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Auditory priming of frequency and temporal information: Effects of lateralized presentation

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Abstract

Asymmetric distribution of function between the cerebral hemispheres has been widely investigated in the auditory modality. The current approach borrows heavily from visual local-global research in an attempt to determine whether, as in vision, local-global auditory processing is lateralized. In vision, lateralized local-global processing likely relies on spatial frequency information. Drawing analogies between visual spatial frequency and auditory dimensions, two sets of auditory stimuli were developed. In the *High-Low Stimulus* set, we manipulate frequency information and in the *Fast-Slow Stimulus* set, we manipulate temporal information. The *Fast-Slow Stimuli* additionally mimic visual hierarchical stimulus structure, in which the arrangement of local patterns determines the global pattern. Unlike previous auditory stimuli, the current stimulus sets contain the experimental flexibility of visual local-global hierarchical stimuli allowing independent manipulation of structural levels. Previous findings of frequency and temporal range priming were replicated. Additionally, by presenting stimuli monaurally, we found that priming of frequency ranges (but not temporal ranges) was found to vary by ear, supporting the contention that the hemispheres asymmetrically retain traces of prior frequency processing. These results contribute to the extensive literature revealing cerebral asymmetries for the processing of frequency information, and extend those results to the realm of priming.

Keywords

Audition; Laterality; Local; Global; Priming; Frequency; Time

Introduction

Visual Local-Global Perception

Accurate perception of the environment requires the organization of sensory inputs into coherent percepts. One approach to understanding this process has been to examine the integration of elements into wholes, for which researchers have often employed local-global stimuli (e.g., Navon, 1977; Robertson, 1996). Commonly, in vision research, *local* elements are arranged to create a *global* form, whereby either level can be independently manipulated

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(Figure 1A). Researchers have employed these hierarchical stimuli to test a variety of hypotheses.

One hypothesis that has been addressed, using hierarchical stimuli, is that the cerebral hemispheres are asymmetrically recruited to process complex input. The presence of hemispheric asymmetries can be important in that they indicate a neural division of labor, likely over critical information-processing dimensions. The local-global laterality hypothesis received early support from visual field studies carried out by Martin (1979). She used a blocked directed-attention task in which participants reported the identity of letters (H or S) at either the local or the global level (Figure 1B). The other unreported level was manipulated to be consistent (H or S), neutral (O) or inconsistent (S or H) with respect to the target letter/response at the attended level. Regardless of consistency, local identification was superior in the right visual field (RVF) compared to the left visual field (LVF) indicating a RVF, and presumably a left hemisphere (LH), local bias. Furthermore, she demonstrated a LVF, and presumably a right hemisphere (RH), global bias, although this was only uncovered in the inconsistent condition.

Martin's (1979) results have been corroborated by a number of neuroimaging findings. For instance, Weissman and Woldorff (2005) conducted a fMRI experiment in which participants were instructed to report letters at either the local or global level (as indicated by a cue, on a trial-by-trial basis). Centrally-presented hierarchical stimuli were consistent, neutral or inconsistent across levels, with respect to the letter/response mappings. In the left inferior parietal lobe/superior temporal gyrus (IPL/STG), local target-related BOLD response was greater than that found for global targets. Again, a LH local bias was present. However, the right IPL/STG did not show differential BOLD response for local and global targets.

Other studies of patients with unilateral lesions have provided stronger evidence for a double dissociation (i.e., a local, LH bias and a complementary global, RH bias). In one patient study, Robertson, Lamb and Knight (1988) classified patients according to the hemisphere of their posterior lesions. They presented hierarchical stimuli centrally and asked patients to perform a divided-attention task (Figure 1C). Patients were assigned two target letters which could appear at either the local or the global level, forcing them to *divide* their attention across levels. When targets appeared equiprobably at each level, patients with LH lesions centered over the temporal-parietal junction showed performance deficits in reporting the local level (relative to the global level). Those with RH lesions showed the opposite deficit: global performance was impaired relative to local performance. Six of six left and four of six right hemisphere lesioned patients showed the expected processing bias. Overall, behavioral, neuroimaging and neuropsychological visual studies converge on a LH bias for local processing, and a RH (albeit perhaps weaker) bias for global processing.

Given the presence of visual local-global lateralization, understanding what information underlies local-global perception is important. A number of findings have indicated that visual local-global hierarchical analysis occurs on the basis of spatial frequency information (e.g., Robertson, 1996; Shulman & Wilson, 1987; Shulman et al., 1986). In one study, Robertson used a level-priming design to investigate the importance of spatial frequency information in local-global analysis. In general, in level-priming experiments, participants perform a divided-attention task (i.e., discrimination between two assigned target patterns that occur with equal likelihood at either the local or global level). On each trial, one target pattern occurs at one level and is accompanied by a distracter pattern at the other level. Responses are analyzed in terms of whether the target's level persisted or changed from the previous trial (Figure 1C). For example, with target letters H and S, if presented with an A made of H's, then an E made of S's, and then an H made of E's, a participant should respond H, then S and then H (as in the first three trials illustrated in Figure 1C). Importantly, level-priming is shown when responses

to targets are improved when their level matches that of the previous trial (as in the transition between an A made of *H*'s and an E made of *S*'s), compared to when the level changes (as in the transition between an E made of *S*'s and an *H* made of *E*'s). Of relevance to the spatial frequency hypothesis, when Robertson presented alternating standard hierarchical stimuli with contrast-balanced stimuli (contrast-balancing reduces the relative amount of low spatial frequency information), level-priming disappeared. The results revealed that disrupting the spatial frequency information disrupted local-global level-priming, whereas varying other stimulus dimensions (e.g., contrast, polarity and color) produced no such disruption. The priming studies contributed support to the spatial frequency hypothesis (e.g., Kinchla, 1977; Sergent, 1982), namely that lower spatial frequency information is critical for global processing and that higher spatial frequency information is critical for local processing.

Furthermore, spatial frequency processing has been shown to occur asymmetrically across the hemispheres, as was initially proposed by Sergent (1982). For instance, Christman, Kitterle and Hellige (1991) showed right and left visual field advantages for higher and lower spatial frequency gratings, respectively. Their results, along with a number of others' (e.g., Christman, 1997; Kitterle, Christman & Hellige, 1990; Kitterle & Selig, 1991; Proverbio, Zani & Avella, 1997), support the claim that the hemispheres asymmetrically process spatial frequency information, and point to spatial frequency as an important dimension over which visual processing parcellation occurs.

