Journal of Experimental Psychology: Human Perception and Performance

Percepts, Not Acoustic Properties, Are the Units of Auditory Short-Term Memory

Samuel R. Mathias and Katharina von Kriegstein

Online First Publication, November 4, 2013. doi: 10.1037/a0034890

Journal of Experimental Psychology:
Human Perception and Performance

0096-1523/13/$12.00 DOI: 10.1037/a0034890

Percepts, Not Acoustic Properties, Are the Units of Auditory Short-Term Memory

Samuel R. Mathias
Max Planck Institute for Human Cognitive and Brain Sciences and Boston University

Katharina von Kriegstein
Max Planck Institute for Human Cognitive and Brain Sciences and Humboldt University of Berlin

For decades, researchers have sought to understand the organizing principles of auditory and visual short-term memory (STM). Previous work in audition has suggested that there are independent memory stores for different sound features, but the nature of the representations retained within these stores is currently unclear. Do they retain perceptual features, or do they instead retain representations of the sound's specific acoustic properties? In the present study we addressed this question by measuring listeners' abilities to keep one of three acoustic properties (interaural time difference [ITD], interaural level difference [ILD], or frequency) in memory when the target sound was followed by interfering sounds that varied randomly in one of the same properties. Critically, ITD and ILD evoked the same percept (spatial location), despite being acoustically different and having different physiological correlates, whereas frequency evoked a different percept (pitch). The results showed that listeners found it difficult to remember the percept of spatial location when the interfering tones varied either in ITD or ILD, but not when they varied in frequency. The study demonstrates that percepts are the units of auditory STM, and provides testable predictions for future neuroscientific work on both auditory and visual STM.

Keywords: short-term memory, storage, spatial location, pitch

Maintaining representations of sensory events is a critical part of our ability to perceive the natural environment (Demany & Semal, 2008; Pearson & Brascamp, 2008). Psychophysical studies have shown that representations of auditory and visual events can be stored nonverbally for up to several seconds (e.g., in audition: Deutsch, 1970; Pechmann & Mohr, 1992; Semal, Demany, Ueda, & Hallé, 1996; in vision: Eriksen & Collins, 1968; Luck & Vogel, 1997; Sperling, 1963). We refer to these types of storage systems as *short-term memory* (STM), as opposed to *working memory*, which is commonly used to describe systems that deal with the manipulation of stored verbal or categorical information (Baddeley, 2012; Miyake & Shah, 1999). In contrast to working memory, the organizing principles of STM remain poorly understood and have been the topic of intense debate in recent years. One of the central questions in this debate has been how best to characterize the units of STM (Fougnie & Alvarez, 2011; Fougnie, Asplund, & Marois, 2010; Lee & Chun, 2001; Luck & Vogel, 1997; Olson & Jiang, 2002; Vogel, Woodman, & Luck, 2001; Woodman & Vogel, 2008).

Previous work has suggested that auditory STM contains multiple distinct stores, each retaining a different feature of a target sound (e.g., Clément, Demany & Semal, 1999; Mercer & McKeown, 2010a, 2010b; Ries, Hamilton, & Grossmann, 2010; Semal & Demany, 1991, 1993; Starr & Pitt, 1997). However, the nature of the units within these stores is not known. A long-standing assumption is that they retain percepts, such as spatial location or pitch (Massaro, 1972). An alternative hypothesis is that they retain representations of the specific acoustic properties that evoke a particular percept. For example, a recent study (Agus, Thorpe, & Pressnitzer, 2010) found that listeners implicitly learn specific samples of random noise that do not differ from one another along traditional perceptual dimensions, suggesting that listeners are able to retain specific acoustic properties in one form or another. Here, we report a psychophysical experiment that aimed to adjudicate between these two possibilities.

