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Memory for pitch in congenital amusia: Beyond a fine-grained pitch discrimination problem

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Congenital amusia is a disorder that affects the perception and production of music. While amusia has been associated with deficits in pitch discrimination, several reports suggest that memory deficits also play a role. The present study investigated short-term memory span for pitch-based and verbal information in 14 individuals with amusia and matched controls. Analogous adaptive-tracking procedures were used to generate tone and digit spans using stimuli that exceeded psychophysically measured pitch perception thresholds. Individuals with amusia had significantly smaller tone spans, whereas their digit spans were a similar size to those of controls. An automated operation span task was used to determine working memory capacity. Working memory deficits were seen in only a small subgroup of individuals with amusia. These findings support the existence of a pitch-specific component within short-term memory and suggest that congenital amusia is more than a disorder of fine-grained pitch discrimination.

Keywords: Congenital amusia; Short-term memory; Span; Working memory.

Congenital amusia (“amusia” hereafter) is thought to affect around 4% of the population (Kalmus & Fry, 1980). Individuals with amusia fail to develop some of the basic abilities associated with the perception and production of music, despite normal exposure to music during development, normal education levels and IQ, and no known neurological or peripheral auditory impairments (Ayotte, Peretz, & Hyde, 2002; Peretz et al., 2002). They often fail to recognise familiar tunes and might avoid social situations where music is present (McDonald & Stewart, 2008). People with amusia should be distinguished from the wider self-report population who describe themselves as “tone deaf” on the basis of difficulties in the production, rather than perception, of music (Cuddy

et al., 2005; Sloboda et al., 2005; Wise & Sloboda, 2008).

The most widely utilised diagnostic test for amusia is the Montreal Battery for the Evaluation of Amusia (MBEA), which requires discrimination of melodic phrases that can vary on different musical dimensions (Peretz, Champod, & Hyde, 2003). Using diagnosis via the MBEA as a starting point, subsequent research has focused on examining the perceptual discrimination abilities of individuals with amusia. Psychophysical tests have revealed that amusia is associated with deficits in the detection of pitch change (Hyde & Peretz, 2004; Foxton et al., 2004) and the discrimination of pitch direction (Foxton et al., 2004; Liu, Patel, Fourcin, & Stewart, 2010).

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There are certain indications, however, that amusia is more than a low-level disorder of perceptual discrimination. Gosselin, Jolicoeur, and Peretz (2009) used a pitch comparison task involving the presentation of two tones, 1650 ms apart, where the retention interval was either unfilled or included irrelevant tones. While controls showed good performance in both cases with pitch intervals of 1, 2, and 3 tones, individuals with amusia were close to chance levels of performance at a pitch interval of 1 tone. For pitch intervals of 2 and 3 tones, amusic participants' performance was good for the unfilled condition but significantly worse than controls when irrelevant tones were present. This finding was extended by Williamson, McDonald, Deutsch, Griffiths, and Stewart (2010b), who reported that individuals with amusia were poorer than controls at recognising the pitch of tones when they were presented over increasing retention intervals (1 s, 5 s, 10 s, and 15 s). In both studies the pitch interval between the comparison tones exceeded the amusic participants' psychophysically measured thresholds, pointing to a memory-based deficit for pitch that extends beyond a perceptual encoding impairment.

A pitch memory deficit has also been found in studies that have tested pitch memory for sequences as opposed to isolated tones. Foxton et al. (2004) demonstrated that amusic participants' recognition memory for four-item pitch sequences was poorer than controls when the consecutive pitch intervals exceeded the amusic participants' perceptual thresholds. Gosselin et al. (2009) replicated this result using a paradigm that required recognition of three- and five-item pitch sequences that were separated by a 2-s retention interval. Tillmann, Schulze, and Foxton (2009) tested amusic participants' recognition of pairs of five event sequences containing all tones, timbres, or words. Importantly, they measured the amusic participants' pitch detection thresholds beforehand in order to ensure that all the pitch intervals were suprathreshold for discrimination. The results indicated that amusic participants were significantly poorer than controls for timbre and tone sequences, but not words. The findings from all three studies are consistent with a sequence memory deficit in amusia that is specific to aspects of musical sounds, particularly pitch.

The study by Tillmann et al. (2009) was the first attempt to assess memory for sequences of pitch-based and verbal items in amusia while controlling for perceptual difficulties. The present study aims to expand upon these findings by

utilising a novel method for measuring memory capacity in amusic individuals. An alternative to the presentation of fixed length lists (as in Foxton et al., 2004; Gosselin et al., 2009; and Tillmann et al., 2009) is the use of an adaptive-tracking paradigm to measure individual capacity or "span" for pitch-based and verbal material. This method generates individual span scores, which are assessed by the presentation and measurement of performance at multiple sequence lengths.

There are at least three possible types of deficit that could, in principle, underlie the pitch memory impairments seen in amusia. First, individuals with amusia may have a problem with short-term memory, a system capable of storing a small amount of information for retention after a short delay, which is specific to pitch-based information. A short-term memory deficit that is specific to pitch would be consistent with evidence that aspects of pitch-based and verbal memory are partly separable (Deutsch, 1970), but also with evidence suggesting that memory for abstract pitch has a degree of specialised function, irrespective of the nature of the sound being processed (Semal & Demany, 1991, 1993; Semal, Demany, Ueda, & Halle, 1996). Second, individuals with amusia may have a general short-term memory deficit, which would predict that they would experience problems in verbal short-term memory as well. So far, individuals with amusia have been shown to have normal digit spans (Foxton et al., 2004; Jones et al., 2009), but these studies did not compare pitch-based and verbal memory using analogous tasks.

Finally, the pitch memory impairments seen in amusia may reflect a deficit in working memory; the ability to not only store information but also to manipulate it, to manage concurrent attention demands, and to discriminate between new and old information (Cowan, 2005; Unsworth & Engle, 2007a, 2007b). Working memory is typically assessed by means of tasks such as operation span, where a participant must carry out a series of mental calculations while being presented with a sequence of items to be recalled. A working memory deficit would have implications for cognitive processes in general, including those related to music.

