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Visual temporal asymmetries are related to asymmetries in linguistic perception

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Abstract

There are numerous recent reports of low-level temporal asymmetries favouring the left hemisphere, and increasing speculation that the left hemisphere's relative superiority at linguistic processing may be related to these asymmetries. The present study sought to test this claim by assessing linguistic lateralization with the Fused Dichotic Words Test and visual temporal asymmetries with a lateralized version of an inspection-time test in a sample of 40 participants balanced for sex and handedness. We found evidence for a significant right-visual-field (left-hemisphere) advantage for accuracy on the inspection-time task, $F(1,36) = 4.38$, $P = 0.043$, and this asymmetry was significantly correlated with laterality scores on the linguistic dichotic-listening task, $r = 0.306$, $P < 0.028$ before disattenuation, and $r = 0.486$ after disattenuation. This result supports the position that low-level temporal asymmetries are related to asymmetries in linguistic processing.

1. Introduction

Functional cerebral asymmetries have traditionally been reported only for higher functions, such as linguistic processing, spatial relations, and facial recognition, and some have claimed that functional asymmetries only emerge at higher levels of information processing [30]. Luria [27] claimed that the more abstract a function is, the more its cerebral basis is asymmetric. Recently investigators have been noting functional asymmetries for much 'lower' perceptual tasks [37]. In the visual modality, a left-hemisphere advantage (LHA) has been reported for critical flicker fusion [21], temporal ordering of stimuli [8,45], perception of simultaneity [11,14,46], etacontrast [41] two-flash fusion [35], and inspection time [38,39], but cf. [44]. In the auditory modality, LHAs have been reported for the perception of temporal order [29], non-linguistic rhythms [32,43], duration discrimination [28], offset of tones [17], and gap detection [3,49] but cf. [15]. There is even some evidence of tactile LHAs [1,23,31,40], but [10]. These reports of tactile LHAs are particularly important because with this methodology, it is possible to avoid confounding the effects of hemispace with those of hemispheric asymmetries (a concern raised by Clark & Geffen [10] and Geffen, Mason, Butterworth, McLean, and Clark [20]). Nicholls and Whelan [40] found that the LHA demonstrated some reduction for midline hand placements, but this effect was only present in the error data, and not in the RT or response bias data. Therefore, hemispace appears to have very weak effects (if any) on these tactile hemispheric asymmetries [40].

Although a consensus is building that such low-level asymmetries exist across modalities, relatively little is known about what they mean. A common, but as yet untested, interpretation is one in which the left hemisphere is generally superior at processing all temporally rapid stimuli, predisposing it to dominate tasks

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Fig. 1. The pi stimulus (a) and its backward mask (b).

requiring great temporal precision, such as linguistic tasks and skilled unimanual behaviours [28]. If this position is correct, using a within-subjects experimental design, the hemisphere that is superior at perceiving rapid temporal events should be the same hemisphere superior at linguistic tasks.

The inspection-time task was first described by Vickers [47,48] and is based on the 'accumulator' model of perception and decision making. This model suggests that there are absolute temporal limitations on an individual's rate of assimilation of stimuli from the environment. To measure the rate at which stimuli could be assimilated, Vickers [47,48] developed a task in which the stimuli (referred to as 'pi' figures), consisting of an inverted U-shaped figure with one 'leg' shorter than the other, were presented and participants were required to judge which leg was shorter (see Fig. 1). By varying the exposure duration of the pi figure and examining the relative performance of a subject at the different durations, one can obtain a measure of 'inspection time', defined as the exposure duration at which a subject can correctly identify the shorter leg on 90% of the stimulus presentations.