The experiment used a paradigm modified from previous studies (e.g., Deutsch, 1972, 1978a, 1978b; Semal & Demany, 1991, 1993; Starr & Pitt, 1997) that measured selective interference on memory. Listeners heard sequences of pure tones and indicated whether the first and last tones in each sequence were the same or different. The first and last tones could differ in exactly one of three acoustic properties: interaural time difference (ITD), interaural level difference (ILD), or frequency. Crucially, ITDs and ILDs individually evoke the percept of spatial location (Lord Rayleigh, 1907). However, because they are acoustically different and have at least partially distinct neural codes (Palomäki, Tiitinen, Mäkinen, May, & Alku, 2005; Ungan, Yagcioglu, & Goksoy, 2001; Yamada, Kaga, Uno, & Shindo, 1996), ITDs and ILDs

Samuel R. Mathias, Neural Mechanisms of Human Communication, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany and Center for Computational Neuroscience and Neurotechnology, Boston University, Boston, MA; and Katharina von Kriegstein, Neural Mechanisms of Human Communication, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany and Department of Psychology, Humboldt University of Berlin, Berlin, Germany.

Correspondence concerning this article should be addressed to Samuel R. Mathias, Center for Computational Neuroscience and Neurotechnology, Boston University, 677 Beacon Street, Boston, MA 02215. E-mail: smathias@bu.edu

produce different sound qualities and are neither indistinguishable nor completely interchangeable (Hafter & Carrier, 1972). By contrast, the frequency of a pure tone determines a different percept, namely its pitch. Listeners were instructed to ignore the middle (interfering) tones, which varied randomly in one of these properties. The experiment also included control conditions in which all interfering tones were identical.

The design of the experiment permitted us to test whether percepts or acoustic properties are the units of auditory STM. If acoustic properties are retained, then due to selective interference, performance should be impaired relative to the control conditions only when the interfering tones vary in the same property that listeners are required to remember. For example, when listeners discriminate ITD changes between the first and last tones, performance should be impaired when the interfering tones vary randomly in ITD, but not when they vary in ILD or frequency. Alternatively, if percepts are retained, performance should be impaired when the interfering tones vary in the same percept regardless of the acoustic properties. For example, when listeners discriminate ITD changes, performance should be impaired when the interfering tones vary randomly either in ITD or ILD, but not when they vary in frequency.

Method

Listeners

Thirteen listeners participated in the experiment (nine female; ranging in age from 21–27 years). Prior to the main experiment, each listener's hearing was assessed with pure-tone audiometry. All had less than 15 dB hearing level for frequencies in the range 250–8,000 Hz.

Stimuli

Each trial in the experiment contained five 300-ms pure tones separated by 200-ms silent intervals. They were generated digitally and delivered via headphones (Sennheiser HD 580, Hannover, Germany) at 65 dB sound pressure level, and were gated on and off with 20-ms raised-cosine amplitude ramps. The first tone in each trial had a random ITD, ILD, or frequency, depending on which of these was to be discriminated. Its other two properties were fixed at "standard" values; these were 0 μs (ITD), 0 dB (ILD), and 500 Hz (frequency). In the experimental conditions, the three interfering tones varied randomly in one acoustic property, with the other properties fixed at the standard values. In the control conditions, all three properties in all three tones were fixed. This resulted in nine experimental conditions and three control conditions (see Figure 1). In all of them, the last tone per trial was either identical to the first or differed only in the property to be discriminated.

The random ITD, ILD, and frequency values were drawn independently and with replacement from discrete probability distributions. The possible ITD values were −700, −350, 0, 350, and 700 μs. ITDs were introduced by shifting the phase of the tones in the listeners' left ears. The possible ILDs were −10, −5, 0, 5, and 10 dB. ILDs were introduced by increasing the level of the tones by half the amount in the left ear and decreasing them by the same amount in the right ear. The possible frequencies were selected from five equally spaced steps of ±0.75 semitone centered on 500 Hz. When the interfering tones had random ITDs, ILDs, or frequencies, these values were drawn from the same probability distributions described above. When the last tone was different from the first tone, it differed from the first in one acoustic property by one step in either direction in the probability distribution; for example, if the first tone had an ITD of 350 μs, the last tone had an ITD of either 0 or 750 μs. Because the first tone was random, listeners could never infer the value of its relevant property from the interfering tones in any condition. Thus, in all conditions, listeners had to retain the first tone in memory throughout the trial to perform the experiment successfully.

