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Differences in Language Asymmetries Between Left- and Right-Hander's Brains:

A Cognitive Neuroscience Approach

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## Abstract

Visual half-field tachistoscopic measures were used to evaluate differences between left-handers and right-handers in the effects of case alternated stimuli and lowercase stimuli on lexical decision asymmetries. Twenty-four left-handed and 24 right-handed native-English speakers with normal or corrected-to-normal vision participated in a 2x2x2x2 (Handedness x Lexicality x Case Type x Visual field) mixed-factorial design lexical decision task study. Case alternation had a greater effect in the RVF than in the LVF. Case alternation was found to affect word recognition much more than nonword recognition for both left- and right-handers due to a whole-word processing mechanism. Left-handers did not differ from right-handers in VF asymmetries. This suggests that left-handers may not be as different from right-handers with respect to language lateralization as previously thought.

## Differences in Language Asymmetries Between Left- and Right-Hander's Brains: A Cognitive Neuroscience Approach

Left-handers may live shorter lives because they experience more accidents resulting from using tools, equipment, and technology designed for right-handers (Coren & Halpern, 1991). Not only do left-handers differ from right-handers in how accommodating society is to them, but they also differ on cognitive task performance. One of the most striking differences between left- and right-handers' brains is the lateralization of language. It has been claimed that if a certain functional asymmetry (defined as the anatomical hemisphere of the brain in which a certain function, like language, is localized) is observed in right-handers, the corresponding function in left-handers will be less lateralized and possibly lateralized in the other direction (Springer & Deutsch, 1998). In other words, language localized to the left hemisphere (LH) for right-handers would be less localized to the LH, or even dominant in the right hemisphere (RH), for left-handers.

Specifically, among those who exhibited some RH language during a sodium amobarbital experiment, a significantly higher proportion were non right-handers. This suggests that left- and mixed-handedness may be indicative of mixed laterality. The study reported that 95 percent of right-handers and 70 percent of left-handers have speech localized to the LH (Loring et al., 1990). Other studies reveal that left-handers have even more language abilities in the RH. Prognosis for recovery from aphasia (due to a stroke) is much better for left-handers than for right-handers (Subirana, 1958; Zangwill, 1960).

Behavioral studies (i.e., tachistoscopic visual and dichotic listening) have also found left-handers to be less asymmetric for language than right-handers (Peters, 1995). In visual half-field tachistoscope tasks, the visual stimulus is rapidly presented to either the left or right visual field

and travels from the retina, via the ocular nerve, to other nerves in the form of a chemical message, until it reaches its final destination in the hemisphere opposite the visual field to which it was presented.

In sum, evidence suggests that language is less lateralized in left-handers. However, less data exists surrounding lateralization of language on left-handers as compared to right-handers (Peters, 1995). Additional research is needed.

### *Degree of Handedness*

The handedness variable is measured differently across studies (Springer & Deutsch, 1998). Some experimenters rely on self-report. Still others use the raw handedness score, calculated from one of many handedness inventories, whereas others use cut-off handedness scores to establish two handedness groups. This process is subjective and results in varying groups across studies.

A key issue in the study of handedness and language is the argument that language laterality should not be considered to be a discrete variable when handedness is a continuous variable (Loring et al., 1990).

### *Word Specific Visual Pattern*

Some studies suggest that each hemisphere uses a somewhat different strategy when recognizing a word (Lavidor & Ellis, 2001; Zaidel et al., 1999). Generally, the LH is able to recognize words in their whole form, as if they were a basic unit unto themselves, whereas the RH recognizes a word in more of a letter-by-letter fashion (Lavidor & Ellis, 2001). However, these same length effects were shown in both hemispheres when the words were case alternated (Lavidor & Ellis, 2001).