Nicholls and Cooper [39] modified the original inspection time task to allow separate presentations of the pi stimulus to the left visual field (LVF) and right visual field (RVF). They found that pi stimuli presented to the RVF were processed significantly more quickly than those presented to the LVF, as revealed by overall accuracy as well as separate estimates for inspection time for each visual field. Out of concern that the RVF advantage on the task might be related to the potentially categorical nature of the task, Nicholls and Atkinson [38] further modified the inspection time task, varying the difficulty of the task (but not the categorical nature of the judgements) by varying exposure duration (time task) or the degree to which one line was shorter than the other (length task), in effect making the categorical part of the task more difficult. Therefore, the temporal and categorical components of the inspection time could be examined separately. Nicholls and Atkinson [38] found a significant RVF-LHA for the time task, but no such asymmetry for the length task. Therefore, the RVF advantage on the task does not appear to be related to the categorical judgements it requires.

However, other investigators have failed to replicate the RVF-LHA for inspection-time [34,44]. The Sadler and Deary [44] study differed from that of Nicholls and Cooper [39] and Nicholls and Atkinson [38] in a number of respects. Sadler and Deary [44] presented pi stimuli tachistoscopically (rather than using a computer monitor), used a modified masking stimulus (in an attempt to reduce apparent movement effects), employed a wider range of stimulus onset asynchronies (SOAs), tested participants over a period of five days, and required verbal (rather than button-press) responses at the subject's leisure, not recording reaction time. Contrary to their hypothesis that the RVF-LHA would disappear with practice, they found no evidence of an RVF-LHA on the initial testing days, but a non-significant RVF-LHA emerging by day 5. It is unclear which differences between the two versions of the bilateral inspection time tasks could be responsible for the discrepancy between the results of these studies.

The present study seeks to investigate the possible relation between performance asymmetries on a visual inspection-time task and linguistic lateralization as measured by the Fused Dichotic Words Test (FDWT) developed by Wexler and Halwes [50]. We chose the FDWT as a test of linguistic laterality because it has performed very well in validation studies [51], and serves as a rapid, inexpensive, and non-invasive test of linguistic lateralization. The lateralized inspection-time paradigm described by Nicholls and Cooper [39] and Nicholls and Atkinson [38] was chosen because a cross-modal (i.e. auditory performance compared with visual performance) comparison would be less vulnerable to potential confounds of two tasks testing the same modality (such as higher sensitivity of one ear affecting two auditory tasks). Studies of low-level temporal asymmetries in the visual modality are also preferable because the visual system demonstrates greater initial contralaterality in its projections than does the auditory system. The RVF-LHA reported for studies of visual temporal asymmetries does not seem to be related to the potentially categorical nature of the tasks [38] or attentional biases [36].

Because the methodology of our inspection-time task was closely modelled after that described by Nicholls and Cooper [39] and Nicholls and Atkinson [38], we expected to replicate their results. Further, we expected that the RVF-LHA on the visual inspection time would be significantly positively correlated with linguistic asymmetries on the dichotic-listening task. Because language laterality appears to vary with both hand preference [26,42] and foot preference [13,16], we recruited participants with consistently right or consistently left lateral preferences. We expected that left-handed/footed participants would be less likely to exhibit a RVF-LHA on the inspection-time task.

2. Method

2.1. Participants

Fifty one undergraduate students participated in this experiment for six dollars remuneration or course credit. The data from 11 participants had to be removed from the analysis because they could not complete the inspection-time task significantly above chance performance. Therefore, the data from 40 participants were included in the analysis. Participants were selectively recruited to include an equal number of males and females within an equal number of left-handers and right-handers. Further, only individuals who were consistently right-handed and right-footed or both left-handed and left-footed were recruited for the experiment. All participants were students at the University of Waterloo, and had normal hearing and normal or corrected-to-normal vision at the time of the experiment.

2.2. Materials

To confirm the consistency and direction of an individual's hand and foot preferences, all participants completed the 'Waterloo Handedness Questionnaire—Revised' (WHQ-R) and the 'Waterloo Footedness Questionnaire—Revised' (WFQ-R).