In the present study we sought to determine whether the pitch memory impairments seen in amusia reflect a pitch-specific short-term memory deficit, a general short-term memory deficit, or a working memory deficit. Using adaptive-tracking procedures in two analogous tasks, we determined

individuals' capacity for pitch-based and verbal memory, by measuring tone and digit spans. A general short-term memory deficit would predict an overall group difference but no group by span task interaction, while a short-term memory deficit that is pitch-specific would predict a group difference for tone but not digit span. A working memory deficit would predict that individuals with amusia would perform poorly on the automated operational span task (Unsworth, Heitz, Schrock & Engle, 2005).

METHOD

Participants

A total of 28 participants took part in all tasks, in return for a small honorarium. All participants completed an online assessment (www.delosis.com/listening/home.html) that was based on the scale subtest of the Montreal Battery for the Evaluation of Amusia (MBEA) (Peretz et al., 2003). Participants took the online test twice and, if they consistently achieved a score of 22/30 or less, were invited to the laboratory to take the scale, contour, interval, and rhythm subtests of the MBEA under controlled conditions. Previous research and the results of the present study suggest that while individuals with amusia perform poorly on the pitch-based subtests of the MBEA (scale, contour, and interval), the majority of rhythm subtest scores are in the normal range (Peretz et al., 2003). Therefore we calculated a composite score for the three pitch-based subtests and applied a cut-off score of 65 as our criterion for confirmation of amusia—the sum of the cut-off scores for the three subtests in Peretz et al. (2003).

The present study involved 14 individuals (four male; M age = 50.00) who were confirmed as amusic

on the basis of the aforementioned behavioural testing. The amusic individuals were matched to 14 control participants (M age = 48.07), all of whom had achieved a pitch composite score in the normal range (Peretz et al., 2003). The two groups were matched on gender, age, score on the National Adult Reading Test (NART), years of formal education, and musical training background, as measured using a rating scale (see Appendix). A summary of the group averages for these variables are presented in Table 1 (see Appendix Table A1 for individual scores).

Pretests: Psychophysical measures of pitch perception

In advance of the tests of short-term and working memory we measured participants' thresholds for the detection of a pitch change ("pitch detection task") and discrimination of pitch direction ("pitch direction task"). The purpose of this testing was to ensure that the pitch intervals used in the subsequent tone span task would be suprathreshold for perceptual discrimination.

Design and results. Both threshold tasks used a two-alternative forced choice AXB procedure and a single trial consisted of the presentation of three pure tones that were each 600 ms in duration. For the pitch detection task the target was a pitch glide, centred on 500 Hz, while non-targets were steady-state tones of 500 Hz. For the pitch direction task, targets and non-targets were pitch glides, centred on 500 Hz. The target was a glide with a direction that was opposite to the non-target glides. In both tasks targets were upward or downward glides, with equal probability and appeared in the first or last position, at random. Participants were required to identify the position of the target by saying "first" or "last". Previous

TABLE 1
Background participant details

	Group	N	Age	NART	Years musical training	Years education	MBEA Scale	MBEA Contour	MBEA Interval	Pitch composite
μ	Amusic	14	50.00	42.57	1.29	16.00	18.07	18.57	17.57	54.21
σ			11.40	4.33	2.95	1.66	2.62	2.95	2.03	6.04
μ	Control	14	48.07	44.69	1.94	15.86	27.29	28.14	27.71	83.14
σ			12.03	2.52	3.01	3.01	2.12	2.11	2.30	5.29
T test			-.44	1.58	.59	-.16	10.23	9.87	12.37	13.48
p			.67	.13	.56	.89	<.001	<.001	<.001	<.001

(unpublished) data show that the use of pitch glides, as opposed to discrete pitch changes, makes no appreciable difference to the eventual thresholds obtained therefore the present study used pitch glides in order to keep memory demands to a minimum.

A “two-up, one-down” staircase procedure was used to determine threshold. The target was initially set to an excursion of six semitones. After two consecutive correct responses at this level, the pitch excursion of the target was reduced. An incorrect response resulted in an increase in the target’s pitch excursion to the previous level, which was defined as a reversal. Following an incorrect response, two consecutive correct responses were required before the pitch excursion was reduced, also defined as a reversal. To increase the precision of the perceptual threshold, the tracking protocol employed variable step sizes. Reversals 1–4 employed a step-size of 1 semitone, reversals 5–8 a step-size of 0.1 semitones, and reversals 9–14 a step-size of 0.02 semitones. The protocol terminated after 14 reversals and a threshold was calculated based on the average pitch excursion of the target for the last 6 reversals.

Table 2 shows the average pitch thresholds for all 28 participants. The amusic and control groups did not differ significantly in their pitch detection thresholds (control $M = .14$ vs amusic $M = .28$), but amusic participants had significantly higher thresholds for pitch direction (control $M = .17$ vs amusic $M = .95$). There was also a significant positive correlation between performance on the detection and direction tasks in the amusic group ($r = .72$, $p = .004$) but not in the control group ($r = .47$, $p = .09$). In order to ensure that the pitch intervals used in the subsequent tone span task were suprathreshold for discrimination we chose four semitones as the minimum interval, a value more than four times larger than the mean threshold for pitch direction discrimination in the

amusic group and a semitone larger than the highest measured threshold in that group.