In summary, visual research has revealed a hemispheric asymmetry for processing of local-global information such that the left preferentially processes local information, whereas the right preferentially processes global information. Furthermore, local-global perceptual organization seems to rely on the relatively higher and lower spatial frequency content of the complex stimulus.

Structural Perception in Audition

As in vision, perceptual organization is necessary for accurate auditory perception. Under conditions of complex stimulation, different aspects within auditory dimensions can carry discrete information. Lateralization of processing can be indicative of which dimensions or relative ranges within a dimension are important for accurate perception. In audition, however, it is not obvious which stimuli or dimension manipulations are appropriate for local-global investigations. An analogy between local-global vision and audition might be drawn on the basis of the dimension (e.g., between visual spatial frequency and auditory frequency or time), or the hierarchical stimulus structure (e.g., arranging local patterns to create an emergent global pattern). These analogies will be referred to as *dimension* and *structural* analogies, respectively. Certainly, it is possible that no apt analogy exists between the visual and auditory modalities, or that auditory local-global processing is best approached in isolation from analogies to vision. However, we propose that the extant visual research provides a rich source of both hypotheses and elegant designs, some of which provide preferable alternatives to past auditory approaches (described below).

One such approach for the investigation of complex auditory structural processing emerged from the music literature, and commonly employed what we will refer to as *interval-contour* stimuli (Figure 2). The stimuli were originally used to investigate the role of different structural components in memory for melodies (Dowling & Fujitani, 1971). Others later employed the *interval-contour* stimuli in studies of hemispheric asymmetries, testing the hypothesis that (as in vision) auditory local information was preferentially processed by the LH and global information was preferentially processed by the RH. Using lateralized presentation¹, only weak support was found for the laterality hypothesis (Peretz, 1987; Peretz & Morais, 1980). Investigations of patients with unilateral lesions are even more equivocal in their support of a double dissociation for local-global organization (when using *interval-contour* stimuli), and

have instead implicated the right hemisphere more generally in musical processing—especially in pitch processing (Ayotte et al., 2000; Liégeois-Chauvel et al., 1998; Peretz, 1990; Zatorre, 1985). Below, we present potential reasons why, for this type of perceptual organization, auditory laterality findings have been less consistent than those reported for vision.

In numerous studies of auditory local-global organization, participants have judged whether a standard melody (Figure 2A) was the same as a comparison melody (Figures 2B-E). With *interval* manipulations (Figure 2B), one note is altered without changing the overall *contour* of the phrase (the patterns of ups and downs, as changed in Figure 2C). Two other types of manipulations have also been used: phrase *transposition* (Figure 2D) and *key violations* (Figure 2E).

The first challenge when evaluating these stimuli is to determine which phrase manipulations require local and/or global processing. This problem is reflected in the literature, where contour violations have been independently employed to invoke global and local processing: global in the presence of interval changes (e.g., Peretz, 1990), and local in the presence of transpositions (e.g., Peretz, 1987). We propose that, as opposed to visual hierarchical stimuli, local and global auditory levels have been inconsistently defined in melodic stimuli because the stimulus-to-process mapping is not transparent. Specifically, comparing Figures 2C through 2E, it is unclear which manipulation appears “global,” especially compared to the global visual manipulations (Figure 1A).

A second concern arises when “local” interval changes are compared to “global” contour, transposition or key variations (e.g., Peretz, 1987; 1990). Each type of “global” change necessitates an interval change; local and global elements cannot be independently manipulated. Therefore, even in studies revealing lateralization, it remains unclear whether effects were due to differences in local-global processing or some alternative (e.g., difficulty—as performance for interval change detection is often worse compared to other conditions [Liégeois-Chauvel et al., 1998; Zatorre, 1985]).

Experimental design may have also contributed to inconsistent lateralization findings. In lateralized presentation studies, there has been little attempt to experimentally verify whether participants use local or global information to perform their task. One study (Peretz & Morais, 1980) used participants’ self-report to determine whether they took a local or global approach to the task, and Bever and Chiarello (1979) assumed that musicians used local information and non-musicians used global information for melodic recognition. The same criticism applies to studies using same-different judgments (e.g., Ayotte et al., 2000; Liégeois-Chauvel et al., 1998; Peretz, 1987; 1990; Zatorre, 1985): although participants may accurately perform the task, the experimenter cannot verify *how* they perform the task. Distinctively, in vision

¹Monaural presentation of stimuli is intended to asymmetrically provide information to the two cerebral hemispheres. More information or earlier access to information is assumed to reach the contralateral hemisphere compared to the ipsilateral hemisphere. The logic of monaural presentation, therefore, is that by comparing stimuli presented to the left or right ear, differences in performance can indicate hemispheric biases. Crossed anatomical pathways, like those in the visual system, are one possibility in how this might occur. However, even with completely symmetric anatomical connections from each ear to both hemispheres, functional differences could emerge in the cortical responses to input from the different ears.

Evidence indicates that there are at least functional contralateral biases in auditory processing. A number of different approaches have supported asymmetric functional representation of contralaterally- vs. ipsilaterally-presented auditory information. In 1951, Rosenzweig recorded ERPs in anesthetized cats presented with monaural stimulation (clicks). He found increased responses in both hemispheres to contralateral input (compared to ipsilateral input), although the RH showed greater ear differentiation. In humans, various neuroimaging reports have corroborated the functional processing bias for contralateral over ipsilateral stimulation. As measured by MEG, both hemispheres show a differentiation of contralateral and ipsilateral response (e.g., Hertrich, Mathiak, Lutzenberger, & Ackermann, 2004; Mathiak, Hertrich, Lutzenberger, & Ackermann, 2002). Converging results have been reported with fMRI (e.g., Behne, Scheich & Brechmann, 2005; Jancke, Wustenberg, Schulze, & Heinze, 2002; only in nonprimary auditory cortices: Devlin et al., 2003). Monaural stimulation is assumed to tap into these biases, and therefore differences in ear advantage (i.e., performance differences between ear of stimulation) are thought to reveal auditory processing differences between the left and right hemispheres.

research, the problem has been avoided by employing tasks that force participants to use either local or global information. In *directed-attention* tasks, participants report letters at only one level, whereas in *divided-attention* tasks, they report which of two target letters was presented regardless of level (see Figures 1B and 1C). Using either task, based on participants' accuracy, the researcher can verify whether participants used local or global information.