Besner and Johnston (1989) suggest the existence of a word specific visual pattern

(WSVP) defined as the complete set of visual characteristics in a word. They propose a mechanism within the brain by which a person is able to recognize or name a word when reading, simply by its unique set of visual features. Critical to the hypothesis of a WSVP is that word processing is more disrupted by case alternation than nonword processing. If case alternation interferes with the use of WSVPs, then only words should be affected. Nonwords, which by definition have no WSVP, should show little or no effect of case alternation. However, in the case of a word, what would be quickly recognized in upper or lowercase via WSVP could not turn up as a word when case alternated, because under normal conditions, the word is not case alternated. Therefore, case alternation changes the usual set of visual features of a word, making it unrecognizable using WSVP.

For example, a person sees the word "purple" and takes 500 milliseconds to identify it as a word by searching the mental lexicon for a match to its visual features. Then, the person sees "pUrPIE" and takes 1 second to respond "word" this time. The delay occurs because letter-by-letter identification was necessary after WSVP found no match. This is a relatively large 500 millisecond difference in response latency. Then, suppose the person sees "scerds". Again, it takes 1 second to respond "nonword," because letter-by-letter identification was necessary after WSVP found no match. Finally, the person sees "sCeRdS," and it takes 1 second for a response because letter-by-letter identification is needed. However, this time the response is "nonword" and the response latency difference between "scerds" and "sCeRdS" is 0 seconds.

Therefore, Besner and Johnston (1989) theorized that the WSVP hypothesis is supported when case alternation affects words more than nonwords. In a lexical decision task experiment, word processing was more disrupted (i.e., accuracy and latency) by case alternation than nonword processing (Allen, Wallace, & Weber, 1995; Besner, 1983; Besner & McCann, 1987).

Other researchers suggest that even though some variation of WSVF may exist, it cannot be necessary to successful reading because subjects are still able to read visually distorted (i.e., case alternated) words (Coltheart & Freeman, 1974). It might be the case that as one reads lowercase or uppercase words, one relies on letter identification in conjunction with WSVFs (Besner & Johnston, 1989).

### *Current Study*

Reliable data on lateralization of language in left-handers are needed. Furthermore, whole-word processing theories need to apply left-handed data. Differences in the lateralization of language between left- and right-handers were predicted. The experiment utilized a lexical decision task to examine the effects of case alternation on word recognition in each hemisphere across left- and right-handers. The following predictions were examined:

1. For right-handers, the RVF/LH (right visual field/left hemisphere) will react more quickly and perform more accurately on a tachistoscopic lexical decision task than the LVF/RH (left visual field/right hemisphere).
2. For right-handers, the RVF/LH will show greater decrement in accuracy and reaction time as a result of case alternation when compared to the LVF/RH.
3. Left-handers will show a reduced RVF/LH advantage for the lexical decision of lowercase words/nonwords compared to right-handers.
4. As the degree of left-handedness increases, the RVF/LH advantage for lexical decision of lowercase words/nonwords will decrease.
5. Case alternation will affect word recognition much more than nonword recognition in the RVF/LH for both left- and right-handers.
6. For left-handers, case alternation will also affect words more than nonwords in the

LVF/RH, due to more of a WSVP in the RH for left-handers.

Although Levy and Reid (1976) proposed that handwriting posture could provide information about cerebral laterality, later research has not been supportive (Springer & Deutsch, 1998). For this reason, we did not evaluate our participants' handwriting posture.

## Method

### *Design*

The experiment consisted of a lexical decision task in a 2x2x2x2 mixed-factorial design (lexicality x visual field x case type x handedness). Handedness was included as a between-subjects variable. The dependent variables were reaction time and accuracy.

### *Participants*

Twenty-four right-handed (12 male, 12 female) and 24 left-handed (12 male, 12 female) participants participated. All were native English speakers and had normal or corrected to normal vision. The participant's handedness was evaluated with a modified version of the Edinburgh handedness inventory containing five items (Bryden, 1982). Participants with scores of + .30 or greater were considered right-handed ( $M = +.8$ ), and participants with scores less than 0 were considered left-handed ( $M = -.6$ ). Participants either received course credit or were paid seven dollars.