Main tests: Short-term and working memory

Short-term memory (span) tasks. Design: Each participant completed both a tone span and a digit span task, with presentation order counterbalanced. The task materials were the same for both groups. The stimuli used in the tone span task were 10 triangle-waveform tones, with fundamental frequencies drawn from between 262 and 741 Hz in equally tempered, whole tone steps (from C4 to F#5). Rise and fall times were linear over 20 ms and tone durations were 500 ms. The stimuli used in the digit span task were numbers between zero and nine inclusive, spoken in British English, with a male voice. In order to equate pitch, tempo, and amplitude across the stimuli, a number of steps were taken: First, the pitch contour of each of the spoken sound files was extracted using PRAAT software and a PSOLA resynthesis was used to impose a constant fundamental frequency of 117 Hz. Second, the onsets of the amplitude envelopes were matched and the files were time stretched to 438 ms using a high precision, pitch-preservation setting. This temporal adjustment was necessary in order to give the digits the even metronomic pace that characterised the stimuli used in the tone span task. A period of 62 ms silence was added to make each stimulus 500 ms in length. Finally, the stimuli were individually matched using the amplitude function in Adobe Audition to give an equal percept of loudness.

Procedure: A trial began when the experimenter pressed the spacebar. A 500-ms pause was followed by two successive sequences. There was an inter-stimulus interval of 383 ms and an inter-sequence interval of 2 s, based on the timings of the original paradigm.¹ The two sequences contained the same number of items, selected from the pool of 10 items by constrained random sampling without replacement. Temporally adjacent digits differed by at least two in absolute value while adjacent tones differed by at least two whole tones. Digit sequence presentation started off at four items while tone sequences began at two items. Tones were selected from the pool of 10 tones ranging from C4 to F#5 in equally tempered,

TABLE 2
Average group thresholds for pitch detection and pitch direction tasks

	Group	Pitch detection	Pitch direction
μ	Amusic	.28	.95
σ		.31	.87
μ	Control	.14	.17
σ		.06	.08
Mann Whitney U		-1.75	-3.68
p		.09	< .001

¹ The original adaptive-tracking span paradigm was kindly provided by Professor Burton Rosner.

whole tone steps by constrained random sampling without replacement, so the resulting sequences would be best described as atonal.

The order of items in the second sequence was either identical to the first or differed due to the reversal in position of two items. The first and last items always remained the same (except in the two and three tones trials) so as to minimise primacy and recency effects. Participants indicated whether the two sequences were the same or different and the experimenter entered the response. Participants then heard a 2-second burst of static pink noise (tone span task) or a 2-second burst of reversed speech (digit span task) in order to minimise the effect of any lingering auditory traces. After the burst of noise or reversed speech there was a 3-second silent pause before the next trial.²

The task followed a two-up, one-down staircase procedure with two trials at each sequence length. Sequence orders were randomly chosen to be identical or different on the first trial. A correct response led to a second trial at the same length. If the sequences had been identical on the first trial, they differed on the second trial and vice versa. After two successive correct responses, the next trial increased in sequence length by one item. Reversals in sequence length, which occurred following an incorrect response on either the first or second trial, were designated using the same logic as outlined above for the threshold tasks. The procedure was terminated after eight reversals and an individual's span was calculated based on the average sequence length for the final six reversals.

Working memory task. Design: In order to measure working memory capacity we used an automated operation span task³ (Unsworth et al., 2005) run on Eprime software.

Procedure: A standard operation span task comprises a series of two separate tasks, which repeat during the course of a trial: First a mathematical question must be answered then a single letter is shown. The letters presented in between the mathematical questions must be retained in serial order for later recall. In the present study participants were shown a mathematical operation—e.g., $(1*2) + 1 = ?$ —which they attempted to solve mentally, and then pressed the spacebar to

indicate that they had reached an answer. The next screen presented a possible answer and the participant indicated if that answer was true or false. A single letter was then presented on screen for 800 ms, which participants were instructed to remember: A consonant was selected randomly without replacement from a pool of 12 letters. A second mathematical operation was then presented, followed by another letter, and so on (see Figure 1).

After a randomly selected trial sequence length, containing anything between 3 and 7 letters, a 4*3 matrix was shown containing the original pool of 12 letters. Participants verbally reported the sequence of letters they saw in serial order, saying “blank” if they reached an item they could not recall. The computer provided feedback on letter recall and mathematical accuracy on each trial. Participants were also shown their running average performance for the mathematical operations, which they used to keep their average score above a set criterion of 75%. This encouraged them to maintain attention on both aspects of the task. Each participant completed 3 trials at each sequence length (3–7) generating 15 trials in total.

A practice session was given which comprised three parts. Participants first practised recalling letters presented onscreen, then they answered 15 mathematical operations. This mathematical practice session was used to calculate an average response time. The average time plus two standard deviations was used as a time limit in the main task for the mathematical operations, such that responses that exceeded this time window were counted as errors. This served to minimise opportunities for verbal rehearsal of the memorised letters during the processing of the mathematical operations. Finally, participants practised three full trials as they would be presented in the main task.

RESULTS

Short-term memory (span)

Individual and average performance on the digit and tone span tasks for the amusic and control groups are shown in Figure 2.

The data were entered into a 2 (group) × 2 (task) split plot ANOVA. There was a significant effect of group, indicating that the control group performed better than the amusic group (control $M = 7.19$ vs amusic $M = 5.52$), $F(1, 26) = 18.03$,

² Examples of the stimuli can be found at <http://www.gold.ac.uk/music-mind-brain/memoryproject/>

³ <http://psychology.gatech.edu/renglelab/>

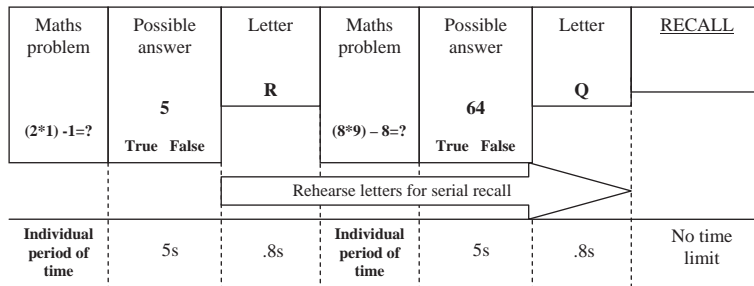


Figure 1. A schematic illustration of stimulus presentation in the automated operation span task. The lower boxes represent the time of presentation for each of the events in seconds (s). The time line shown is that for a two-item sequence.