Pilot work was conducted to find suitable ITD and ILD values. Consistent with previous studies (e.g., Mills, 1958), these experiments revealed that listeners' difference limens for ITD were not equivalent in terms of perceived spatial distance to those for ILD. Another issue was that the range of useful ITDs was smaller than that of ILDs because tones with very large ITDs can be perceived as coming from the side contralateral to the sound's nominal location (Yost, 1981). For the main experiment, we therefore chose ITD values that were large enough to be highly discriminable from one another, but were small enough to avoid the problem of the tones being perceived on the "wrong" side of the head. Based on previously published data (Yost, 1981), we then selected ILD values so that the overall perceived spatial range of the tones with ILDs was similar to that of the tones with ITDs.

Procedure

Testing was conducted individually in a quiet room. Listeners completed four experimental sessions, each lasting approximately 1 hr, on different days. Sessions comprised 12 randomly ordered blocks of 50 trials, one block per condition, resulting in a total of 200 trials per condition per listener.

At all times during the experiment, the task instructions ("Are the first and the last tones the same or different?") and response options ("same" and "different") were displayed on the PC monitor. At the beginning of each block, a brief message indicated in which percept the first and last tones might differ ("spatial location" or "pitch"). The listeners were unaware of the properties of the interfering tones before the block. Responses were followed by immediate feedback and response times were unlimited.

The design of the experiment corresponded to the same/different paradigm from signal detection theory. There are two ways to calculate indexes of sensitivity and response bias for this paradigm: one that assumes an optimal decision rule (Noreen, 1981), and a simpler method that uses the "differencing" rule (Sorkin, 1962). Theoretical work has shown that these methods are equivalent when wide stimulus roving is used (Dai, Versfeld, & Green, 1996). Because our paradigm involved wide roving, we used the simpler method.

Results

Indexes of sensitivity (d') were calculated separately for each listener and condition (see Figure 2), and were subjected to a repeated-measures analysis of variance (ANOVA). The ANOVA had two factors: the acoustic property in which listeners discriminated changes (ITD, ILD, or frequency), and the acoustic property in which the interfering tones varied (ITD, ILD, frequency, or no