Language lateralization was assessed using the FDWT developed by Wexler and Halwes [50]. The test consists of 15 dichotic pairs of rhyming single-syllable words (e.g. coat/goat) that vary only in the initial phoneme. Stimuli were natural speech signals that were digitized on a PDP-2/24 computer and recorded on audio cassette by T. Halwes at Precision Neurometrics. The tape was played on a Sony Professional Walkman (model WM-D6C) through JVC (model HA-D500) earphones with circumaural cushions. Each stimulus pair was presented four times in each of two possible stimulus arrangements (Stimulus A in left ear or Stimulus A in right ear) for a total of 120 trials. Four blocks of 30 trials were presented, and earphones were reversed after the first and third blocks to control for mechanical defects in the testing equipment. Test trials were preceded by 30 monaural practice trials in which each stimulus was presented once to each ear. During the testing, participants indicated which word they heard by circling it from among four possibilities presented in pseudo-random order on an answer sheet: the word in the left ear; the word in the right ear, and two rhyming distractors.

The inspection-time task was very similar to that employed by Nicholls and Atkinson [38]. The test was administered via an IBM compatible 386/SX computer, interfaced with a Magnavox CM9039 Color VGA Monitor. At a viewing distance of 50 cm (held constant by employing a chin rest), the pi figures occupied 2.3° of visual angle in width and 3.0° in height. The shorter 'leg' of the pi figure occupied 1.3° of visual angle. The stimuli were displayed in black against a white background.

At 500 ms before each trial, a central fixation cross measuring 0.5° of visual angle was presented. The pi figures were presented randomly on either the left or right side of the fixation cross, with the nearest leg 2.3° from the central point, and the outer leg a further 2.3° away. The pi figure was presented for 40, 60, 80, 100, or 120 ms, after which a similar backward mask with both legs of equal length was presented. A new trial was initiated 1000 ms after the subject responded. Fig. 1 shows the pi stimulus and the backward mask.

Each subject completed 196 trials of this task, divided unequally between the five different exposure durations: 28 trials at 40 ms, 28 trials at 60 ms, 56 trials at 80 ms, 56 trials at 100 ms, and 28 trials at 120 ms. Pilot testing using the exposure durations (20–100 ms) employed by Nicholls and Atkinson [38] indicated that exposure times of both 20 ms and 40 ms were vulnerable to floor effects, so to avoid the possibility of a large number of participants performing at chance on the task, the exposure durations used by Nicholls and Atkinson [38] were increased by 20 ms for the present study. Twice as many trials were presented at the 80 and 100 ms durations because pilot testing indicated that they were the least vulnerable to floor and ceiling performance effects. The testing sessions were broken up into seven blocks of 28 trials. Within each block, representative proportions of the possible combinations of stimulus duration, side of the shorter leg on the pi figure, and side of presentation were included. These three parameters were randomized within each block to prevent the participants from being able to predict the location and type of the next trial.

Participants responded by pressing one of four keys on a keyboard, with their index and middle fingers of each hand, using two keys on their right side for stimuli that fell in their right visual field and vice versa for stimuli presented to their left visual field. Using this spatially mapped arrangement, when responding correctly, participants pressed the key that corresponded to the location of the shorter leg of the pi figure.

Prior to beginning the test, participants were instructed to keep their chin firmly in the chin rest, and that they should be very careful to keep their eyes fixated on the cross in the middle of the screen to maximize their performance, because the side of presentation was randomized. Accuracy of response, rather than response speed, was emphasized to the subject.

Participants were encouraged to take breaks between blocks to facilitate concentration, and short cartoons were presented between blocks. The inspection time task took between 15 and 20 min to complete.

2.3. Procedure

To enable the recruitment of an equal number of participants from each handedness/footedness group and sex, a screening questionnaire was administered to 600 undergraduate students. Participants who could not complete the visual inspection-time task significantly above chance were replaced with someone from the same handedness, footedness, and sex group. First, each participant completed the WHQ—R, followed by the WFQ—R. Then, 120 trials of the FDWT were completed. After completion of the dichotic task, participants performed the inspection-time task. The entire testing procedure took approximately 45 min.

