… come…umm…once… come…umm…come come…umm…come…

Examiner: Are you finished?

KV: Yeah.

Examiner: Okay.