Current Experiments

We have developed an approach, using two different sets of auditory stimuli, that does not succumb to the above-described limitations. Our auditory stimuli have unambiguously-defined local and global levels, which can be orthogonally manipulated, and we control strategies through task demands (Justus & List, 2005). Furthermore, the stimulus attributes (frequency and time) that we manipulated were chosen for their roles as *indispensable attributes* in audition, i.e., they are necessary for auditory events to be perceived (Kubovy & Van Valkenburg, 2001)². Using binaural presentation of these stimuli, we previously demonstrated auditory level-priming in a divided-attention task (Justus & List, 2005), as described above (and as has been demonstrated with visual hierarchical stimuli by Robertson [1996] and Ward [1982], among others).

In the following two experiments, we used the same level-priming design but employed monaural presentation to test the laterality hypothesis: local-global information will be processed asymmetrically by the cerebral hemispheres. In Experiment 1, we use the *High-Low Stimuli*, in which the local level is defined as a higher frequency range and the global level as a lower frequency range. The *High-Low Stimuli* were developed on the basis of a *dimension analogy* to visual spatial frequency information, which likely underlies the processing of visual local-global stimuli. Namely, we drew a parallel between local high spatial frequency information and high auditory frequency, and global low spatial frequency information and low auditory frequency. We aimed to determine whether there was a right ear (and presumably a LH) advantage for processing high frequency information and a complementary left ear (and presumably a RH) advantage for processing low frequency information.

In Experiment 2, we also tested the laterality hypothesis. However, unlike Experiment 1, we used the *Fast-Slow Stimuli*, in which we adopt both a *dimension* and a *structural analogy* to the visual local-global stimuli. Here, the dimension of auditory time is used as an analogy to visual spatial-frequency: fast temporal rates as analogous to high spatial frequency, and slow temporal rates as analogous to low spatial frequency. Additionally, there is a structural analogy between the visual hierarchical stimuli and the *Fast-Slow Stimuli*: local (fast) elements are arranged to create an emergent global (slow) pattern. We aimed to determine whether there was a right ear (and presumably a LH) advantage for processing faster temporal information and a complementary left ear (and presumably a RH) advantage for processing slower temporal information.

In both experiments, a divided-attention task was employed (i.e., participants determined which of two target patterns was presented regardless of level), affording trial-by-trial verification of participants' attention. Critically, target patterns were orthogonal to the frequency and temporal manipulations. Ear advantages (improved performance for presentation to one ear compared to the other) are expected to vary by level, as shown in an interaction of ear and frequency range in Experiment 1, or of ear and temporal range in Experiment 2. In other words, a left ear/RH advantage is predicted for global (low or slow) processing and a right ear/LH advantage is predicted for local (high or fast) processing.

²A major difference between the auditory and visual modalities is the property of space. We are convinced by Kubovy and Van Valkenburg's (2001) argument that a visual space:time :: auditory frequency:time analogy is most apt when considering object properties within each modality, as we are.

Experiment 1

The *High-Low Stimuli* used in Experiment 1 contained patterns at high and low frequency ranges on every trial. Frequency has not only been deemed a critical attribute for auditory events (Kubovy & Van Valkenburg, 2001), but has also been advanced as a possible dimension over which asymmetric auditory processing occurs. Particularly, Ivry and Robertson's (1998) Double Filtering by Frequency (DFF) theory states that the hemispheres are differentially biased to process relevant frequency information (left-high, right-low), for both auditory frequency ranges and visual spatial frequency ranges. Here, we tested whether frequency range-specific ear advantages were present, and also sought to replicate frequency priming (Experiment 1, Justus & List, 2005).

Method

Participants—Sixteen University of California, Berkeley students (age $M=20$ years; 8 men; 8 women) gave informed consent and received course credit for participation. All reported normal hearing, right-handedness and at least five years of musical experience ($M=10$ years, range 6–16)³.

Stimuli—Stimuli were identical to those reported by Justus and List (2005, Experiment 1). The stimulus elements were complex tones consisting of five harmonics, each at 1/n loudness. Each 150-ms tone ramped on and off over 10 ms and was presented at one of two different fundamental frequencies ranges: *high* between 371–467 Hz ($F\#_4$ - $G\#_4$ - $A\#_4$) or *low* between 262–330 Hz (C_4 - D_4 - E_4). All were presented monaurally through Sennheiser EH 2200 headphones at approximately 70 dB SPL.

To form patterns with these tones, they were arranged sequentially without inter-stimulus interval (ISI) in sets of three at each frequency range. A *rising* transition between two tones occurs when the second tone is higher in frequency than the first tone, and a *falling* transition is the opposite. In our patterns, three sequential tones are presented, and adjacent tones vary in frequency. The four patterns we created can be described as follows: rising-rising (*rr*), rising-falling (*rf*), falling-rising (*fr*) and falling-falling (*ff*). They are visually depicted in Figure 3 and Appendix A (in musical notation). Importantly, these patterns can be independently manipulated at each frequency range (as were the letters H and S in Figure 1).

Each participant was assigned two target patterns to discriminate between: one same-direction and one changing-direction pattern (e.g., *rr* and *rf*). On each trial, one target pattern was always presented with one distracter pattern. The stimuli therefore combined for a 2 (Target Pattern: same, changing direction) X 2 (Distracter Pattern: same, changing direction) X 2 (Target Frequency Range: high, low) design.

Design—For each trial, two patterns—one in each frequency range—were presented simultaneously to either the left or right ear. Each pattern was presented equally often to each ear and at the high and low frequency ranges (Figure 3).

Moreover, transitions between trials were controlled to ensure that changes of Target Pattern, Target Frequency Range and Ear occurred as often as these factors remained the same. Each trial served as both a prime and a probe (barring the first and last trials in each block). Responses

³When recruiting participants for this and other experiments using these stimuli, we have found that individuals with five or more years of musical experience master the discrimination task quickly enough that testing can be completed in one hour. Occasionally, although not in this experiment, someone without musical experience has participated and mastered the task within our practice criterion. However, we have not systematically explored the effects of musical expertise on the processing of these stimuli and relegate that question to future research.

on each trial enabled verification of whether participants attended to the desired frequency range. The priming design was: 2 (Target Pattern Priming: same, different) X 2 (Target Frequency Range Priming: same, different) X 2 (Ear Priming: same, different), as shown in Figure 3. Target variables can also be interpreted as response variables.