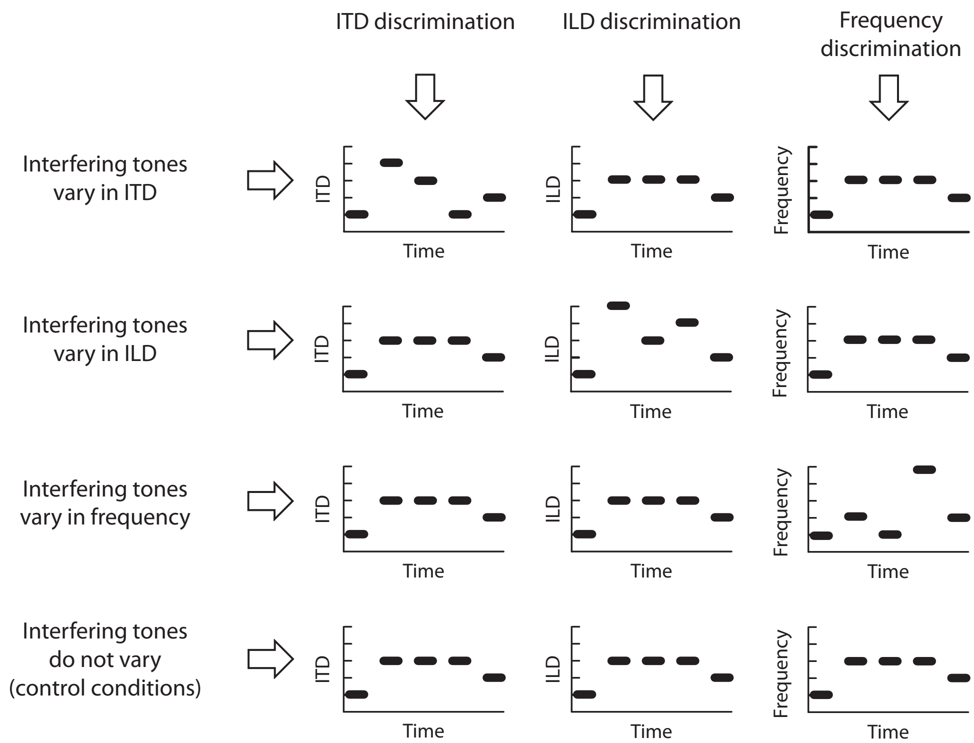

Figure 1. Overview of the 12 conditions in the experiment. Each diagram illustrates an example trial (one per condition); in each case, the correct response would be "different." The diagrams are organized into columns depending on which acoustic property listeners discriminated in the condition, and rows depending on which property varied in the intervening tones in the condition. ITD = interaural time difference; ILD = interaural level difference.

variation). The interaction between the factors was significant, $F(6, 72) = 10.776$, $p < .001$, $\eta_p^2 = .473$, indicating effects of selective interference on d'. Planned contrasts showed that listeners were worse at discriminating changes between the first and last tones when the interfering tones varied in the acoustic property they were required to remember than when the interfering tones did not vary. This was the case for all three properties, $F(1, 12) \geq 3.077$, $p < .05$, $r^2 > .204$.

The aim of the experiment was to test whether acoustic properties or percepts are the units of auditory STM. Crucial to the adjudication between these possibilities was that when listeners discriminated ITD changes, performance was worse when the

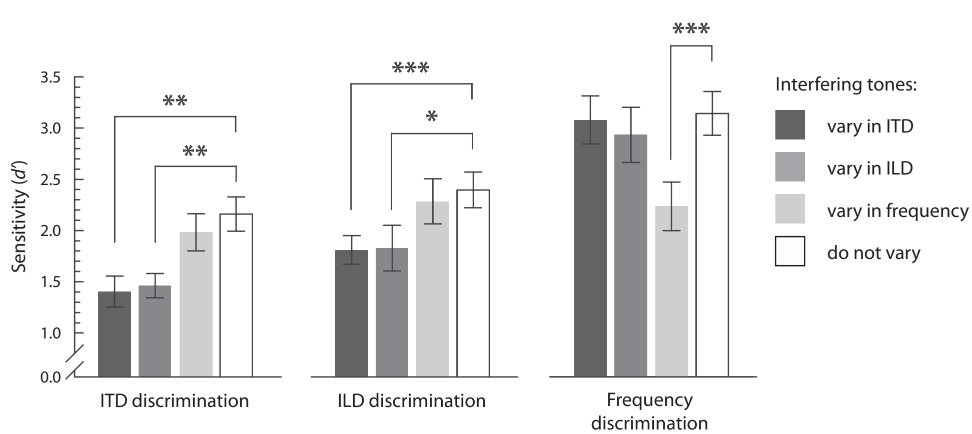

Figure 2. Group mean d' scores. Bars are grouped depending on which property listeners discriminated, and bar shades represent which property varied in the intervening tones. Error bars are ± 1 standard error of the mean. ITD = interaural time difference; ILD = interaural level difference. $^{*} p < .05$. $^{**} p < .01$. $^{***} p < .001$.