### *Stimuli*

The experiment consisted of 120 words and 120 nonwords. The words were equated across lists for mean familiarity, imageability, nouniness, and length (4-6 letters) (Chiarello, Shears, & Lund, 1999). The familiarity ratings were from unpublished norms collected in Dr. Chiarello's laboratory.

Nonword stimuli were created by changing one letter in a real word that was comparable to the word stimuli (i.e., highly imageable 4-6 letter nouns). However, the nonword had to be pronounceable and orthographically legal. Each letter position was changed equally often in creating the nonwords.

The stimuli were counterbalanced across conditions and horizontally presented in lowercase or case alternated (e.g. cAsE aLtErNaTeD) form using Times New Roman 26 point font. Stimuli ranged in length from 1.5-3.1 cm. Uppercase and lowercase letters had heights of .6 cm and .4 cm, respectively.

#### *Apparatus and Procedure*

Participants were seated 60 cm in front of a Power Macintosh computer with a 17-inch monitor. The computer presented stimuli and recorded responses with the PsyScope program (Cohen et al., 1993). An adjustable headrest was used to stabilize head position.

A practice set of 35 words and 35 nonwords was given before the first block. There were a total of 4 blocks consisting of 60 trials each. Rest periods between blocks counteracted fatigue effects. The order of trials was independently randomized for each subject. The medial edge of each stimulus was positioned 1.81 degrees eccentric to a central "+". This "+" served as the fixation point. A 300 millisecond (ms), centrally displayed "+" followed by a 50 ms flickering red "+" preceded each trial. When the stimulus appeared to either the LVF or RVF, it remained for 130 ms. Meanwhile, the "+" remained for 325 ms after stimulus onset. The next trial was initiated 1300 ms after the participant's response or after the timeout interval (3000 ms) elapsed.

Participants were instructed to keep their head in the headrest, to maintain their focus on the central "+" as long as it remained visible, and to respond as quickly as possible. Right-handed participants were told to use their right hand to press the designated word "." or nonword "0"

keyboard button on the number pad. Left-handers were told to use their left hand. In both cases, one-half of the subjects used their index finger to press the "nonword" button and the middle finger to press the "word" button. The remaining one-half used the opposite configuration. The PsyScope program recorded reaction time, measured from stimulus onset, and accuracy.

### Results

Analyses of variance (ANOVAs) were performed on the data for both reaction time and accuracy (% correct), examining the variables VF, Lexicality, Case Type, and Handedness. Mean accuracy values for left-handers and right-handers are shown in Table 1. Mean reaction times values for left-handers and right-handers are shown in Table 2. In these tables the mean accuracy and reaction times for each of the conditions (e.g., case alternated word in LVF) were calculated for all participants within each handedness group.

There was no significant main effect for handedness for either accuracy,  $F(1, 46) = 2.58$ ,  $p < .1148$ , or reaction time,  $F < 1$ . Main effects for case were significant for both accuracy,  $F(1, 46) = 206.11$ ,  $p < .0001$ , and reaction time,  $F(1, 46) = 98.13$ ,  $p < .0001$ ; responses were quicker (914 ms) and more accurate (80.9%) for lowercase stimuli than for case alternated stimuli (reaction time = 999 ms; accuracy = 70.6%). Significant main effects for VF were found for both accuracy,  $F(1, 46) = 20.59$ ,  $p < .0001$ , and reaction time,  $F(1, 46) = 14.00$ ,  $p < .0005$ ; RVF responses were made more quickly (938 ms) and accurately (78.1%) than LVF responses (reaction time = 975 ms; accuracy = 73.4%). There was a significant main effect for lexicality under the reaction time measure,  $F(1, 46) = 152.37$ ,  $p < .0001$ ; reaction time was quicker for words (859 ms) than for nonwords (1054 ms).