Procedure—Participants were assigned their target patterns and response mapping. Each pattern was associated with one of two response buttons. On every trial, participants indicated which of their two target patterns was presented. Target patterns and response mappings were counter-balanced across participants. Within-block trial order was fixed to ensure that participants experienced at least one presentation of each trial in the Target Pattern (same, changing direction) X Target Pattern Priming (same, different) X Target Frequency Range (high, low) X Target Frequency Range Priming (same, different) X Ear (left, right) X Ear Priming (same, different) factorial design. (Randomized trial ordering would not have assured that each of the 64 possible trial types was presented within each block). Basically, each trial type was presented equally often after all other trial types. Because of the complex restrictions to produce this pattern of trials, only four such blocks were created and presented to participants in a counter-balanced order. Stimulus presentation and response collection were controlled by Presentation software (<http://www.neurobs.com/>).

To participate in this experiment, participants were required to achieve 14/16 correct during a practice block. They were allowed up to four 16-trial practice blocks ($M=2.2$) to master target identification. In each practice block, targets were equally divided across high and low frequency ranges, and across each response. Each participant then completed four blocks of 65 trials, separated by breaks. The first trial of each block was discarded, as it was not subject to priming.

Trials began with a white central visual fixation circle, which appeared throughout the trial on a black background. After 1000 ms of fixation, a simultaneous pair of auditory patterns was presented to one ear for 450 ms. Trials ended with the participant's response, or when the fixation circle extinguished 2600 ms after auditory stimulus offset. A blank and silent 1500-ms inter-trial interval (ITI) followed. Participants were encouraged to respond as quickly and as accurately as possible, using both index fingers on a button-box.

Results

Trials in which participants failed to respond or responded too late (once the fixation for the subsequent trial appeared) were removed ($M=0.3\%$). Errors ($M=9.2\%$) were excluded from reaction time (RT) analyses, along with their subsequent trials ($M=7.7\%$). RT analyses were carried out on remaining correct trials within three standard deviations (SDs) of each participant's mean RT ($M=1.4\%$ exclusion).

A $2 \times 2 \times 2$ within-subjects ANOVA was run on RT and error means. The analysis factors were: Target Frequency Range (high, low), Ear (left, right), Target Frequency Range Priming (same, different) and Target Pattern Priming (same, different). Priming variables refer to whether the target pattern or frequency range on the present trial was matched or not to the previous trial, i.e. the influence of the previous trial on the current trial. T-tests were carried out for *frequency priming effects* (FPEs): comparing same vs. different target frequency ranges.

A main effect for Target Frequency Range Priming was found: [$F(1,15)=25.0$, $MSE=18457$, $p<0.001$; errors: $F\text{-value}<1.0$]. RTs were 85 ms faster when target frequency range remained the same compared to when it changed, i.e. there was a FPE (Figure 4A). The FPE reflects a RT difference between trials in which target frequency range is repeated and trials in which the target frequency range is changed (relative to the previous trials). No other main effects

were found for RTs [F -values <1.0]. The two-way interaction between Ear and Target Frequency Range was absent [F -value <1.0].

Interestingly, we found a three-way interaction between Target Frequency Range, Ear and Target Frequency Range Priming [Figure 4B; RTs: $F(1,15)=7.38$, $MSE=9441$, $p<0.05$; errors: $F(1,15)=4.0$, $MSE=62$, $p=0.06$]. For stimuli presented to the left ear, participants showed numerically greater FPEs when targets were in the low rather than in the high frequency range: low FPE [123 ms, $t(15)=3.08$, $p<0.01$], high FPE [78 ms, $t(15)=3.22$, $p<0.01$]. The opposite pattern was found for the right ear: high FPE [113 ms, $t(15)=3.35$, $p<0.01$], low FPE: [23 ms, $t(15)=0.72$, $p=0.48$]. This result demonstrates asymmetric frequency priming for low and high frequency ranges.

None of the two-way interactions within the three-way interaction was reliable for RTs: Target Frequency Range by Ear [F -value <1.0], Target Frequency Range by Target Frequency Range Priming [F -value <1.0], and Target Frequency Range Priming by Ear [$F(1,15)=1.46$, $MSE=12197$, $p=0.25$]. In accuracy, the former two interactions had F -values <1.0 ; only Frequency Range Priming by Ear reached significance: the FPE was greater overall in the left than right ear [$F(1,15)=13.7$, $MSE=44$, $p<0.01$]. This may reflect a speed-accuracy tradeoff for the right ear, in which more errors were made with faster RTs for same compared to different frequency conditions.

Lastly, an interaction between Target Frequency Range Priming and Target Pattern Priming was present [RTs: $F(1,15)=17.0$, $MSE=22685$, $p=0.001$; errors: $F(1,15)=9.12$, $MSE=106$, $p<0.01$]. The FPE was greater when target patterns remained the same [180 ms, $t(15)=5.92$, $p<0.001$] than when they changed [41 ms, $t(15)=2.53$, $p<0.05$], as in Justus and List (2005). Reliable priming for changing target patterns emphasizes that *level*-priming effects were present, not only pattern-specific repetition priming effects.

Neither the four-way [$F(1,15)=2.50$, $MSE=5175$, $p=0.14$], nor any of the other interactions reached significance [all F -values <1.0].

A second $2 \times 2 \times 2 \times 2$ ANOVA was performed with the same factors as above, excepting the replacement of the Target Pattern Priming factor with Ear Priming (same, different)⁴. As before, only the main effect of Target Frequency Range Priming reached significance [RT: $F(1,15)=21.12$, $MSE=20595$, $p<0.001$; errors: F -value <1.0]. RTs to targets presented to the same ear as on the previous trial were 28 ms slower than when the ear changed, although not reliably so [RT: $F(1,15)=2.79$, $MSE=17286$, $p=0.12$; errors: F -value <1.0]. There were no other main effects [F -values <1.0].