$MSE = 19.31, p < .001, \eta_p^2 = .41$. There was a significant main effect of task, reflecting higher average digit span compared to tone span (7.13 vs 5.58), $F(1, 26) = 18.40, MSE = 33.81, p < .001, \eta_p^2 = .41$. The interaction between factors was also significant, $F(1, 26) = 4.62, MSE = 8.49, p = .04, \eta_p^2 = .15$. Simple main effects analysis revealed a significant between-group difference in performance on the tone span task, $F(1, 26) = 20.74, MSE = 2.01, p < .001$, but no difference between the two groups in performance on the digit span task, $F(1, 26) = 2.77, MSE = 1.97, p = .11$.⁴ When the two groups were considered separately only amusic participants, and not controls, showed a significant difference in performance on the digit and tone span tasks ($p < .001$ vs $p = .22$).

Relationships with other tasks

The pitch intervals used in the present tone span task were chosen to be suprathreshold for perceptual discrimination but, in order to determine whether short-term memory ability was related to perceptual discrimination ability, an ANCOVA analysis was carried out to partial out any possible effect of the psychophysically measured perceptual thresholds upon variance in scores on the tone span task. Neither pitch detection thresholds nor pitch direction discrimination thresholds were found to be significantly related to performance on the tone span task, $F(1, 24) = .001, MSE = < .001, p = .98$, and $F(1, 24) = .65, MSE = 1.34, p = .43$, respectively, and the significant group difference on this task remained after controlling for

⁴ This pattern of main effects remained when the outlier from the tone span task was removed from the analysis (a significant between-group difference in performance on the tone span task, $F(1, 25) = 21.42, MSE = 1.44, p < .001$, but no difference between the two groups in performance on the digit span task, $F(1, 25) = 2.75, MSE = 2.04, p = .11$).

the performance on both of the perceptual tasks, $F(1, 24) = 9.54, MSE = 19.74, p = .005$.

Next, a correlation analysis was carried out to determine if performance on either the tone or the digit span task was related to MBEA score (pitch composite), years of musical training, years of formal education, age, or score on the NART. Pitch composite score was significantly related to tone span, $r = .75, p < .001$, however, after group analysis this result only remained significant in the controls, $r = .60, p = .02$ (amusic group $r = .36, p = .20$). None of the remaining correlations was found to be significant.

Finally we investigated possible responses bias in the digit and tone span tasks, since Williamson et al. (2010b) reported that individuals with amusia were more likely than controls to respond “same” than “different” in a pitch memory task. The nature of the adaptive-tracking procedure was such that standard guess correction analysis could not be

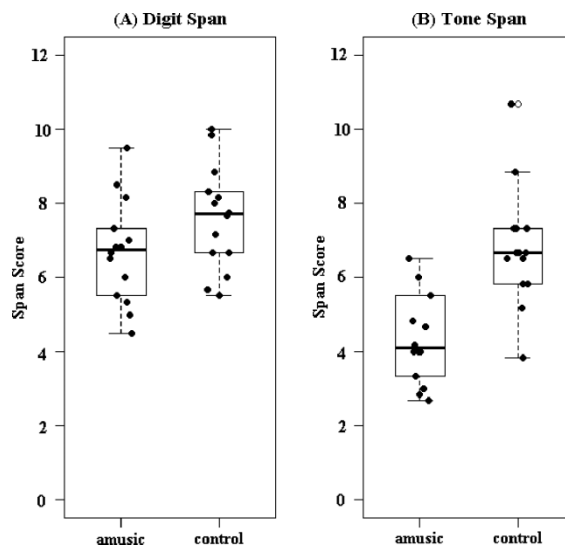


Figure 2. Digit and tone spans for amusic and control groups. Median performance is represented by the solid black line. The clear circle indicates an outlier in the tone span task.

applied⁵ so we calculated the proportion of “same” and “different” responses for each participant in each span task and compared these in a 2 (group) × 2 (task) × 2 (response) split plot ANOVA. The data are presented in Figure A1 of the appendix. A significant three-way interaction was found, $F(1, 26) = 6.37$, $MSE = .011$, $p = .02$, indicating that the types of response made in the tone and digit span tasks were different for amusic and control groups. One-way ANOVAs indicated no differences in the type of response given in the digit span task (“Different”; control $M = .54$ vs amusic $M = .56$; “Same”; control $M = .46$ vs amusic $M = .44$; $p < .30$), but in the tone span task the responses of the two groups differed (“Different”; control $M = .48$ vs amusic $M = .38$; “Same”; control $M = .52$ vs amusic $M = .62$; $p = .005$). Paired t -tests confirmed that amusic participants responded “same” significantly more than “different” in the tone span task ($p < .001$). This difference was not seen in the control group ($p = .30$).

Working memory

Two scores were generated from the working memory span task. One reflected the total number of whole sequences correctly reported (“span”), the other reflected the number of letters reported in correct serial position (“count”). The results of both these measures are shown in Figure 3.

Levene’s test indicated a significant heterogeneity of variance between the groups’ scores ($p < .01$) therefore Span and Count were compared between the groups using Mann Whitney U tests. No significant between-group difference was found on either measure (Span: $z = -.90$, $p = .38$; Count: $z = -1.06$, $p = .31$). Overall the analysis suggests that amusic and control groups did not differ in working memory capacity. However, four amusic participants had a score that was below two standard deviations from the overall average, as can be seen in Figure 3. These four individuals performed significantly worse on the NART ($p = .02$) compared to the rest of the amusic group, but their performance on all other tasks in this study

⁵ Standard guess correction requires equal presentation of same and different trials, which was often not the case in the present adaptive-tracking task since participants could be presented with one or two trials at each sequence length depending on their performance.