interfering tones varied in ILD than when they did not vary, $F(1, 12) = 4.518$, $p < .001$, $r^2 = .274$. Likewise, when listeners discriminated ILD changes, performance was worse when the interfering tones varied in ITD than when they did not vary, $F(1, 12) = 6.586$, $p < .001$, $r^2 = .354$. These results indicate that the interfering tones' spatial locations, not their ITDs or ILDs, determined whether they produced interference. Variation in frequency did not impair ITD or ILD discrimination, and variation in neither ITD nor ILD impaired frequency discrimination, $F(1, 12) \leq 1.528$, $p \geq .152$ (see also Ries et al., 2010), confirming that there are independent memory stores for spatial location and pitch. There were no significant differences between the ITD- and ILD-variation conditions for any discriminated property, $F(1, 12) \leq 0.974$, $p \geq .349$, indicating that ITDs were just as effective as ILDs in producing interference overall.

We performed a second ANOVA with the same design as the first on the response-bias data [$\ln(\beta)$]. This revealed no significant main effects or interactions ($p \geq .068$), indicating that the experimental manipulations did not influence listeners' task strategies.

Discussion

The results of this study validate the long-standing assumption that percepts are the units of auditory STM. In both audition and vision, it is thought that information is retained for a short time (on the order of milliseconds) within very high-capacity stores (e.g., Cowan, 1984; Phillips, 1974). According to Massaro (1972), these stores retain "preperceptual" representations that are progressively read out into perceptual STM. Although some authors have disputed the idea of initial preperceptual storage (see Demany & Semal, 2008), the idea of purely perceptual STM has been widely accepted. However, to our knowledge, it had never been experimentally tested until now.

The results of many previous studies are consistent with the idea that listeners possess special stores for different auditory percepts, of which pitch has been the most frequently studied. In a classic experiment, Deutsch (1970) showed that listeners' memory for pitch was disrupted by interfering tones with random pitches, but not by random spoken digits (see also Semal et al., 1996). The strength of the interference effect is influenced by the musical relationships between the pitches of the target and interfering tones (e.g., Deutsch, 1973, 1978a, 1982; Deutsch & Roll, 1974), but not by their timbres (Semal & Demany, 1991, 1993). Taken together, these and other findings strongly suggest that musical pitch is stored separately from other perceptual features (see Deutsch, 2012). However, although it is still not clear precisely how the brain extracts pitch (e.g., Oxenham, Micheyl, Keebler, Loper, & Santurette, 2011), it is likely that it is achieved largely via a single underlying physiological mechanism (Gockel, Carlyon, & Plack, 2004). Therefore, previous studies cannot demonstrate that listeners retain the percept of pitch per se in memory. By contrast, separate representations of ITD and ILD may be maintained up to the level of the cortex in humans (Palomäki et al., 2005; Ungan et al., 2001; Yamada et al., 1996; but see also, Grothe, Pecka, & McAlpine, 2010). Moreover, ITDs and ILDs produce different sound qualities and are distinguishable from one another (Hafter & Carrier, 1972). Thus, ITDs and ILDs were ideal acoustic properties for the aims of the present study.

Although the present study suggests that listeners retain percepts in STM, specific acoustic properties may be retained in different memory systems. Agus et al. (2010) instructed listeners to detect repetitions within instances of Gaussian noise, and found that performance was better when they had heard the specific noise instances previously (see also Agus & Pressnitzer, 2013). Noise instances do not differ in traditional perceptual features, yet this study shows that listeners retain information from them. We speculate that these findings reflect a type of implicit learning that does not necessarily operate on perceptual units and is therefore distinct from STM. Another study (Wright & Fitzgerald, 2001) measured the effects of implicit learning on ITD and ILD discrimination, and found that while listeners' difference limens for both ITDs and ILDs rapidly improved, only their difference limens for ILDs experienced subsequent, long-term improvement. Given the main finding of the present study—that ITDs and ILDs are stored together in STM—the results of Wright and Fitzgerald (2001) support the speculation that implicit learning and STM are distinct.