A Handedness x Lexicality interaction was found on the accuracy measure. Specifically, there was a difference between left- and right-handers for nonwords,  $F(1, 46) = 7.09$ ,  $p < .0106$ ,

but not for words,  $F < 1$ . Right-handers were more accurate (77.6%) than left-handers (72.2%) in rejecting nonwords.

There was a Case x Lexicality interaction for both accuracy,  $F(1, 46) = 114.44$ ,  $p < .0001$ , and reaction time,  $F(1, 46) = 26.81$ ,  $p < .0001$ ; words were more affected by case alternation than were nonwords (see Figures 2 and 3). There was a main effect of case for words for both accuracy,  $F(1, 46) = 249.09$ ,  $p < .0001$ , and reaction time,  $F(1, 46) = 120.01$ ,  $p < .0001$ ; responses were quicker (795 ms) and more accurate (88.3%) for lowercase words than for case alternated words (reaction time = 922 ms; accuracy = 64.8%). A significant main effect of case was also found for nonwords for both accuracy,  $F(1, 46) = 4.25$ ,  $p < .0450$ , and reaction time,  $F(1, 46) = 13.53$ ,  $p < .0006$ ; responses were quicker (1033 ms) for lowercase nonwords than for case alternated nonwords (1076 ms). However, responses were more accurate (76.3%) for case alternated nonwords than for lowercase nonwords (73.5%).

There was a significant interaction between case and visual field for reaction time,  $F(1, 46) = 7.86$ ,  $p < .0074$ ; as predicted, the RVF had greater decrement in reaction time for case alternated stimuli than did the LVF (see Figure 4). A main effect of VF for lowercase stimuli was found for reaction time,  $F(1, 46) = 17.67$ ,  $p < .0001$ ; responses for lowercase stimuli were quicker (886 ms) in the RVF than in the LVF (942 ms). A main effect of VF for case alternated stimuli was marginally significant for reaction time,  $F(1, 46) = 3.51$ ,  $p < .0672$ ; responses were quicker (989 ms) for case alternated stimuli in the RVF than for case alternated stimuli in the LVF (1009 ms). A significant interaction between case and VF was also found for accuracy,  $F(1, 46) = 12.63$ ,  $p < .0009$ . There was an accuracy difference between the LVF and the RVF for lowercase stimuli,  $F(1, 46) = 41.45$ ,  $p < .0001$ , but not for case alternated stimuli,  $F(1, 46) = 2.38$ ,  $p < .1297$ . The RVF accuracy advantage (84.6%) over the LVF (77.2%) was significant for

lowercase stimuli but not for case alternated stimuli (RVF = 71.7%; LVF = 69.5%)(see Figure 5). No other interactions were statistically significant.

In addition, reaction time and accuracy laterality coefficients were calculated as follows: the reaction time formula was  $(LVF-RVF)/(LVF+RVF)$  and the accuracy formula was  $(RVF-LVF)/(LVF+RVF)$ , such that a positive value would indicate a RVF/LH advantage. These coefficients were used to compute correlations with the handedness index scores. No statistically significant correlation was found between handedness index score and degree of VF laterality.

### Discussion

Handedness was not as closely related to differences in hemispheric asymmetries for language as prior studies have reported (Cohen & Freeman, 1978; Peters, 1995; Springer & Deutsch, 1998; Zangwill, 1960). In addition, right-handers did not have an overall accuracy and reaction time advantage over left-handers, which is inconsistent with prior studies showing right-handers' advantage on language tasks (Cohen & Freeman, 1978). Given this finding, it is likely that another variable operated on the data. Many studies have included ambidextrous participants in their left-handed group, whereas ours did not. Perhaps the inclusion of the ambidextrous group inaccurately represents language asymmetry differences between right-handers and *true* left-handers.

The degree of handedness was not significantly correlated with language asymmetries. Handedness was treated as a continuous variable (Loring et al., 1990). The lack of significant correlation may indicate that there was not enough participants in each handedness index score group for sufficient power.