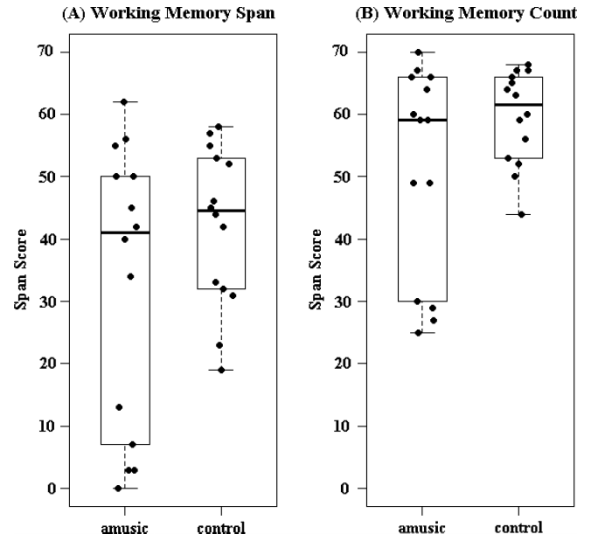


Figure 3. Working memory capacity for amusic and control groups. The figure shows two measures of span: working memory span (A) and working memory count (B). Median performance is represented by the solid black line.

(including the two span tasks) did not differ significantly from the rest of the group. We repeated the main 2 × 2 ANOVA between group and span tasks with these four individuals removed and the main pattern of findings remained; a main effect of group (control $M = 7.19$ vs amusic $M = 5.51$; $p = .001$) and an interaction ($p = .03$), suggesting no group difference in performance on the digit span task (control $M = 7.57$ vs amusic $M = 6.88$) but a significant difference in performance on the tone span task (control $M = 6.80$ vs amusic $M = 4.13$).

Relationships with other tasks

Finally, as with the span tasks, a correlation analysis was carried out to determine if performance on the working memory task was related to MBEA score (pitch composite), years of musical training, years of formal education, age, score on the NART, or score on the tone and span digit tasks. Working memory span scores were found to correlate with digit span, $r = .52$, $p = .005$ (control $r = .38$, $p = .19$ vs amusic $r = .56$, $p = .04$). Working memory span task score also correlated with score on the NART ($p = .03$), however this correlation was not significant when the four low-performing individuals from the amusic group were removed from the analysis. None of the remaining correlations was found to be significant.

DISCUSSION

Congenital amusia has been largely conceived of as a disorder of auditory perception (Foxton et al., 2004; Hyde & Peretz, 2004). However, musical listening is, by definition, a process that requires the integration of sounds over time and several lines of evidence have suggested that limitations in auditory memory may also play a role in this disorder (Foxton et al., 2004; Gosselin et al., 2009; Tillmann et al., 2009; Williamson et al., 2010b). In the present study we measured short-term memory for verbal and tonal information, in order to determine whether a short-term memory deficit exists in amusia and, if so, whether it is specific to the pitch domain or extends to other auditory information such as spoken digits. We also tested working memory capacity, since the ability to manage attention resources has clear implications for the processing of information that unfolds over time.

Using analogous adaptive-tracking tests of short-term memory we found that individuals with amusia had significantly smaller tone spans compared to controls, but similar spans for digits. The finding that amusic participants had problems in recognising tone sequences which cannot be accounted for by their difficulties in discriminating individual tones is consistent with data reported by Foxton et al. (2004) and Tillmann et al. (2009). Foxton et al. (2004) showed that individuals with amusia were impaired on the discrimination of four-item pitch patterns, while Tillmann et al. (2009) reported that individuals with amusia had deficits in memory for five-item timbre and tone sequences, but not analogous word sequences.

The present work corroborates and builds on the previous findings in the following ways. First, the findings support the results of Tillmann et al. (2009) in showing intact verbal short-term memory in amusic people in the presence of impaired pitch sequence memory. This replication, achieved using an alternative task and different stimuli, provides even stronger evidence for the sparing of verbal memory in individuals with amusia. In addition to this, the present study also highlights the way in which adaptive-tracking procedures can quantify ability at the individual level in populations where there is likely to be heterogeneity in performance.

Second, while Foxton et al. (2004) and Tillmann et al. (2009) both used pitch intervals that were

suprathreshold for the detection of a pitch change in order to rule out an effect of perceptual discrimination ability on tone sequence memory, the present study also accounts for the ability to discriminate pitch direction (Patel, 2008). Pitch direction is an important building block of contour, known to be crucial for the encoding of melodies in memory (Dowling, 1991; Edworthy, 1985). Amusic people's thresholds for the discrimination of pitch direction are typically larger than those associated with pitch detection (.28 vs .95 semitones in the present study), and approach (in the present study) or exceed (Foxton et al., 2004) one semitone. In order to rule out deficits related to a failure to discriminate pitch direction, it is therefore necessary to ensure that constituent intervals used in tone sequence memory tasks are suprathreshold for the discrimination of pitch direction, in addition to being suprathreshold for the detection of a pitch change. The present study measured both types of threshold and set the minimal interval in the tone span task to be more than four times greater than the average pitch direction threshold of the amusic participants. The finding of significantly reduced performance on the tone span task in the amusic group using stimuli that are suprathreshold, both for the detection of pitch differences and discrimination of pitch direction, implies that the memory difficulty is unlikely to be attributable to a low-level perceptual discrimination deficit, a finding supported by the absence of a correlation between discrimination thresholds and tone span scores.

It is reasonable to ask whether amusic people's short-term memory deficits for pitch could concern storage, rehearsal, or retrieval processes. Williamson et al. (2010b) and Gosselin et al. (2009) conducted studies of single-tone comparison in the presence of increasing retention intervals and irrelevant tones respectively, and their findings suggest that the ability to store and rehearse the pitch of single tones is impaired in individuals with amusia. However, the effects of these types of manipulations on pitch memory for sequences is not yet known. Future research could examine rehearsal of pitch sequences by measuring controls' performance on the tone span task when rehearsal is blocked by suppression (Logie & Edworthy, 1986; Schendel & Palmer, 2007). If rehearsal of pitch is impaired in amusia, then controls' tone span task performance under suppression should approach the level of the amusic group. If such a performance decrement was not

seen, a hypothesis based on weakness in storage of pitch would seem parsimonious.