2.4. Scoring analysis

The FDWT data were scored using a log-linear analysis procedure described by Grimshaw, McManus, and Bryden [22], which calculates a laterality index (λ^*) controlling for effects of stimulus dominance (the λ^* index is analogous to the λ index described by Bryden and Sprott [7]). Ear advantages are calculated by fitting a model that includes every relevant effect except the 'response' × 'stimulus arrangement' interaction (one would include main effects of 'stimulus pair', 'response', 'stimulus arrangement', and the 'stimulus pair' × 'stimulus arrangement' interaction) and note the likelihood ratio Chi-square test statistic. Next, one must fit a second model that includes every effect in the first model in addition to the 'response' × 'stimulus arrangement' interaction. The parameter estimates provided for each subject's 'response' by 'stimulus arrangement' interaction provide an index of lateralization that is unbounded, approximately normally distributed, unconstrained by accuracy, and that controls for the effects of stimulus dominance. Positive λ^* scores are indicative of a right-side advantage, and negative scores indicate left-side advantages.

The first (practice) block of the inspection-time task was not scored, but the data from the remaining six blocks were scored using the λ log-linear procedure described by Bryden and Sprott [7]. The λ index = $\log_e$ [(right hits × left misses)/(left hits × right misses)]. This index is unbounded, approximately normally distributed, and unconstrained by accuracy. In addition to scoring the inspection-time data with the λ index, it was also scored in terms of percent correct and median reaction time for each SOA within each visual field.

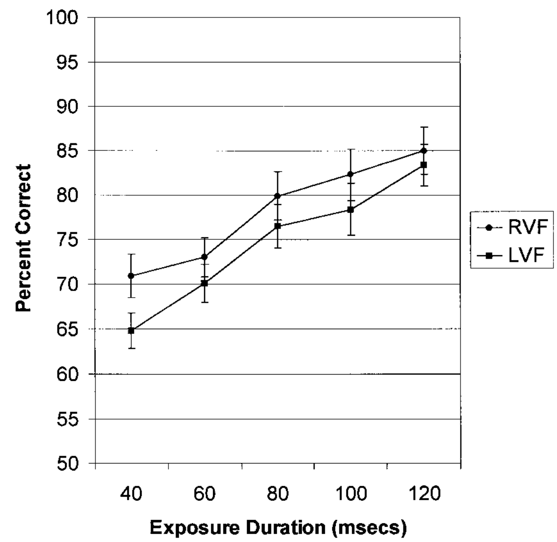

Fig. 2. Percent correct for pi presentations to RVF and LVF across the five SOAs.

3. Results

3.1. Inspection-time task

The accuracy data on the inspection-time task were analyzed using a repeated-measures ANOVA, with within-subjects variables of visual field (left or right) and duration of exposure (40, 60, 80, 100, or 120 ms), and between-subjects variables of hand/foot preference (left or right) and sex (male or female). There was a significant main effect of visual field (see Fig. 2), with participants more accurately detecting the shorter leg in the RVF, $F(1,36) = 4.38$, $P = 0.043$. There was also a significant main effect of exposure duration in which longer stimulus presentations were identified more accurately, $F(4,33) = 45.36$, $P < 0.001$. To our surprise, there was also a significant main effect of sex: males were significantly more accurate than females, $F(1,36) = 5.79$, $P = 0.021$. There were no significant interactions between any of the variables.

Despite the non-significant interaction between sex and visual field of presentation, $F(1,36) < 1$, the possibility that the two groups might differ in the strength of visual-field asymmetry warranted investigation because the laterality data of the two groups could be confounded by the significant differences in performance [7]. Therefore, a log-odds ratio laterality index, $\lambda = \log_e$[(right misses × left hits)/(right hits × left misses)], which avoids the confounds of performance effects, was calculated for each individual. Although males tended to exhibit slightly greater RVF advantages than females, this effect was not significant, $t(38) = 0.54$, $P = 0.596$.