Barring the three-way interaction described above and also found here [Target Frequency Range by Ear by Target Frequency Range Priming: RTs $F(1,15)=5.51$, $MSE=9646$, $p<0.05$; errors: $F(1,15)=4.27$, $MSE=59.8$, $p=0.06$], another three-way interaction was present in the current analysis: Ear by Target Frequency Range Priming by Ear Priming [RTs: $F(1,15)=9.00$, $MSE=12238$, $p<0.01$; errors: $F(1,15)=2.79$, $MSE=155.7$, $p=0.12$]. Within this interaction, Frequency Range Priming by Ear Priming reached significance [$F(1,15)=7.75$, $MSE=4942$, $p=0.01$; errors: F -value <1.0], showing that the FPE was greater when presented sequentially to the same ear [FPE=124 ms, $t(15)=6.11$, $p<0.001$] than to different ears [FPE=94 ms, $t(15)=8.05$, $p<0.01$]. Returning to the three-way interaction: when stimuli were presented to the left ear, the FPE was greater for repeated-ear [FPE=170 ms, $t(15)=5.15$, $p<0.001$] when compared to changed-ear [FPE=71 ms, $t(15)=3.63$, $p<0.01$], whereas the reverse was true for FPEs presented to the right ear: the same-ear FPE was 77 ms [$t(15)=3.12$, $p<0.01$] and was smaller

⁴A single five-way ANOVA was not run because there were inadequate trials in each cell for the analysis.

than the different-ear 110 ms FPE [$t(15)=5.12, p<0.001$]. In other words, target frequency range priming was greatest when the previous trial was presented the left ear (see Table 1 for RT and error means). Neither of the two other two-way interactions contained within the three-way RT interaction reached significance [both F -values < 1.10].

Two trends emerged in the RT data [all other F -values < 1.0]: the three-way interaction between Target Frequency Range, Target Frequency Range Priming and Ear Priming [$F(1,15)=3.10, MSE=16810, p=0.10$] and the two-way interaction between Target Frequency Range and Ear Priming [$F(1,15)=3.52, MSE=19545, p=0.08$] contained within it. High frequency RTs benefited from a change in ear [by 54 ms, $t(15)=2.40, p<0.05$], whereas ear priming had no effect on low frequency RTs [1 ms, $-1.0 < t\text{-value} < 1.0$]. The three-way interaction revealed that the FPEs were undifferentiated for the low frequency range: same-ear FPE [67 ms, $t(15)=1.94, p=0.07$] vs. different-ear FPE [75 ms, $t(15)=1.71, p=0.11$]. However, at the high frequency range, the same-ear FPE [149 ms, $t(15)=5.20, p<0.001$] was greater than the different-ear FPE [51 ms, $t(15)=1.89, p=0.08$].

Discussion

The frequency priming effect reported by Justus and List (2005, Experiment 1) was replicated. Here, it was shown to interact with target frequency range and ear of presentation: priming of both frequency ranges was found with left ear presentation (the low FPE exceeded the high FPE), whereas stimulus presentation to the right ear resulted only in high frequency priming (the high FPE exceeded the low FPE). Although we did not find the expected two-way interaction between ear and target frequency range, the three-way interaction (Target Frequency Range by Ear by Target Frequency Range Priming) is indicative of an asymmetric trace of prior frequency range selection. Presumably, this interaction reveals that the RH preferentially processes sequential low frequency elements (vs. high frequency elements), while the LH has the opposite bias to preferentially process sequential low frequency elements (vs. low frequency elements).

Furthermore, Target Frequency Range Priming also varied by Ear and Ear Priming: a left ear prime (for a right or left ear probe) resulted in greater FPEs than with right ear primes. This is likely indicative of superior pitch sensitivity in the RH (for reviews, see e.g., Peretz & Zatorre, 2005 or Tervaniemi & Hugdahl, 2003). Research has indicated, among other findings, that the RH shows differentiation (with a pitch bias) between pitch and phonemes (Tervaniemi et al., 1999), pitch and temporal information (Zatorre & Belin, 2001), and that pitch processing deficits are more likely after RH brain injury or excision (compared to the left; e.g., Johnsrude, Penhune & Zatorre, 2000; Liégeois-Chauvel et al., 1998; Zatorre, 1985). Our experiment complements this existing literature, but extends it to show that the RH advantage in frequency processing can extend over time: frequency processing in the RH has a stronger influence over future frequency processing than that in the LH.

As previously stated, our hypothesis was that Target Frequency Range would vary by Ear. Similarly, according to the above-described literature supporting a RH pitch processing bias, we might have expected a main effect of ear (i.e., a left ear advantage for any response). However, we found neither. A broad literature suggests that laterality effects are most frequently observed when either the stimuli or the task, or both are complex (as argued by Johnsrude et al., 2000). For instance, Johnsrude and colleagues (2000) did not find evidence for asymmetries in patients with temporal lobe excisions when they were engaged in a simple pure tone same-different task, but did find it when those same tones were judged on the basis of direction (i.e., rising and falling pitch). Even earlier, Kimura (1967) argued for the use of dichotic stimulus presentation (when participants are instructed to attend to information presented to one ear while ignoring distracting information presented simultaneously to the

opposite ear) when testing for lateralization. She found laterality effects present under dichotic stimulation that had not been evident with monaural stimulation. Also using a dichotic approach, Ivry and Leiby (1993) found left and right ear advantages for higher and lower pitches, respectively, but only in a *relative* sense (the biases were found within, not between, higher or lower *absolute* frequency ranges). Our results demonstrate that lateralized biases might also be probed through priming designs.

Experiment 2

Because time has also been widely considered an indispensable attribute for audition (e.g., Ivry & Robertson, 1998; Kubovy & Van Valkenburg, 2001; Poeppel, 2003), and because the *High-Low Stimuli* fail to capture the nested hierarchical structure so obvious in the visual stimuli, we developed a second set of stimuli: the *Fast-Slow Stimuli*. As previously described, the design of the *Fast-Slow Stimuli* rely on both dimensional and structural analogies to local-global visual stimuli: local fast patterns are arranged to form a global slow pattern.

Furthermore, as with the dimension of frequency, researchers have advanced theories of auditory lateralization based on temporal processing (e.g., Poeppel's [2003] Asymmetric Sampling in Time (AST) theory and Ivry & Robertson [1998] allow for time as an alternative attribute to auditory frequency in their DFF theory). Generally, the theories argue that many auditory laterality findings can be attributed to asymmetric temporal sampling: the LH samples information over shorter temporal intervals than does the RH. Poeppel proposes fixed duration sampling (LH: ~25–40 Hz or 25–40 ms windows; RH: ~4–10 Hz or 100–250 ms windows), whereas Ivry and Robertson invoke relative temporal sampling.