Alternatively it may be the case that individuals with amusia have a problem with the retrieval of pitch-based information from memory. This theory would be analogous to that proposed to explain the phonological similarity effect, whereby immediate serial recall of a sequence of visual-verbal items is detrimentally affected when the items are acoustically similar compared to when they are dissimilar (e.g., B, V, G, P, C, and D vs F, K, Y, W, M, and R; Conrad & Hull 1964). The phonological similarity effect cannot be explained by perceptual confusion at encoding (Baddeley, 1966), just as the amusic participants' poorer performance on the present tone span task cannot be explained by their impaired pitch thresholds for detection of a pitch change or discrimination of a pitch direction. Instead, it may be that some difficulty exists in discriminating the traces of pitch codes when they are retrieved from memory storage.⁶

The finding of a pitch-specific memory deficit in amusia ostensibly supports the existence of a memory system that is specialised for processing pitch, (Semal & Demany, 1991, 1993; Semal et al. 1996) and that is, to a degree, separable from verbal memory (Berz, 1995; Deutsch, 1970). However, it is also possible that certain abstract pitch and verbal information is processed in a similar way in short-term memory. The multi-component working memory model (Baddeley, 2000; Baddeley & Hitch, 1974) posits a temporary storage system for speech-like material—the phonological loop—that may also be capable of processing pitch (Williamson, Baddeley, & Hitch, 2010a). The phonological loop has access to long-term knowledge, which can be utilized to support maintenance (Baddeley, 2007). Individuals with amusia may have weaker or absent long-term knowledge of musical structure that would otherwise be used to help them maintain tone sequences, thereby leading to poorer performance on the tone span task. It is possible that people with amusia never acquire knowledge of musical regularities as a result of their perceptual deficits (Tillmann et al., 2009). Alternatively, they may learn about musical regularities but have impaired conscious access to such knowledge, possibly as a result of impaired connectivity between auditory and frontal cortices (Hyde et al., 2007;

Loui, Alsop, & Schlaug, 2009; Tillmann, Peretz, Bigand, & Gosselin, 2007).

Turning to our findings on working memory, it is interesting to note that, with the exception of a subgroup of four individuals, the present study found no evidence for working memory deficits in amusia. Attention problems in amusia have previously been noted but, as in the present study, occurrences were confined to a small subset of individuals (Jones, Zalewski, Brewer, Lucker, & Drayna, 2009). Such corroborating findings indicate that the music-listening difficulties of a small subgroup may have a different aetiology from the majority of those diagnosed with amusia, and suggest the need to take into account possible subtypes of the disorder in future studies. In the case of the present experiment, however, analysis has shown that the finding of significantly shorter tone spans in the absence of a general short-term memory deficit cannot be explained by the presence of this subgroup of amusic people with poor working memory abilities.

Music listening, a task that is often difficult for individuals with amusia, draws heavily on auditory memory. However, there has been relatively little research so far into the memory capacities of amusic individuals. The evidence from the present study suggests that individuals with amusia have difficulties maintaining pitch-based sequences but not analogous verbal sequences in short-term memory, and that a small subgroup are likely to have working memory deficits. Our findings support the existence of a pitch-specific component within short-term memory, and contribute to growing evidence that congenital amusia is more than a low-level disorder of pitch discrimination.

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REFERENCES

- Ayotte, J., Peretz, I., & Hyde, K. (2002). Congenital Amusia: A group study of adults afflicted with a music-specific disorder. *Brain: A Journal of Neurology*, *125*(2), 238–251.
- Baddeley, A. D. (1966). The influence of acoustic and semantic similarity on long-term memory for word sequences. *Quarterly Journal of Experimental Psychology*, *18*, 302–309.
- Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, *4*, 417–423.

⁶ We are grateful to one of our reviewers for alerting us to this alternative explanation of our findings.

