Rhythm, Timbre, and Hyperacusis in Williams-Beuren Syndrome

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Anecdotal reports have long suggested that individuals with Williams-Beuren syndrome (WBS) are especially musical. Recent research has attempted to *quantify* and better understand the nature and extent of these reported musical abilities in an effort to enhance our understanding of the relation among genes, development, brain, and cognitive function. This chapter reports on the extant literature on three of the phenotypic markers of auditory and musical function in WBS: rhythmic ability (both production and perception), timbre perception and memory, and hyperacusis.

Rhythm, along with pitch, is one of the two dissociable attributes of music (Krumhansl 2000; Levitin 2002) and is fundamentally important in distinguishing one musical piece from another. Controlled experiments have been conducted to compare the rhythmic abilities of individuals with WBS with those of typically developing, normal controls, as well as with individuals with Down syndrome and autism. The research on timbre perception has led to both behavioral and neuroimaging research, as reported here. The term *hyperacusis*—an unusual sensitivity to sound—has an unfortunate history of inconsistency of use in both the clinical and research communities; it has been used to describe four vastly different auditory disorders, and we attempt here to clarify and reconcile these reports.

At the outset, the most important observation to stress is that individuals with WBS comprise a heterogeneous group with respect to musical ability and achievement. That is, there is as much individual difference in this population as in a normal population, and it would be inaccurate to claim that all individuals with WBS are "musical." What can be said is that they are more likely to express love for music, to engage in musical activities (either creative or receptive), and to have longer-lasting emotional reactions to music (Don et al. 1999; Levitin et al. 2004).

Rhythm

Rhythm is that aspect of music that encodes the temporal components of a musical piece. In Beethoven's *Fifth Symphony*, for example, the opening phrase consists of four notes played in a rhythm of short-short-short-long (bum-bum-bum-baaaah). If this rhythmic phrase is inverted to long-short-short-short, the piece becomes unrecognizable and has a completely different semantic meaning (Levitin and Menon 2003).

Rhythm Production

We have investigated the rhythmic abilities of individuals with WBS and examined rhythm production and memory (Levitin and Bellugi 1998). Using a series of rhythmic patterns of increasing complexity, we engaged participants in an echo clapping task to assess their mental representations of musical rhythms and their ability to reproduce them. In this task, the experimenter would clap a rhythm and the participant's task was to clap that rhythm back as accurately as possible. The patterns were based on those used in the Gordon Musical Aptitude Profile (Gordon 1965) and by Bruscia (1981) in a similar paradigm, and they provided a wide variety of temporal ratios.

The age of the WBS participants ranged from nine to twenty years (mean, 13.4 years; SD = 3.6 years); there were two female and six male participants. To provide a comparison with mental age–matched, typically developing children, eight participants were recruited from Palo Alto, California, in June 1997: two normally developing girls and six boys, with chronological age ranging from five to seven, two participants for each age category. Given that the WBS participants may have had a greater number of hours of musical exposure because of their greater chronological age, we attempted to balance this by recruiting as controls educationally sophisticated children who had taken at least three years of continuous formal musical instruction, were from one of the highest rated school districts in California, and were currently studying music privately.

Even though not specifically instructed to do so, the WBS participants in this experiment (more so than the control participants) tended to look the experimenter in the eye rather than watching the experimenter's hands during presentation of the examples. This tendency toward eye contact was first documented in the documentary film *Williams Syndrome—A Highly Musical Species* (Wilmowski 1995) by the drum instructor K. B. McConnel. Also, on nearly every trial, the WBS participants clapped back the rhythms immediately in perfect time, without missing a beat, as if their response formed part of the same rhythmic sequence. That is, when the experimenter was finished giving the exemplar, the participants came right in on the next beat without pausing. All of the WBS participants thus seemed to interpret the examples as forming part of a larger musical set; they acted as though they understood there to be an implied time signature and tempo, and they responded to the "first measure" of music played by the experimenter in time for the downbeat (or in some cases pickups) to the "second measure." Moreover, the WBS participants revealed a remarkable ability to track changes in rhythmic pulse, including changes to swing time, straight eighths, triplets, sixteenths, syncopations, and so on. In some cases, the experimenter began the next trial without pausing after the participants' response, giving the experimental session the flavor of a jazz "jam" session of "trading ones," the technical term used to describe musicians who alternate playing measures of a musical phrase.