Theories of asymmetric temporal sampling draw on a broad range of literature (for reviews, see, e.g., Nicholls, 1996; Poeppel, 2003). Initially, evidence accumulated for a LH advantage in processing rapidly changing temporal information. For instance, Tallal and colleagues (Schwartz & Tallal, 1980) advanced the hypothesis that LH dominance in language processing was the result of its underlying ability to analyze rapidly changing information (e.g., consonant formant transitions). Their research showing that temporal training can improve language abilities in individuals with deficits supports the notion that temporal information processing is critical for accurate language processing (Merzenich et al., 1996; Tallal et al., 1996). Later findings have supported the hypothesized LH bias for temporal information processing by showing, for example, a LH processing bias for temporal vs. spectral changes (Zatorre & Belin, 2001; Jamison, Watkins, Bishop & Matthews, 2006; cf. Boemio, Fromm, Braun, & Poeppel, 2005). Other studies have demonstrated a complementary RH processing bias for longer duration or slower-evolving temporal events (Boemio et al., 2005; prosody, e.g., Nicholson et al., 2003).

In Experiment 2, we first aimed to replicate temporal range priming with the *Fast-Slow Stimuli*. Secondly, we investigated whether the hemispheres are differentially biased to sample information over relatively shorter and longer temporal ranges (as revealed by ear advantages interacting with target temporal range) within a single study, using hierarchical stimuli.

Method

Participants—Another sixteen University of California, Berkeley students (age $M=20$ years; 6 men; 10 women) gave informed consent and received course credit for participation. All reported normal hearing, right-handedness and at least five years of musical experience ($M=9$ years).

Stimuli—Stimuli were identical to those reported by Justus and List (2005, Experiment 2). The stimulus building blocks were complex tones, as in the current Experiment 1. Tones lasted

100 ms and were presented between 185–467 Hz ($F\#_3$ – $A\#_4$). The 70 dB SPL tones were presented monaurally via headphones, as before.

The three-tone patterns were the same as in Experiment 1: *rr*, *rf*, *fr* and *ff*. In this experiment, three three-tone patterns (the *local* elements) were presented sequentially, not simultaneously, to form a nine-tone *global* sequence (illustrated in Figure 5 and in musical notation in Appendix B). No ISIs were introduced between local elements. By varying the frequency range of the local elements (unfolding over a fast temporal range of 300 ms) a global three-pattern sequence was created (unfolding over a slower temporal range of 900 ms). The fast/local and slow/global patterns could therefore be manipulated independently.

As in Experiment 1, on each trial, one target pattern was always presented with one distracter pattern. The stimuli therefore combined for a 2 (Target Pattern: same, changing direction) X 2 (Distracter Pattern: same, changing direction) X 2 (Target Temporal Range: fast, slow) design, as shown in Figure 5.

Design—As with the *High-Low Stimuli*, each pattern was presented equally often at each range, and trials were presented to one ear at a time. Also as before, trial sequences were fixed within blocks to equate cell size over the priming variables: 2 (Target Pattern Priming: same, different) X 2 (Target Temporal Range Priming: same, different) X 2 (Ear Priming: same, different) design. Each type of transition was equally likely (Figure 5). Target variables can also be interpreted as response variables.

Procedure—One same-direction (*rr* or *ff*) and one changing-direction (*rf* or *fr*) pattern was assigned to each participant, each having its own associated response button. Target patterns, response mappings and block order were counter-balanced across participants.

On average, participants took 2.8 practice blocks to reach at least 14/16 correct. Four blocks of 65 trials followed, with intervening breaks. Despite reaching criterion during practice, two participants were replaced because of excessive error rates in the experimental session (over 27%).

As in Experiment 1, trials began with a white central visual fixation circle on a black background. After 1000 ms, the 900-ms auditory stimulus was presented. Responses made within 2600 ms terminated the trial, followed by a 1500-ms ITI. Participants responded on each trial using either of their index fingers. They were encouraged to respond quickly and accurately.

Results

Trials were excluded from RT analyses if participants failed to respond or responded too late ($M=0.2\%$), as were errors ($M=10.6\%$) and their subsequent trials ($M=8.7\%$). Reaction time (RT) analyses were carried out on remaining trials within three standard deviations (SDs) from each participant's mean RT ($M=1.6\%$ exclusion).

Reaction times and errors were submitted to a $2 \times 2 \times 2 \times 2$ within-subjects ANOVA with Target Temporal Range (fast, slow), Ear (left, right), Target Temporal Range Priming (same, different) and Target Pattern Priming (same, different) as factors. T-tests were carried out for *temporal priming effects* (TPEs): comparing same vs. different target temporal ranges.

A main effect of Temporal Range Priming was found: targets in the same temporal range as the previous trial resulted in RTs 62 ms faster than those in a different temporal range [Figure 6; $F(1,15)=11.8$, $MSE=20911$, $p<0.01$; errors: F -value <1.0]. No other main effects were found [F -values <1.13].

An interaction between Target Temporal Range Priming and Target Pattern Priming was found and showed a greater priming effect for same- versus different-targets (consistent with Justus & List [2005], although here the effect was reliable only in accuracy [RTs: $F(1,15)=2.63$, $MSE=30373$, $p=0.13$; errors: $F(1,15)=5.77$, $MSE=92$, $p<0.05$]). Also reliable only in accuracy, a smaller TPE was found when presenting stimuli to the left ear compared to the right; there was an interaction between Ear and Target Temporal Range Priming [RTs: $F(1,15)=1.08$, $MSE=13723$, $p=0.32$; errors: $F(1,15)=5.01$, $MSE=51$, $p<0.05$]. No interaction between Ear and Target Temporal Range was found [F -value=1.16], nor were any other interactions reliable [F -values 1.61].

Although non-significant, for comparison with Experiment 1, we report the analysis of the three-way interaction between Target Temporal Range, Ear and Target Temporal Range Priming [F -value<1.0]. Some similarities to the left ear level-priming effects in Experiment 1 were found (Figure 6): the slow temporal priming effect (TPE) [118 ms, $t(1,15)=3.54$, $p<0.01$] was numerically greater than the fast TPE [51 ms, $t(1,15)=1.27$, $p=0.22$]. For the right ear, however, the priming effects were identical [slow TPE: 48 ms, $t(1,15)=1.57$, $p=0.14$; fast TPE: 46 ms, $t(1,15)=1.29$, $p=0.22$].