The reaction time (RT) data did not reveal any visual-field asymmetry, $F(1,36) < 1$, and the sex differ-

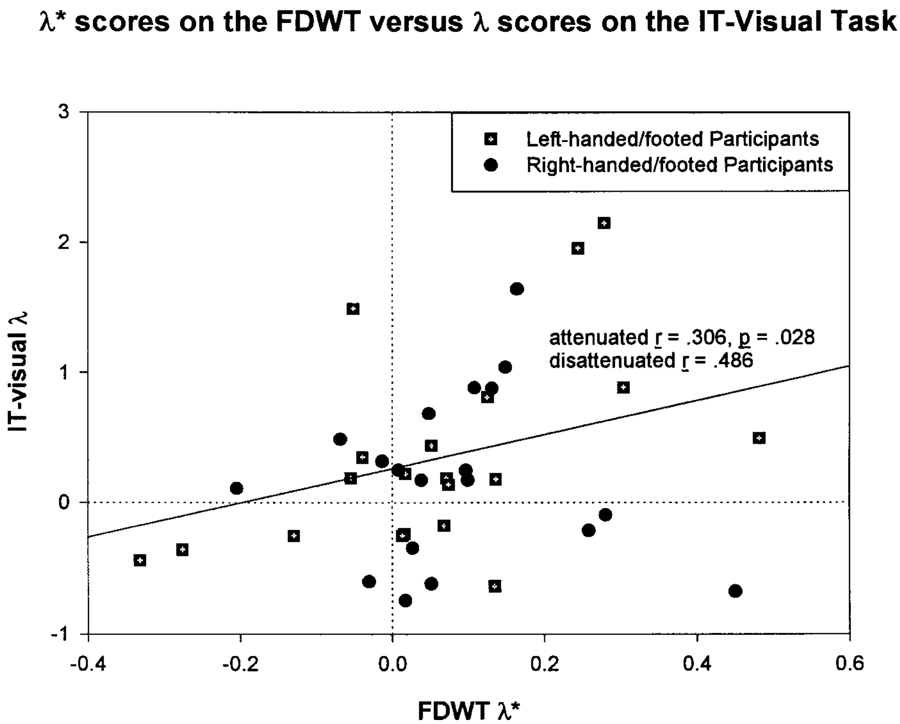

Fig. 3. Scatterplot of λ* scores on the FDWT vs λ scores on the inspection time task.

ence noted in the accuracy data did not reach significance, $F(1,36) = 2.71$, $P = 0.11$. The only significant effect in RT was one of exposure duration, $F(4,33) = 39.16$, $P < 0.001$, wherein participants responded faster to longer exposures of the pi figure.

3.2. Fused Dichotic Words Test

As expected, most participants (30/40) exhibited right-ear advantages (REAs) on the FDWT. Although left-handed/footed participants tended to exhibit lower λ* scores (indicating a smaller REA) than right-handed/footed participants, this effect was non-significant, $F(1,39) < 1$, and there was no sex effect or interaction between these variables.

As hypothesized, λ* scores on the FDWT and the inspection-time task were significantly positively correlated, $r = 0.306$, $P = 0.028$ (one-tailed). However, because the correlation of interest is that between the latent variables of inspection-time and dichotic-listening, and the correlation above is based on measured values (incorporating measurement error), the correlation must be disattenuated for error. Split-half reliability of the inspection-time task in the present experiment was $r = 0.482$. The FDWT has proven considerably more reliable in our laboratory, demonstrating split-half reliability of $r = 0.823$. Therefore, after disattenuation, the correlation increases to $r = 0.486$ (Fig. 3).