- Baddeley, A. D. (2007). *Working memory: Thought and action*. Oxford, UK: Oxford University Press.
- Baddeley, A. D., Eysenck, M. W., & Anderson, M. C. (2009). *Memory*. Hove, UK: Psychology Press.
- Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation, vol. 8* (pp. 47–89). New York: Academic Press.
- Berz, W. L. (1995). Working memory in music: A theoretical model. *Music Perception, 12*(3), 353–364.
- Conrad, R., & Hull, A. J. (1964). Information, acoustic confusion and memory span. *British Journal of Psychology, 55*, 429–432.
- Cowan, N. (2005). *Working memory capacity*. Hove, UK: Psychology Press.
- Cuddy, L. L., Balkwill, L.-L., Peretz, I., Holden, R. R., Avanzini, G., Lopez, L., et al. (2005). Musical difficulties are rare: A study of 'Tone deafness' among university students. In G. Avanzini, L. Lopez, S. Koelsch, & M. Manjano (Eds.), *The neurosciences and music II: From perception to performance* (pp. 311–324). New York: New York Academy of Sciences.
- Deutsch, D. (1970). Tones and numbers: Specificity of interference in immediate memory. *Science, 168*, 1604–1605.
- Dowling, W. (1991). Tonal strength and melody recognition after long and short delays. *Perception and Psychophysics, 50*(4), 305–313.
- Edworthy, J. (1985). Interval and contour in melody processing. *Music Perception, 2*, 375–388.
- Foxton, J. M., Dean, J. L., Gee, R., Peretz, I., & Griffiths, T. D. (2004). Characterization of deficits in pitch perception underlying 'tone deafness'. *Brain: A Journal of Neurology, 127*(4), 801–810.
- Gosselin, N., Jolicoeur, P., & Peretz, I. (2009). Impaired memory for pitch in congenital amusia. *The Neurosciences and Music III - Disorders and Plasticity: Annals of the New York Academy of Sciences, 1169*, 270–272.
- Hyde, K., & Peretz, I. (2004). Brains that are out of tune but in time. *Psychological Science, 15*(5), 356–360.
- Hyde, K. L., Lerch, J. P., Zatorre, R. J., Griffiths, T. D., Evans, A. C., & Peretz, I. (2007). Cortical thickness in congenital amusia: When less is better than more. *Journal of Neuroscience, 27*(47), 13028–13032.
- Jones, J., Zalewski, C., Brewer, C., Lucker, J., & Drayna, D. (2009). Widespread auditory deficits in tune deafness. *Ear and Hearing, 30*(1), 63–72.
- Kalmus, H., & Fry, D. B. (1980). On tune deafness (dysmelodia): Frequency, development, genetics and musical background. *Annals of Human Genetics, 43*, 369–382.
- Liu, F., Patel, A. D., Fourcin, A., & Stewart, L. (2010). Intonation processing in congenital amusia: Discrimination, identification and imitation. *Brain*, doi: 10.1093/brain/awq089
- Logie, R. H., & Edworthy, J. (1986). Shared mechanisms in the processing of verbal and musical material. In D. G. Russell, D. Marks, & J. Richardson (Eds.), *Imagery 2* (pp. 33–37). Dunedin, New Zealand: Human Performance Associates.
- Loui, P., Alsop, D., & Schlaug, G. (2009). Tone deafness: A new disconnection syndrome? *The Journal of Neuroscience, 29*(33), 10215–10220.
- McDonald, C., & Stewart, L. (2008). Uses and functions of music in congenital amusia. *Music Perception, 25*(4), 345–355.
- Patel, A. D. (2008). *Music, language, and the brain*. New York: Oxford University Press.
- Peretz, I., Ayotte, J., Zatorre, R. J., Mehler, J., Ahad, P., Penhune, V. B., et al. (2002). Congenital amusia: A disorder of fine-grained pitch discrimination. *Neuron, 33*, 185–191.
- Peretz, I., Brattico, E., Jarvenpaa, M., & Tervaniemi, M. (2009). The amusic brain: In tune, out of key, and unaware. *Brain, 132*(5), 1277–1286.
- Peretz, I., Champod, A.-S., & Hyde, K. L. (2003). Varieties of musical disorders. The Montreal Battery of Evaluation of Amusia. *Annals of the New York Academy of Sciences, 999*, 58–75.
- Schendel, Z. A., & Palmer, C. (2007). Suppression effects on musical and verbal memory. *Memory and Cognition, 35*(4), 640–650.
- Semal, C., & Demany, L. (1991). Dissociation of pitch from timbre in auditory short-term memory. *Journal of the Acoustical Society of America, 89*(5), 2404–2410.
- Semal, C., & Demany, L. (1993). Further evidence for an autonomous processing of pitch in auditory short-term memory. *Journal of the Acoustical Society of America, 94*(3), 1315–1322.
- Semal, C., Demany, L., Ueda, K., & Halle, P.-A. (1996). Speech versus nonspeech in pitch memory. *Journal of the Acoustical Society of America, 100*(2), 1132–1140.
- Sloboda, J. A., Wise, K. J., Peretz, I., Avanzini, G., Lopez, L., Koelsch, S., et al. (2005). Quantifying tone deafness in the general population. In G. Avanzini, L. Lopez, S. Koelsch, & M. Manjano (Eds.), *The neurosciences and music II: From perception to performance* (pp. 255–261). New York: New York Academy of Sciences.
- Tillmann, B., Peretz, I., Bigand, E., & Gosselin, N. (2007). Harmonic priming in an amusic patient: The power of implicit tasks. *Cognitive Neuropsychology, 24*(6), 603–622.
- Tillmann, B., Schulze, K., & Foxton, J. M. (2009). Congenital amusia: A short-term memory deficit for nonverbal, but not verbal sounds. *Brain and Cognition, 71*(3), 259–264.
- Unsworth, N., & Engle, R. W. (2007a). On the division of short-term and working memory: An examination of simple and complex spans and their relation to higher-order abilities. *Psychological Bulletin, 133*, 1038–1066.
- Unsworth, N., & Engle, R. W. (2007b). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 14*, 104–132.
- Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the

operation span task. *Behavior Research Methods*, 37, 498–505.

Williamson, V. J., Baddeley, A. D., & Hitch, G. J. (2010a). Musicians' and nonmusicians' short-term memory for verbal and musical sequences: Comparing phonological similarity and pitch proximity. *Memory and Cognition*, 38(2), 163–175.

Williamson, V. J., McDonald, C., Deutsch, D., Griffiths, T. D., & Stewart, L. (2010b). Faster decline of pitch

memory over time in congenital amusia. *Advances in Cognitive Psychology*, 6, 15–22.

Wise, K. J., & Sloboda, J. A. (2008). Establishing an empirical profile of self-defined 'tone deafness': Perception, singing performance and self-assessment. *Musicae Scientiae*, 12(1), 3–26.

APPENDIX

TABLE A1
Participant details

<i>Participant ID</i>	<i>Gender</i>	<i>Age</i>	<i>NART</i>	<i>Years musical training</i>	<i>Years education</i>	<i>MBEA Scale</i>	<i>MBEA Contour</i>	<i>MBEA Interval</i>	<i>Pitch composite</i>
A1	M	67	49	.00	16	19	16	18	53
A2	M	54	46	.00	16	18	21	16	55
A3	M	38	38	.00	20	18	20	18	56
A4	M	35	42	.00	13	14	15	14	43
A5	F	56	47	.00	16	16	14	16	46
A6 *	F	63	36	1.00	16	14	15	18	47
A7	F	60	47	2.00	16	17	19	15	51
A8 *	F	53	40	.00	16	18	19	18	55
A9	F	51	43	11.00	17	17	20	19	56
A10 *	F	53	44	1.00	13	23	16	17	56
A11	F	46	48	.00	17	17	19	18	54
A12	F	58	40	.00	16	20	20	20	60
A13	F	29	38	3.00	16	22	24	17	63
A14 *	F	37	38	.00	16	20	22	22	64
C1	M	36	44.67#	4.00	21	28	28	27	83
C2	M	43	47	5.00	13	22	27	27	76
C3 +	M	45	43	.00	21	26	29	30	85
C4	M	63	44	.00	13	28	29	25	82
C5	F	20	44	10.00	13	28	30	28	86
C6	F	30	47	5.00	16	27	30	28	85
C7	F	56	48	.00	16	25	27	24	76
C8	F	55	44	.00	11	29	30	30	89
C9	F	57	39	1.00	17	30	28	29	87
C10	F	57	41	2.00	17	30	30	30	90
C11	F	52	47	.00	16	26	28	29	83
C12	F	54	47	.25	17	29	29	30	88
C13	F	54	45	.00	13	27	22	23	72
C14	F	51	45	.00	18	27	27	28	82