Surprisingly, we found that the WBS participants performed as well as their mental age–matched controls, and, most interestingly, on the one-third of the trials in which the individuals with WBS made errors, the errors were far more likely to be musically coherent than those of the controls. Put another way, their errors were *musical,* as if completing the rhythmic phrase they were attempting to reproduce. This finding was especially interesting, as it stands in contradiction to Miller's position (1989) that musical savants tend to lack rhythmic ability. In addition, Serafine (1979) argued that metric conservation in normally developing children is correlated with the standard Piagetian conservation tasks; given that most individuals with WBS do not reach this Piagetian stage (Bellugi et al. 1994) but our WBS participants demonstrated conservation of musical time, their performance is especially surprising and challenges important theoretical models of cognitive abilities that couple these two forms of conservation. We concluded our report of this study by suggesting that participants with WBS had evidenced a quality we called rhythmicity or rhythmic musicality.

Rhythm Perception

Four other studies have examined rhythmic perception in WBS. Don et al. (1999), Hopyan et al. (2001), and our research group (D. J. Levitin and U. Bellugi, unpublished data). all administered the Gordon Primary Measures of Musical Audiation (PMMA), a standard rhythm perception test (Gordon 1986). The test is furnished on cassette tape, and participants listen to pairs of examples that consist of short rhythmic phrases that are either identical or slightly different; participants are instructed to respond "same" or "different." Don compared nineteen individuals with WBS (mean age, 10.5 years; SD = 1.83 years; range, 8–13 years) with nineteen typically developing, normal participants (mean age, 7.9 years; SD = 2.3 years; range not given), matched for their levels of general cognitive ability (as indexed by the Peabody Picture Vocabulary Test–Revised [PPVT-R]). The control group performed better than the WBS group on the rhythm subcomponent of the

PMMA, but the statistical analyses employed were subject to question and therefore it is difficult to draw a firm conclusion as to whether the differences are statistically significant. Don and colleagues apparently made multiple post hoc comparisons without appropriate adjustments in significance level, and they failed to report the main effect of group in their analysis of variance statistic.

Hopyan and colleagues (2001) administered the same test to fourteen children with WBS (mean age, 12 years; SD = 3 years) and fourteen chronological age–matched controls (mean age, 12 years; SD = 3 years). This study reported that the control group performed significantly better than the WBS group on the rhythm test. In our own laboratory, in an experiment currently underway, we obtained the same results as Hopyan. But the pattern of errors made by the WBS participants alerted us to a potential confound with the stimulus materials. More often than not, our WBS participants were labeling "different" some pairs of examples that the PMMA had intended to be the same. On closer listening to the examples, we discovered that the cassette tapes contained numerous rhythmic confounds, rendering the rhythmic task more difficult to complete for a careful listener. Specifically, the test as furnished by the manufacturer contains random static and recording artifacts that create unintended spaces and gaps during long tones of the rhythm test. Thus, a reference rhythm and its matched comparison rhythm may in fact seem different to a careful listener when intended to be the same by the test maker. To remove this potential confound from the experiment, we resynthesized and rerecorded all the examples digitally and administered the test to a fresh group of participants.

The participants performed very well on this resynthesized version. To give the comparison group the best possible chance of performing better than our WBS group—in an effort to replicate the findings of Hopyan and colleagues of better rhythm performance among the controls—our control participants were not simply matched on chronological age but were drawn from a pool of true musical experts: students at the Julliard School of Music in New York. In this work we found that WBS and Julliard students performed equivalently on the rhythm tests, evidence that the WBS group was performing significantly above overall cognitive level and, indeed, on a par with chronological age–matched controls (Levitin and Bellugi, unpublished data).

Brochard and colleagues (in press) tested rhythmic sequence discrimination by employing a same/different task in which the "different" examples differed either in meter or gestalt grouping. Although the nine adults with WBS performed more poorly overall than the nine controls (matched for sex and chronological age), the WBS participants showed a relative strength in perceiving the metric rather than the grouping examples. Moreover, the processing of rhythmic pauses was highly disturbed when some musical semantic content was present.