To further investigate the relation between performance on these two tests, participants were classified as either left- or right-hemisphere advantaged (LHA or RHA) on each task to enable odds-ratio testing. Strictly speaking, if both tests are measuring the same underlying process, no individual should exhibit an LHA on one task and an RHA on another. In other words, given that an individual exhibits an REA (LHA) on the FDWT, the odds of his or her also showing an LHA (as opposed to an RHA) on the inspection-time task should be high whereas those odds given an RHA on the FDWT should be very low. The ratio of the former odds to the latter, then, should be high. The natural log of odds ratio is easily tested for significance using a z-test [6]. For the present data, after dichotomizing participants' scores on both measures, the resulting odds ratio was not significant. Thus, individuals were no more likely to show an LHA on the inspection-time task if they had shown an LHA on the dichotic task than if they had shown an RHA on the dichotic task. The odds ratio, then, although > 1 as would be predicted, is not significant.

4. Discussion

The present study provides clear support for the claim that low-level temporal asymmetries are related to linguistic asymmetries. Similar to the results of Nicholls and Cooper [39] and Nicholls and Atkinson [38], analysis of our data revealed a significant RVF-

LHA for a lateralized visual inspection-time task, and this visual processing asymmetry was significantly correlated with linguistic asymmetry measured with the dichotic-listening paradigm.

Although the correlation between these two tests may seem low ($r = 0.306$ before disattenuation, $r = 0.486$ after disattenuation), it becomes more impressive when one considers the strength of cross-modal correlations between visual and auditory linguistic laterality tests reported in the literature. Despite the fact that these tests are meant to tap similar (if not identical) processes, many investigators have failed to find any significant positive correlation between these measures, and some have even found weak negative correlations [4,5,18,19,25,30]. On those occasions when significant positive correlations are obtained between the measures, they are usually rather low. For example, Hines and Satz [24] found modest correlations, which were only significant in their right-handed participants ($r = 0.39$). Conversely, Dagenbach [12] found significantly larger cross-modal correlations for his left-handed participants ($r = 0.302$) than for his right-handed participants ($r = -0.138$). In light of the relatively poor relation between visual half-field tests of linguistic laterality and dichotic-listening tasks, the significant positive correlation between inspection-time asymmetries and laterality scores on the FDWT in the present study provides evidence that the two tasks may be relying on a common process.

The absence of a clear RVF-LHA in the RT data despite a significant effect on accuracy is puzzling, but not unprecedented. Nicholls and Atkinson [38] also found a significant RVF-LH advantage in accuracy but no such advantage in RT on a lateralized inpsection task. There is no evidence of a speed/accuracy tradeoff in the present study. The discrepancy between the accuracy and RT results may be due to decreased power in studying reaction time, because of much greater individual variation. Alternatively, the effect could have been mediated by the experimental instructions, where accuracy, not response speed, was stressed to the participants as the critical part of the task.

We predicted that there would be significant effects of lateral preference in the RVF-LHA exhibited in the inspection-time task. Although the two lateral preference groups differed in the predicted direction, this effect did not approach statistical significance. Similarly, the left-handers exhibited non-significantly weaker REAs than the right-handers on the dichotic task. The present study may not have had enough power to detect differences between the handedness groups.

The sex difference in accuracy on the inspection time was unexpected. Although some authors have suggested that inspection time is significantly related to intelligence [2,9,33,52], it seems unlikely that the males participating in this study were significantly more intelligent than the females. The physical nature of the task may be more to blame for the sex difference. When completing the task, participants have to quickly press buttons in response to rapidly flashing stimuli on a computer screen, a task not entirely unlike playing a video game. Because males seem to be more likely to be well practiced at such games and performance on the inspection-time task improves significantly with practice [44], the greater practice experienced by males on similar tasks might account for the observed sex difference in the present study.

Given that visual asymmetries as measured with the inspection-time paradigm appear to be related to linguistic asymmetries, this suggests the possibility that other low-level temporal asymmetries will exhibit a similar relatedness. Further, the results of the present study lend support to the position that the left hemisphere is usually superior at processing all temporally rapid stimuli, predisposing it to dominate tasks requiring great temporal precision, such as linguistic tasks and skilled unimanual behaviours [28].

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