Similar principles govern auditory and visual STM (e.g., Darwin, Turvey, & Crowder, 1972; Visscher, Kaplan, Kahana, & Sekuler, 2010). Therefore, it seems reasonable to predict that visual STM also retains percepts rather than specific visual properties. This prediction could be tested experimentally if a duplex phenomenon analogous to that of the processing of ITDs and ILDs could be identified in vision. The results also predict that the encoding and retention of representations in STM occurs at a stage of cortical processing after acoustic or visual properties are combined to form percepts. Recent neuroimaging studies have revealed sustained patterns of activity in sensory cortical areas during the retention of visual memories (e.g., Harrison & Tong, 2009; Serences, Ester, Vogel, & Awh, 2009). Our results suggest that the recruitment of these areas reflects the maintenance of perceptual representations.

References

Agus, T. R., & Pressnitzer, D. (2013). The detection of repetitions in noise before and after perceptual learning. *Journal of the Acoustical Society of America, 134*(1), 464–473. doi:10.1121/1.4807641

Agus, T. R., Thorpe, S. J., & Pressnitzer, D. (2010). Rapid formation of robust auditory memories: Insights from noise. *Neuron, 66,* 610–618. doi:10.1016/j.neuron.2010.04.014

Baddeley, A. (2012). Short-term memory: Theories, models, and controversies. *Annual Review of Psychology, 63,* 1–29. doi:10.1146/annurev-psych-120710-100422

Clément, S., Demany, L., & Semal, C. (1999). Memory for pitch versus memory for loudness. *Journal of the Acoustical Society of America, 106,* 2805–2811. doi:10.1121/1.428106

Cowan, N. (1984). On short and long auditory stores. *Psychological Bulletin, 96,* 341–370. doi:10.1037/0033-2909.96.2.341

Dai, H., Versfeld, N. J., & Green, D. M. (1996). The optimum decision rules in the same-different paradigm. *Perception & Psychophysics, 58,* 1–9. doi:10.3758/BF03205469

Darwin, C. J., Turvey, M. T., & Crowder, R. G. (1972). An auditory analogue of the Sperling partial report procedure: Evidence for brief auditory storage. *Cognitive Psychology, 3,* 255–267. doi:10.1016/0010-0285(72)90007-2

Demany, L., & Semal, C. (2008). The role of memory in auditory perception. In W. A. Yost, A. N. Popper, & R. R. Fay (Eds.), *Auditory perception of sound sources* (Vol. 29, pp. 77–113). New York, NY: Springer-Verlag. doi:10.1007/978-0-387-71305-2_4

Deutsch, D. (1970). Tones and numbers: Specificity of interference in immediate memory. *Science, 168*(3939), 1604–1605. doi:10.1126/science.168.3939.1604

Deutsch, D. (1972). Mapping of interactions in the pitch memory store. *Science, 175*(4025), 1020–1022. doi:10.1126/science.175.4025.1020

Deutsch, D. (1973). Octave generalization of specific interference effects in memory for tonal pitch. *Perception & Psychophysics, 13,* 271–275. doi:10.3758/BF03214138

Deutsch, D. (1978a). Interactive effects in memory for harmonic intervals. *Perception & Psychophysics, 24,* 7–10. doi:10.3758/BF03202968

Deutsch, D. (1978b). Interference in pitch memory as a function of ear or input. *The Quarterly Journal of Experimental Psychology, 30,* 283–287. doi:10.1080/14640747808400675

Deutsch, D. (1982). The influence of melodic context on pitch recognition judgment. *Perception & Psychophysics, 31,* 407–410. doi:10.3758/BF03204849

Deutsch, D. (2012). The processing of pitch combinations. In D. Deutsch (Ed.), *The psychology of music* (3rd ed., pp. 249–325). San Diego, CA: Elsevier.