Thus, with the exception of specific impairments on metrical sequences and semantic pauses documented by Brochard et al. (in press), we would argue that *both* rhythm production and rhythm perception are relative strengths in WBS, when bias-free tests are used. Preliminary studies suggest a neuroanatomic basis for this relative sparing of rhythmic ability, as discussed below. The most direct implication of this finding is that caregivers may want to encourage individuals with WBS to play rhythm instruments (percussion, drums, etc.) as a musical outlet. Indeed, a large number of the males at the WBS music camp where we made our observations (Belvoir Terrace) play the drums at a relatively proficient level and play in small bands.

Timbre Perception and Hyperacusis

As has been noted previously, individuals with WBS tend to be unusually sensitive to and interested in sound (Udwin 1990), a characteristic dubbed "soundscape sensitivity" (Levitin and Bellugi 1998) and often referred to by the medical term *hyperacusis.* Because the sensitivity to sound experienced by most individuals with WBS seems to be related to specific tonal colors or timbres of those sounds, we deal with these two topics together.

The medical definition of hyperacusis is "abnormal sensitivity to sound" (Dirckx 2001; Venes et al. 2001) that indicates lowered hearing thresholds (an ability to hear soft sounds that others cannot), but this description does not adequately capture the phenomenology of WBS. Whereas there have been many anecdotal accounts of people with WBS who have lowered hearing thresholds (a claim not yet supported by our own research), three unusual behaviors have additionally been reported in WBS.

The first is aversion to certain types of normal-volume sounds (Morelock and Feldman 2000), such as lawnmowers, leaf blowers, or vacuum cleaners—although the particular sounds seem to be idiosyncratic—and there are many others. The distress extends even to the anticipation of such noises (Hagerman 1999), and typical reactions are for children to put their hands over their ears and cry or attempt to avoid the source of the sound (Udwin 1990). The aversion does not result from the *loudness* of the sounds but from some quality of the sounds that has yet to be completely characterized. Because this shares a conceptual similarity with allodynia, a pathologic state (typically following tissue or nerve damage) in which patients feel pain from stimuli that are not normally perceived as painful, we propose renaming this condition *auditory allodynia,* as first suggested by Levitin et al. (2003). These symptoms have sometimes been referred to in the literature as *phonophobia,* but that term, like *hyperacusis,* also has a history of misuse, and consequently we opted for a new term without prior ambiguous associations.

Second, sounds that are not too loud for others are perceived as painfully loud by individuals with WBS. This is essentially a lowered uncomfortable loudness threshold (LULL); it is not necessarily related to a lowered hearing threshold and should be referred to by the term *odynacusis* (Venes et al. 2001; Dirckx 2001). This is distinct from auditory allodynia because individuals with LULLs react negatively to any sound beyond a certain level, not only to particular sounds that they find idiosyncratically aversive. Third is an intense fascination for certain classes of sounds, often the same sounds that frightened the individual at a younger age (Levitin et al. 2005).

The literature has tended to lump these behaviors together, using the single term *hyperacusis* somewhat indiscriminately to describe these phenomena (Katznell and Segal 2001; Klein et al. 1990; Marriage 1995; Phillips and Carr 1998). Because these symptoms stem from different underlying physiologic correlates and etiologies, it is important to be precise with terms so as not to lead to confusion. Klein and colleagues (1990), for example, used the term *hyperacusis* to describe cases of individuals with WBS who experienced "consistently exaggerated or inappropriate responses or complaints of uncomfortable loudness to sounds that are neither intrinsically threatening nor uncomfortably loud to a typical person . . . these responses would occur on nearly every occasion that the sounds are presented and do not habituate with repeated exposures" (339)—what we have categorized as odynacusis. Hopyan et al. (2001) used *hyperacusis* to mean simply "an abnormally strong affective response to certain categories of sounds" (42).

Aversion: Auditory Allodynia

Recently we have had the opportunity to refine our understanding of auditory sensitivities in WBS through a questionnaire administered to 118 individuals with WBS, 40 individuals with Down syndrome, 30 with autism, and 118 typically developing, normal controls (Levitin et al. 2005). As we have noted, individuals with WBS experience strong aversion to certain types of sounds, independent of their loudness. The sounds tend to be spectrally broad-band sounds, such as those emanating from motors, fans, fireworks, and thunder. Compared with typically developing, normal children and children with Down syndrome or autism, individuals with WBS are more than three times as likely to have suffered from auditory aversions, with 91% of respondents reporting this (compared with 27% of individuals with autism and fewer than 7% of individuals with Down syndrome or normal controls).