A second $2 \times 2 \times 2 \times 2$ ANOVA was run with Target Temporal Range (fast, slow), Ear (left, right), Target Temporal Range Priming (same, different) and Ear Priming (same, different) as factors. The TPE was present, as in the previous analysis [RT: $F(1,15)=12.3$, $MSE=22028$, $p<0.01$; errors: F -value<1.0]. No other main effects reached significance [F -values<1.0].

In RTs, no interactions reached significance. A trend was present for Target Temporal Range Priming and Ear Priming [RT: $F(1,15)=3.55$, $MSE=20848$, $p=0.08$; errors: F -value<1.0], revealing that the TPE was larger when presented to the same ear [TPE=105 ms, $t(15)=4.26$, $p=0.001$] compared to when ear changed between sequential trials [non-significant TPE=36 ms, $t(15)=1.44$, $p>0.10$]. This pattern is similar to that found in Experiment 1. All other interactions had F -values <1.70.

In accuracy, the four-way interaction reached significance (data are reported in Table 2; [$F(1,15)=4.50$, $MSE=205$, $p=0.05$; RT: F -value<1.0]). The TPE for the fast range was greater in the right ear when ear changed (vs. repeated), and greater in the left ear when ear remained the same (vs. changed). In other words, for fast probes, TPEs were smaller with right ear primes. The opposite pattern was true for the slow range. The TPE for the slow range was greater in the right ear when ear remained the same (vs. changed), and greater in the left ear when ear changed (vs. repeated). TPEs were reversed with left ear primes for slow probes. Within this four-way interaction, there was a trend for the TPE in the fast range to be greater when ear changed, whereas the TPE in the slow range was greater when the ear remained the same [$F(1,15)=3.33$, $MSE=39$, $p=0.09$; RT: F -value<1.0]. No other accuracy effects reached significance [all F -values<1.05, except Ear by Target Temporal Range Priming by Ear Priming: $F(1,15)=1.65$].

Discussion

The temporal priming effect that we previously reported (Justus & List, 2005, Experiment 2) was replicated. We again failed to find an overall ear bias for local or global processing. Unlike Experiment 1, even priming effects were absent: the three-way interaction between Target Temporal Range, Ear and Target Temporal Range Priming was not statistically reliable, despite the means suggesting a left-ear advantage for slow-range priming.

Recently, we employed the *Fast-Slow Stimuli* in an electrophysiology experiment of implicit local-global processing, using a mismatch negativity design (List, Justus, Robertson & Bentin, 2007). Conceding that event-related potentials (ERPs) are perhaps not best-suited to detect

lateralization of function, we failed to find any evidence for asymmetric local-global processing. Using similar stimuli to ours (local frequency-modulated sweeps presented over varying frequency ranges to produce a global pattern), Sanders and Poeppel (2006) also failed to find hemispheric asymmetries in an explicit task using ERPs as a measure. These two studies converge with the present findings to suggest that the temporal hierarchical organization of auditory stimuli may not tap into lateralized processing biases. This conclusion remains to be tested, perhaps using other neuroimaging methods better suited for functional localization and/or neuropsychological investigations, which might reveal asymmetric biases for hierarchical stimulus processing.

General Discussion

We have presented two experiments aimed at exploring hemispheric asymmetries in auditory perceptual organization. The stimuli and experimental design were chosen for the explicit purpose of improving upon previous investigations, which we propose have various reparable limitations. Compared to studies of auditory organization using melodic *interval-contour* stimuli, our stimuli present advances by both capturing the experimental flexibility of the visual hierarchical stimuli and because they are manipulated over theoretically relevant dimensions: frequency and time.

Using this approach, we replicated the frequency and temporal priming previously found (Justus & List, 2005). However, the expected interaction between ear and auditory hierarchical level (local or global) was not found, whether using the *High-Low* or *Fast-Slow Stimuli*. Interestingly, in Experiment 1, we did find that frequency priming varied by ear and by frequency range, indicative of the hemispheres asymmetrically retaining traces of recently processed frequency ranges. This is a novel finding.

Based on previous literature (e.g., Ivry & Lebel, 1993; Ivry & Robertson, 1998), it is possible to interpret the asymmetry as high and low frequency biasing for the left and right hemispheres, respectively. However, depending on underlying assumptions of what priming reflects, there are at least two possible interpretations of the data. If level-priming is indicative of a benefit for a previously processed level, then the results support a left-local/right-global asymmetry. However, if level-priming is instead considered a cost of switching between levels, then the results support the opposite left-global/right-local asymmetry. Here we have demonstrated that an asymmetry exists for frequency processing. The question of its direction remains open, and is relegated to future neuropsychological and/or neuroimaging research.

Our failure to find processing asymmetries for fast or slow temporal ranges converges with previous ERP studies using similar hierarchical stimuli (List et al., 2007; Sanders & Poeppel, 2006). However, it conflicts with the notion that the hemispheres are inevitably asymmetrically recruited for temporal processing. A challenge for current theories of auditory lateralization will be to account for differences across studies. As previously mentioned, task and/or stimulus parameters may be important in determining whether asymmetries are found. For example, in a fMRI study using a different class of non-verbal stimuli (narrow-band noise), Boemio and colleagues (2005) found that the superior temporal sulcus showed a differentiation between temporal processing (on the order of 85–300 ms) between the left and right hemispheres. The RH showed increased activation for these longer (in the context of the experiment) duration time windows. In the temporal manipulation used in Experiment 2, 300-ms time windows constituted the local (fast) temporal manipulation. Indeed, Tallal and her colleagues have long argued that the LH is involved in rapid (tens of ms) temporal processing (e.g., Tallal, Miller & Fitch, 1993; Tallal, 2004). It is possible that the temporal window chosen, or even the relative temporal range chosen, is important in determining the degree to which asymmetric neural recruitment occurs.

Others, using PET (Zatorre & Belin, 2001) and fMRI (Jamison et al., 2006), have taken yet another approach to understanding laterality in audition. They have instead compared hemispheric processing *across* auditory dimensions, instead of *within* dimensions (as we have done with frequency in Experiment 1 and time in Experiment 2). In those cross-dimension investigations, a LH bias has been demonstrated for temporal over spectral processing, and the opposite bias for the RH. These are the same dimensions proposed by Kubovy (e.g., Kubovy & Van Valkenburg, 2001) to be indispensable attributes of auditory objecthood.