Deutsch, D., & Roll, P. L. (1974). Error patterns in delayed pitch comparisons as a function of relational context. *Journal of Experimental Psychology, 103,* 1027–1034. doi:10.1037/h0037359

Eriksen, C. W., & Collins, J. F. (1968). Sensory traces versus the psychological moment in the temporal organization of form. *Journal of Experimental Psychology, 77*(3, Pt. 1), 376–382. doi:10.1037/h0025931

Fougnie, D., & Alvarez, G. A. (2011). Object features fail independently in visual short-term memory: Evidence for a probabilistic feature-store model. *Journal of Vision, 11*(12), 1–12.

Fougnie, D., Asplund, C. L., & Marois, R. (2010). What are the units of storage in visual short-term memory? *Journal of Vision, 10*(12), 1–11.

Gockel, H., Carlyon, R., & Plack, C. (2004). Across-frequency interference effects in fundamental frequency discrimination: Questioning evidence for two pitch mechanisms. *Journal of the Acoustical Society of America, 116,* 1092–1104. doi:10.1121/1.1766021

Grothe, B., Pecka, M., & McAlpine, D. (2010). Mechanisms of sound localization in mammals. *Physiological Reviews, 90,* 983–1012. doi:10.1152/physrev.00026.2009

Hafter, E. R., & Carrier, S. (1972). Binaural interaction in low-frequency stimuli: The inability to trade time and intensity completely. *Journal of the Acoustical Society of America, 51*(6B), 1852–1862. doi:10.1121/1.1913044

Harrison, S. A., & Tong, F. (2009). Decoding reveals the contents of visual working memory in early visual areas. *Nature, 458,* 632–635. doi:10.1038/nature07832

Lee, D., & Chun, M. M. (2001). What are the units of visual short-term memory, objects or spatial locations? *Perception & Psychophysics, 63,* 253–257. doi:10.3758/BF03194466

Luck, S. J., & Vogel, E. (1997). The capacity of visual short-term memory for features and conjunctions. *Nature, 390*(6657), 279–281. doi:10.1038/36846

Massaro, D. W. (1972). Preperceptual images, processing time, and perceptual units in auditory perception. *Psychological Review, 79,* 124–145. doi:10.1037/h0032264

Mercer, T., & McKeown, D. (2010a). Interference in short-term auditory memory. *The Quarterly Journal of Experimental Psychology, 63,* 1256–1265. doi:10.1080/17470211003802467

Mercer, T., & McKeown, D. (2010b). Updating and feature overwriting in short-term memory for timbre. *Attention, Perception, & Psychophysics, 72,* 2289–2303.

Mills, A. W. (1958). On the minimum audible angle. *Journal of the Acoustical Society of America, 30,* 237–246. doi:10.1121/1.1909553

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control.* New York, NY: Cambridge University Press. doi:10.1017/CBO9781139174909

Noreen, D. (1981). Optimal decision rules for some common psychophysical paradigms. In S. Grossberg (Ed.), *Mathematical psychology and psychophysiology* (Vol. 13, pp. 237–279). Providence, RI: American Mathematical Society.

Olson, I. R., & Jiang, Y. (2002). Is visual short-term memory object based? Rejection of the "strong-object" hypothesis. *Perception & Psychophysics, 64,* 1055–1067. doi:10.3758/BF03194756

Oxenham, A. J., Micheyl, C., Keebler, M., Loper, A., & Santurette, S. (2011). Pitch perception beyond the traditional existence region of pitch. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 7629–7634. doi:10.1073/pnas.1015291108

Palomäki, K. J., Tiitinen, H., Mäkinen, V., May, P. J. C., & Alku, P. (2005). Spatial processing in human auditory cortex: The effects of 3D, ITD, and ILD stimulation techniques. *Cognitive Brain Research, 24,* 364–379. doi:10.1016/j.cogbrainres.2005.02.013