Attraction and Auditory Fascinations

Individuals with WBS were also nearly ten times as likely to report auditory fascinations, that is, an unusual attraction to certain sounds, sometimes manifesting as auditory fetishes. Interestingly, this attraction is often toward sounds that the individuals initially found aversive. We also noted that 80% of individuals with WBS (compared with 33% or less in the comparison groups) were reported by their caregivers to have LULLs (sounds that are not too loud for others are perceived as painfully loud) and 5% were reported to experience hyperacusis (here meaning the ability to hear soft sounds that are imperceptible to others), whereas no other group reported this. Previous research (discussed below) has established that peripheral auditory mechanisms in WBS function normally (Neville et al. 1994) and therefore it seems reasonable to infer that the LULLs and hyperacusis are probably mediated by hyperexcitability of cortical neurons in the auditory pathway (Neville et al. 1994; Bellugi et al. 1992).

Timbral Identification

We recently completed a behavioral experiment to quantify the timbral/soundscape-processing abilities of individuals with WBS. Numerous observations have told us that not only are many individuals with WBS attracted to the sounds of motors, but many have learned to classify and label the sounds with great accuracy and precision. We have encountered individuals with WBS who can accurately identify different lawnmowers or vacuum cleaners, based solely on the sound of their motors. To turn this observation into an experiment, we digitally recorded twelve different vacuum cleaners and administered a same/different discrimination task to individuals with WBS (Levitin and Bellugi, unpublished data). For a control group, we used the chronological age–matched Julliard students mentioned above. We found that the performance of the WBS participants was as good as that of these highly selected controls, making timbral identification one of only a small set of tasks at which individuals with WBS perform on a par with typically developing, chronological age–matched equivalents.

Neurobiological Studies

The types of neurobiological studies that have been conducted with individuals with WBS fall into three categories: electrophysiologic (primarily using event-related potentials, taken from scalp recording electrodes), neuroimaging (primarily using magnetic resonance imaging [MRI]), and cytoarchitectonic (study of the arrangement of cells in neural tissue in postmortem brains).

Event-Related Brain Potentials

A series of studies using event-related potentials (ERPs) investigated the timing and organization of neural systems connected with auditory function in WBS (Neville et al. 1994). ERPs are well suited to this type of study because they have very high temporal resolution and thus can track changes in auditory processing of the presented stimuli in nearly real time. Of additional importance is that they are relatively noninvasive, although some individuals report slight discomfort or irritation at having the scalp prepared for the electrode attachment or from the electrodes being taped to the scalp.

One hypothesis tested was that hyperexcitability of neuronal responses at some point along the auditory pathway could account for the clinical symptoms of hyperacusis and LULLs. Tests of the auditory recovery cycle revealed that auditory brainstem-evoked potentials were normal in WBS participants, ruling out auditory hyperexcitability at the level of the brainstem. However, data from an auditory recovery paradigm pointed to a possible cortical mechanism subserving the sensitivity to sounds. This is evident only over temporal cortex and occurs only with auditory input, not visual; WBS participants are indistinguishable from normal controls on a visual recovery paradigm. Taken together, these studies suggest that some of the distinctive auditory symptoms observed in WBS may be mediated by hyperexcitability, specifically within cortical regions associated with auditory processing.

Neuroimaging

Findings from functional MRI (fMRI) studies have pointed to a possible neural substrate subserving musical, timbral, and affective processing in WBS (Levitin et al. 2003). Like ERPs, fMRI is a noninvasive technique, but some participants (both normal and WBS) find the procedure stressful because it requires being confined in a small space and being subjected to the loud operating noise of the scanner. Five participants with WBS were scanned with fMRI (1.5T) and compared with chronological age–matched, typically developing controls. The participants were also matched for musical training, though none had had extensive formal training. Chronological age–matched controls were necessary, as opposed to mental age–matched controls, because the young developing brain has functional neuroanatomic differences from the adolescent or adult brain, so this served as the most rigorous comparison of neural organization. The participants in the study listened to orchestral music and environmental sounds of the type eliciting a positive response in individuals with WBS (fans, motors, running water, etc.). We compared the blood oxygenation–level dependent (BOLD) brain response in the two conditions for the two participant groups.