It is also notable that visual neuropsychological investigations have pointed to the inferior parietal area as necessary for level-priming to occur, while its absence imposes no overall level bias, as shown with temporal-parietal lesions (Rafal & Robertson, 1996; Robertson et al., 1988). Neuroimaging results have corroborated this functional organization (Weissman & Woldorff, 2005). Although no analogous studies have been carried out in audition, we speculate that the same multi-modal parietal area may be critical for auditory level-priming. Primary and secondary auditory cortices are candidate sites for local or global analysis, and are likely modulated by those parietal areas for the ongoing selection of relevant frequency and/or temporal information.

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A. Independence of local and global levels in visual hierarchical stimuli

B. Directed-attention design with visual hierarchical stimuli

C. Divided-attention design with visual hierarchical stimuli

Figure 1.

A. Examples of hierarchical visual stimuli: a standard and variations of either the global, local or both levels. B. In directed-attention tasks, participants are asked to report letters at one level. Correct target report is indicated for globally- and locally-directed blocks separately. Note that global and local levels can be consistent, inconsistent or be presented with a neutral (rightmost figures). C. In divided-attention tasks, participants are asked to report which of two assigned target letters is present, regardless of level. Here, targets H and S are given as examples. Note that priming variables are also indicated for the targets and levels; i.e., whether the target pattern and target level repeats or changes between trials.

A. Standard

B. Interval Change

C. Contour Change

D. Transposition

E. Key Change

Figure 2.

Examples of auditory *interval-contour* melodic stimuli used with a same/different judgment task. A. a standard melody; B. an interval-changed melody; C. a contour-changed melody; D. a transposed melody; and E. a key-changed melody. (Melodies adapted from Figure 3, Liégeois-Chauvel et al., 1998). Compared to the standard phrase A, B-E are examples of “different” phrases, with asterisks indicating sites of melodic changes.

Figure 3. Experiment 1: examples of *High-Low Stimuli* trial sequences for the priming design. On any given trial, participants performed a two-alternative forced choice task between their two assigned target patterns. One target pattern was presented at either of the two possible frequency ranges, and was presented with a distracter pattern to either the left or right ear. From trial to trial, target patterns could be the same or different, could occur in the same or different frequency range, and could be presented to the same or different ear relative to the previous trial. Therefore, each trial served as a probe (of the previous trial) and a prime (to the next trial). For each trial, the correct response is circled given the target assignment of rising-rising and rising-falling. Solid circles indicate targets at the high frequency range and dashed circles indicate targets at the low frequency range. The priming variables are indicated below each trial pair.

Figure 4.

Experiment 1 results. A. Target Frequency Range Priming (same/different), plotted by Ear for mean RTs (ms) from stimulus offset. Significant frequency priming effects were present for both ears. B. Significant interaction between Target Frequency Range, Ear and Target Frequency Range Priming (here shown as difference scores, i.e. the frequency range priming effect is calculated by subtracting *same* target frequency range RTs from *different* target frequency range RTs). Error bars are standard error means.

Figure 5. Experiment 2: examples of *Fast-Slow Stimuli* trial sequences for the priming design. On any given trial, participants performed a two-alternative forced choice task between their two assigned target patterns. One target pattern was presented at either of the two possible temporal ranges, and was presented with a distracter pattern to either the left or right ear. From trial to trial, target patterns could be the same or different, could occur in the same or different temporal range, and could be presented to the same or different ear, relative to the previous trial. Therefore, each trial served as a probe (of the previous trial) and a prime (to the next trial). For each trial, the correct response is circled given the target assignment of rising-rising and rising-falling. Solid circles indicate targets at the fast temporal range and dashed circles indicate targets at the slow temporal range. The priming variables are indicated below each trial pair.

Figure 6.

Experiment 2 results. A. Target Temporal Range Priming (same/different), plotted by Ear for mean RTs (ms) from stimulus offset. Significant frequency priming effects were present for both ears. B. Non-significant interaction between Target Temporal Range, Ear and Target Temporal Range Priming (shown as difference scores, i.e. the temporal range priming effect is calculated by subtracting *same* temporal range RTs from *different* temporal range RTs).

Table 1

Experiment 1 mean RTs (from stimulus offset) and error rates for the Target Frequency Range by Ear by Target Frequency Range Priming by Ear Priming analysis. Ear Priming variables Same and Different also indicate in parentheses to which ear the previous trial was presented. Bold characters indicate reliable ($p<0.05$) frequency priming effects (FPE, i.e., the difference between same and different target frequency range), whereas gray characters indicate a t -value between -1.0 and 1.0 .

Frequency Range	Ear	Ear Priming	RT Means (ms)		FPE	Error rates (%)		FPE
			Same	Frequency Range Different		Same	Frequency Range Different	
High	Left	Same (Left) Different (Right)	874 889	1052 879	178 -10	10.1 9.5	14.2 9.6	4.1 0.1
	Right	Same (Right) Different (Left)	881 851	1009 955	128 104	10.8 7.7	10.7 8.4	-0.1 0.7
Low	Left	Same (Left) Different (Right)	862 911	1008 980	146 69	5.3 11.1	13.8 13.6	8.5 2.5
	Right	Same (Right) Different (Left)	957 910	934 980	-22 70	13.2 11.7	3.9 12.3	-9.3 0.6

Experiment 2 mean RTs (from stimulus offset) and error rates for the Target Temporal Range by Ear by Target Temporal Range Priming by Ear Priming analysis. Ear Priming variables Same and Different also indicate in parentheses to which ear the previous trial was presented. Bold characters indicate reliable ($p < 0.05$) temporal priming effects (TPE, i.e., the difference between same and different target temporal range), whereas gray characters indicate a t -value between -1.0 and 1.0 .

Table 2

Temporal Range	Ear	Ear Priming	RT Means (ms)		TPE	Error rates (%)		TPE
			Temporal Priming			Same	Different	
			Same	Different				
Fast	Left	Same (Left)	853	946	93	8.1	15.4	7.3
		Different (Right)	836	859	23	9.8	9.0	-0.8
	Right	Same (Right)	834	925	89	14.1	8.7	-5.4
		Different (Left)	859	853	-6	6.5	13.2	6.7
Slow	Left	Same (Left)	818	935	117	13.4	11.9	-1.5
		Different (Right)	791	898	107	12.8	12.6	-0.2
	Right	Same (Right)	839	933	94	9.6	13.8	4.2
		Different (Left)	885	886	1	14.6	10.1	-4.5