Pearson, J., & Brascamp, J. (2008). Sensory memory for ambiguous vision. *Trends in Cognitive Sciences, 12*(9), 334–341. doi:10.1016/j.tics.2008.05.006

Pechmann, T., & Mohr, G. (1992). Interference in memory for tonal pitch: Implications for a short-term-memory model. *Memory & Cognition, 20,* 314–320. doi:10.3758/BF03199668

Phillips, W. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics, 16,* 283–290. doi:10.3758/BF03203943

Rayleigh, Lord. (1907). On our perception of sound direction. *Philosophical Magazine, 13,* 214–232. doi:10.1080/14786440709463595

Ries, D. T., Hamilton, T. R., & Grossmann, A. J. (2010). The effects of intervening interference on short-term memory for sound location as a function of inter-comparison interval. *Hearing Research, 268,* 227–233. doi:10.1016/j.heares.2010.06.004

Semal, C., & Demany, L. (1991). Dissociation of pitch from timbre in auditory short-term memory. *Journal of the Acoustical Society of America, 89,* 2404–2410. doi:10.1121/1.400928

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, Pt. 1), 1315–1322. doi:10.1121/1.408159

Semal, C., Demany, L., Ueda, K., & Hallé, P. (1996). Speech versus nonspeech in pitch memory. *Journal of the Acoustical Society of America, 100*(2, Pt. 1), 1132–1140. doi:10.1121/1.416298

Serences, J. T., Ester, E. F., Vogel, E. K., & Awh, E. (2009). Stimulus-specific delay activity in human primary visual cortex. *Psychological Science, 20*(2), 207–214. doi:10.1111/j.1467-9280.2009.02276.x

Sorkin, R. D. (1962). Extension of the theory of signal detectability to matching paradigms in psychoacoustics. *Journal of the Acoustical Society of America, 34,* 1745–1751. doi:10.1121/1.1909115

Sperling, G. (1963). A model for visual memory tasks. *Human Factors, 5,* 19–31.

Starr, G. E., & Pitt, M. (1997). Interference effects in short-term memory for timbre. *Journal of the Acoustical Society of America, 102*(1), 486–494. doi:10.1121/1.419722

Ungan, P., Yagcioglu, S., & Goksoy, C. (2001). Differences between the N1 waves of the responses to interaural time and intensity disparities: Scalp topography and dipole sources. *Clinical Neurophysiology, 112,* 485–498. doi:10.1016/S1388-2457(00)00550-2

Visscher, K. M., Kaplan, E., Kahana, M. J., & Sekuler, R. (2007). Auditory short-term memory behaves like visual short-term memory. *PLoS Biology, 5*(3), e56. doi:10.1371/journal.pbio.0050056

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 92–114. doi:10.1037/0096-1523.27.1.92

Woodman, G. F., & Vogel, E. (2008). Selective storage and maintenance of an object's features in visual short-term memory. *Psychonomic Bulletin & Review, 15,* 223–229. doi:10.3758/PBR.15.1.223

Wright, B. A., & Fitzgerald, M. (2001). Different patterns of human discrimination learning for two interaural cues to sound-source location. *Proceedings of the National Academy of Sciences of the United States of America, 98,* 12307–12312. doi:10.1073/pnas.211220498

Yamada, K., Kaga, K., Uno, A., & Shindo, M. (1996). Sound lateralization in patients with lesions including the auditory cortex: Comparison of interaural time difference, (ITD) discrimination and interaural intensity difference (IID) discrimination. *Hearing Research, 101,* 173–180. doi:10.1016/S0378-5955(96)00144-X

Yost, W. (1981). Lateral position of sinusoids presented with interaural intensive and temporal differences. *The Journal of the Acoustical Society of America, 70*(2), 397–409. doi:10.1121/1.386775

Received May 15, 2013
Revision received September 20, 2013
Accepted September 30, 2013 ■