Our most intriguing finding was that the overall pattern of activation in the whole brain was markedly different between the two groups. An analysis of whole-brain activation patterns revealed that all five control participants showed consistent and overlapping patterns of activation bilaterally in extended areas of the superior temporal gyrus, middle temporal gyrus, and superior temporal sulcus for the processing of music compared with noise, with no other brain regions showing consistent activation among the control participants (fig. 16.1 shows the locations of these brain structures). In contrast, the WBS participants showed substantially decreased activation in these regions, accompanied by more variable patterns of activation throughout the cortex and neocortex and higher activation levels than controls in the paleocortical amygdaloid complex. The WBS group showed significantly higher activation levels in the right amygdala compared with the controls. The WBS participants—but not the controls—all showed consistent cerebellar activation as well as activation in the pons and brainstem.

Thus, we can conclude that the normally developed participants demonstrated a relatively well-defined activation pattern in the neocortex, whereas the WBS participants showed a relatively dispersed pattern of activation involving *both* neocortical and paleocortical regions.

That the amygdala was activated in the WBS group is interesting in the context of findings by Adolphs et al. (1998) that the human amygdala triggers socially and emotionally relevant information in the visual domain. In their study, patients with bilateral amygdala damage showed abnormal responses to unfamiliar faces with a threatening appearance; the patients tended to rate all faces as friendly and, in particular, showed a disproportionate impairment in judging threatening faces. Individuals with WBS also display this behavior; they are socially outgoing and tend to be utterly unable to judge whether a stranger is trustworthy or untrustworthy (see chapter 7), acting in these ways like amygdala-damaged patients. The abnormal emotional responses to sound observed phenotypically in WBS seem to correlate with abnormal amygdala activation in our earlier study (Levitin et al. 2003).

The vermal, pons, and brainstem activation may also be related to affective processing in WBS. Previous research (Griffiths et al. 1999; Levitin et al. 2003) has implicated the posterior vermis in music listening, which may be associated with the emotional component of listening to meaningful sounds (Schmahmann 1997; Blood et al. 1999). These activations are presumably mediated by major connections linking the prefrontal cortex with the basal ganglia and the cerebellar vermis and are consistent with the notion that a region in the right cerebellum may be functionally related to those in the left inferior frontal cortex for semantic processing (Roskies et al. 2001; Levitin and Menon 2003), thus serving to link the cognitive and emotional aspects of music.

Findings from structural scans of the brains of individuals with WBS have revealed additional neuroanatomic differences. Volumetric analyses revealed selective decreases in the posterior cerebrum, with relative sparing of volume in the cerebellum and temporal lobes (Reiss et al. 2000; see also chapter 14). Differences in gray and white matter density were also discovered. Cerebral white matter was disproportionately reduced, and reductions in the posterior portions of the corpus callosum were also observed. Gray matter den-

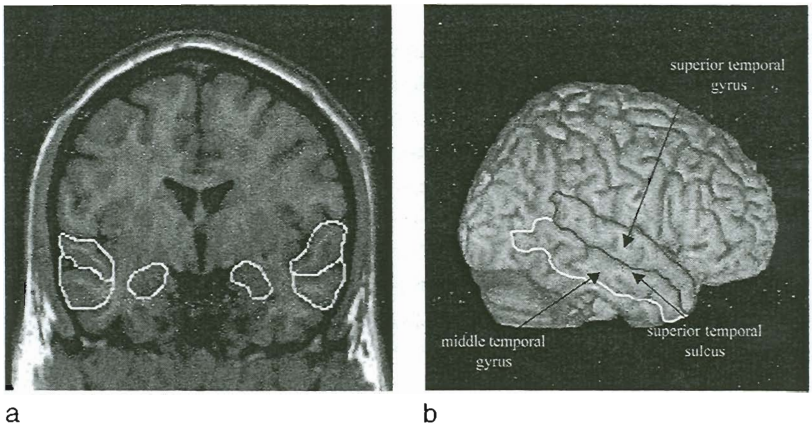


Fig. 16.1. Locations of key neural regions in the text in a typical brain. (*a*) Middle temporal gyrus, superior temporal gyrus, and the amygdala, coronal view. (*b*) Middle temporal gyrus,