Downloaded By: [University College London] At: 14:36 16 February 2011

<i>Participant ID</i>	<i>Threshold pitch detection</i>	<i>Threshold pitch direction</i>	<i>Digit span</i>	<i>Tone span</i>	<i>Working memory span</i>	<i>Working memory count</i>
A1	1.29	2.97	7.33	4.00	45	59
A2	.07	.10	8.50	6.00	55	66
A3	.27	1.33	8.17	3.33	50	70
A4	.21	.37	7.00	2.83	40	60
A5	.13	.20	6.83	4.17	50	64
A6 *	.35	1.79	5.50	5.50	3	30
A7	.37	.30	9.50	4.83	56	66
A8 *	.26	1.66	6.00	4.00	0	27
A9	.15	1.97	4.50	2.67	13	49
A10 *	.22	.45	6.83	4.67	3	29
A11	.20	1.00	5.00	3.00	34	49
A12	.23	.29	5.33	4.00	42	59
A13	.05	.52	6.67	6.50	62	67
A14 *	.12	.29	6.50	5.50	7	25
C1	.14	.12	10.00	5.83	45	59
C2	.13	.18	7.50	6.50	23	53
C3+	.08	.10	7.17	10.67	31	52
C4	.17	.20	8.83	7.33	32	50
C5	.16	.12	5.67	7.33	33	56
C6	.09	.09	6.00	6.67	44	60
C7	.26	.24	8.17	5.17	55	64
C8	.24	.18	8.33	7.33	57	67
C9	.10	.16	5.50	6.50	19	44
C10	.09	.12	8.00	6.67	53	67
C11	.16	.18	6.67	6.67	42	65
C12	.08	.09	7.67	8.83	58	68
C13	.15	.14	6.67	3.83	52	66
C14	.15	.40	9.83	5.83	46	63

The four individuals excluded from part of the working memory analysis as a result of low performance are highlighted with *.

C1 used the NART during his occupation as a psychiatrist. He was therefore assigned a score based on the average of the other male control participants.

+ Control outlier for the tone span task.

Rating scale used to measure musical experience

1. I am a professional musician, meaning that I earn a living by performing music.
2. I am a serious amateur musician, meaning that I reached a high standard at an earlier stage of life and I still keep my hand in, playing several times a year.
3. I was a serious amateur musician – I reached a high standard at an earlier stage of life but I no longer play.
4. I had musical training as a child but I gave up after [] years. (PLEASE INSERT NUMBER OF YEARS YOU PLAYED)
5. I have never had any musical training.
6. I have not received training on a musical instrument but I am involved with music in a different capacity, e.g., I am a DJ/sound engineer/other. (PLEASE SPECIFY)

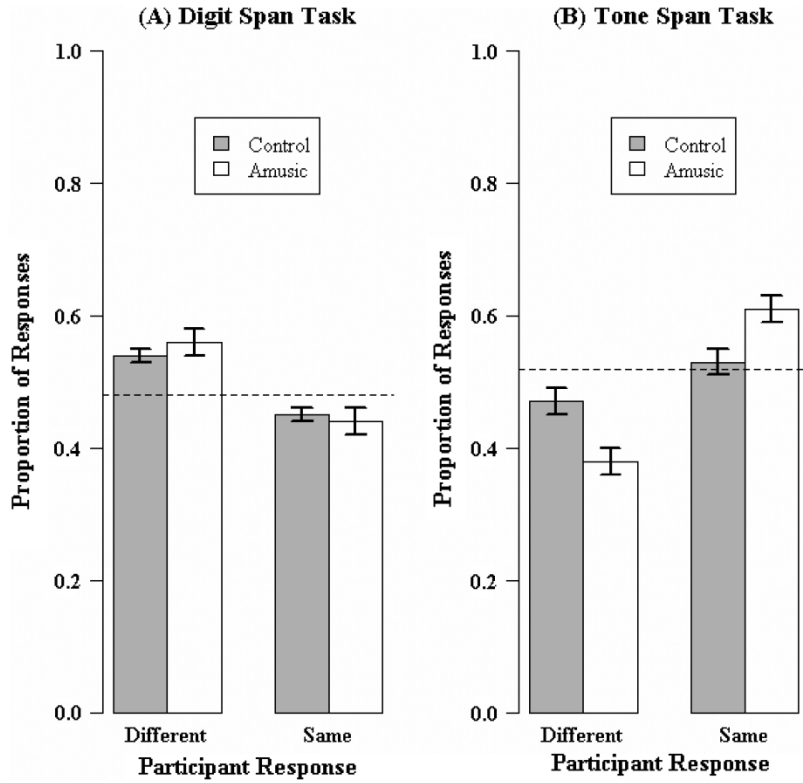


Figure A1. Proportion of same and different responses for amusic and control groups, in both the Digit Span (A) and Tone Span (B) tasks. The mean presentation of “different” trials across all participants is represented by the dotted black line (.48 in digits and .52 in tones). Equal presentation of same and different trial was not possible in the present adaptive-tracking task since participants could be presented with one or two trials at each sequence length depending on their performance.