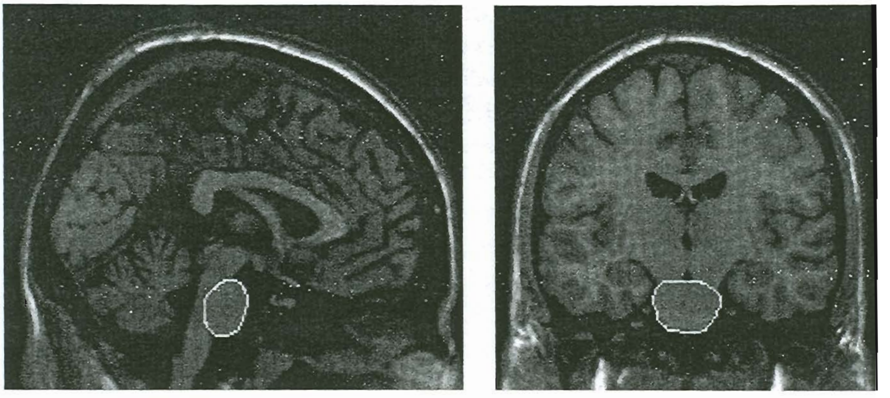
sity was reduced in some regions (caudate nucleus and intraparietal sulcus) and increased in others (insular cortex, cingulate gyrus, and cerebellum).

Cytoarchitectonics

Auditory cell-packing density and neuronal size (in area 41) also showed abnormalities in cytoarchitectonic studies of WBS (Holinger et al. 2005). Autopsy specimens from individuals with WBS had an excess of midsize and large cells in layers II in both the left and right hemispheres and in layer VI in the left hemisphere. There was a hemisphere by diagnosis interaction between WBS and control brains in cell-packing density in layer IV, and a hemisphere by diagnosis interaction between WBS and control brains in neuronal size in layer III. In other words, the different participant populations showed complementary hemispheric asymmetries. Larger pyramidal neurons were found bilaterally in layer II and in left layers III and VI and were interpreted as being consistent with a hypothesis of increased connectivity in the WBS auditory cortex. This hyperconnectivity may be related to the relative sparing of language, music, and other auditory functions.

Clinical Implications

Clinicians who are aware of the various auditory phenomena in Williams-Beuren syndrome are in a better position to counsel and advise individuals with WBS and their families. First, rhythmic ability is an area of relative strength in many individuals with WBS, and music in general is something that many find to be especially engaging, comforting, and attractive. Although great individual differences do exist within the WBS phenotype,



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superior temporal gyrus, and superior temporal sulcus, lateral view. (*c*) Pons, sagittal view. (*d*) Pons, coronal view. *Source:* Figures prepared by and courtesy of Dr. Vinod Menon.

many people with WBS have become quite proficient at music, and consequently musical activities—particularly those involving rhythm instruments—can be reasonably encouraged. Music can also be used as a reward in a variety of behavioral situations, whether the reward is the opportunity to listen to music or to perform it. Music may also be an avenue for learning certain motor skills. Although many people with WBS have difficulty with motor action plans and eye-hand coordination in day-to-day activities, such as buttoning a shirt or tying shoes, these same individuals can execute arguably more difficult motor action sequence plans when they are musical. There have been anecdotal reports of limited success with teaching motor action sequences, such as tying shoes, if those sequences are set to music and taught slowly and gradually. Knowing the great comfort to be derived from music will encourage parents and caregivers to allow music to become a regular routine in the life of individuals with WBS who are in their care. In the past ten years, several music camps have been developed in Massachusetts, Michigan, Connecticut, Texas, Canada, Hungary, Spain, and Ireland.

Music may have a psychotherapeutic role for individuals with WBS. The Berkshire Hills Music Academy (Massachusetts) is now using music to facilitate learning in other domains by building on the musical strengths of individuals with WBS and other cognitively impaired people. The range of uses of music in a therapeutic setting can include activities as diverse as social bonding through group singing, motivation for certain tasks, and mental discipline. Several individuals with WBS perform music in rest homes and hospitals. Such activities, while mentally and logistically challenging, allow the WBS performers to develop certain skills they might not otherwise develop, including planning a repertoire, developing stage presence and stage skills, and increasing their consciousness of time and appointment scheduling.

Clinicians and caregivers should understand that certain sounds may cause serious distress in people with WBS and should allow appropriate measures to be taken, which will often include avoidance and coping strategies and, in some cases, simply waiting until the individual grows out of it.

The greatest promise comes from the hope that the type of research reported here will someday be integrated into a deeper understanding of the brain and the relation between brain and behavior. Although this is no doubt in the distant future, such an increased understanding could potentially allow clinicians to propose certain pharmacologic or behavioral interventions that would dramatically improve the lives of individuals with WBS and their families.

Future Directions

Neuroscientific studies in the next few years may find identifiable neural correlates for the processing of music, but we think these neural structures are unlikely to constitute a circumscribed anatomic music "center," any more than language constitutes a "center." That is, there may well be specific componential correlates for things such as musical semantics, musical expectation, tonality, and so forth, but it is unlikely that we will find a "music module." We already know that there are specific brain structures devoted to the processing of pitch, musical timbre, and tempo (Zatorre and Peretz 2001), but these structures are distributed as neural networks spanning several functional areas of the brain—they are not locally isolable blocks of neural tissue. Future work may uncover the affective link between certain sounds and the fear/aversion reaction, and this reaction may be treatable pharmaceutically, perhaps with selective neurotransmitter blocking agents or reuptake inhibitors. Finally, the intense pleasure that WBS people report in response to musical activity may have either a neurochemical or neuroanatomic basis, undoubtedly one that is linked to the microdeletion on chromosome 7. Huron (2001) has speculated that individuals with WBS have fewer inhibitions than most people, perhaps resulting from an underdeveloped "inhibition module." This could explain both the increased sociability of individuals with WBS and their increased musicality—music and sociability have been speculated to share an evolutionary basis.

One question that is often asked is whether there are musical geniuses in the WBS community. A *savant* is defined as a person with a serious mental handicap who exhibits spectacular islands of ability or brilliance that are in stark, incongruous contrast to the handicap (Down 1887; Grossman 1983; Morelock and Feldman 2000; Treffert 1989). Savantism is typically characterized by several common features, including impaired capacity for abstraction, lack of metacognition (Scheerer et al. 1945; Morelock and Feldman 2000), and extraordinary memory (Treffert 1988, 1989). As Tager-Flusberg and Sullivan (2000) note, individuals with neurodevelopmental disorders and mental retardation rarely exhibit absolutely spared cognitive function; rather, the sparing is relative.

To date, we have not been able to verify reports of any individual with WBS who is considered a world-class musician or "musical genius." But we know of dozens who are musical savants—people whose achievements are extraordinary given the deficits they hold in other domains. One individual sings hundreds of songs from memory in twenty-five languages that she doesn't even speak (Lenhoff et al. 1997). Another is a prolific composer and has written several songs for our research team on the spot, songs that conform to structural rules of harmony and form and the lyrical conventions of the popular song (Levitin and Bellugi 1998). Many dozens of Williams-Beuren musicians, as noted above, have relatively preserved musical skills that stand in stark contrast to their lack of skills in other domains, and this is, according to the formal definition, sufficient evidence of savantism.

Conclusions

Music is among a small set of cognitive domains (including language and face processing) that seem to be relatively preserved in individuals with WBS. Apart from this relatively spared ability, individuals with WBS seem to be genuinely *drawn* to music, and this may be because it offers them an opportunity to control structure, sound, and time in ways they cannot do in the rest of their lives.

Our qualitative observations of hundreds of individuals with WBS have confirmed anecdotal reports that they love music and have a more intense relationship with it than most typically developing people. Their relatively preserved rhythmic abilities challenge conventional notions about Piagetian stages and conservation of number and time, and they seem to be equivalent to the abilities of even highly trained, chronological age–matched controls.

Individuals with WBS may suffer from four different auditory abnormalities: lowered uncomfortable loudness levels, hyperacusis, auditory fascinations, and auditory aversions. We argue that the neural basis for some of these behaviors may be in hyperexcitability of cortical neurons. Functional and structural neuroimaging experiments have revealed certain irregularities in the function and structure of specific brain regions in WBS. Compared with normally developed subjects, those with WBS tend to use different regions of their brain for processing music and noise, with a particular emphasis on amygdala activation. Differences in gray and white matter density, as well as cell-packing density and neuronal size, have also been observed in WBS brains. The study of WBS, a neurodevelopmental disorder with a genetic basis, can inform important issues about the evolutionary basis of music.

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