A RVF/LH advantage was found for the lexical decision task for both left- and right-handers, confirming the well-established idea that the RVF/LH is dominant for language. For

accuracy on the Case x VF interaction, the RVF/LH advantage was for lowercase stimuli. This pattern seems to suggest that case alternated stimuli effectively disrupt the processing mechanism that the LH employs. Otherwise, the advantage should be shown for case alternated stimuli, as well.

Across visual fields the RVF showed greater decrement in reaction time for case alternated stimuli with respect to lowercase stimuli than did the LVF for both left- and right-handers. The hypothesis regarding this result was supported by the data with the exception that the effect was shown for both right- and left-handers. Left-handers usually tend to show the same functional asymmetries as right-handers, but to a lesser degree (Springer & Deutsch, 1998).

For accuracy, the greater RVF/LH advantage was only for lowercase stimuli. These results suggest that the LH is able to recognize words in their whole form, whereas the RH recognizes words in more of a letter-by-letter fashion (Lavidor & Ellis, 2001). The discussion of the next prediction lends further support to case alternation affecting words more than nonwords. Thus, further evidence suggests global processing of words.

Consistent with the fifth prediction case alternation did affect word recognition more than nonword recognition. However, contrary to the prediction was the result that the effect occurred in both visual fields. Because case alternation affecting words more than nonwords is an indication of WSVP (Besner & Johnston, 1989), this processing mechanism might exist in both hemispheres to some degree. This would be inconsistent with a laterality study that found evidence for the global pattern word recognition mechanism solely in the RVF/LH (Zaidel, Bloch, & Arguin, 1999).

The final prediction was not supported because case alternation affected words more than nonwords across both VFs for both left- and right-handers. It is likely that if a WSVP does exist

primarily in the LH for right-handers, that it would be less lateralized to the LH for left-handers. However, given our results that support whole word processing in both hemispheres for right-handers, it would be unlikely that left-handers would show a different pattern because the right-handers are really *not* showing a VF asymmetry along this dimension.

#### *Future Studies*

Future studies might further explore language processing in the LH for left-handers. It would also be interesting to evaluate language asymmetries for ambidextrous participants. Indeed, these participants could be responsible for many studies suggesting language asymmetry differences between left- and right-handed participants because they have often been included with the left-handed group. Further studies might also evaluate whether degree of handedness is correlated with language asymmetries by obtaining enough participants in each handedness index score group to attain sufficient power.

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Table 1

*Accuracy Means (Standard Deviations) for Left- and Right-Handers*

Left-Handers (N=24)				
Visual Field	Words		Nonwords	
	CA	LC	CA	LC
LVF	63.4 (14.1)	83.1 (11.5)	72.7 (11.6)	67.1 (12.2)
RVF	66.1 (15.2)	93.6 (5.5)	76.2 (8.1)	73.0 (10.3)
Right-Handers (N=24)				
LVF	63.7 (12.6)	84.2 (10.8)	78.2 (10.0)	74.4 (10.1)
RVF	66.2 (14.0)	92.4 (7.8)	78.2 (7.5)	79.5 (9.7)

*Note.* CA= case alternated. LC= lowercase.

Table 2

*Reaction Time Means (Standard Deviations) for Left- and Right-Handers*

Left-Handers (N=24)				
Visual Field	Words		Nonwords	
	CA	LC	CA	LC
LVF	950 (215.9)	862 (246.0)	1113 (257.7)	1097 (246.1)
RVF	915 (181.1)	778 (143.9)	1092 (247.2)	1048 (198.4)
Right-Handers (N=24)				
LVF	927 (219.2)	792 (132.5)	1045 (257.1)	1016 (240)
RVF	895 (196.1)	750 (158.6)	1055 (281.0)	970 (195.4)

*Note.* CA= case alternated. LC= lowercase.

### Figure Captions

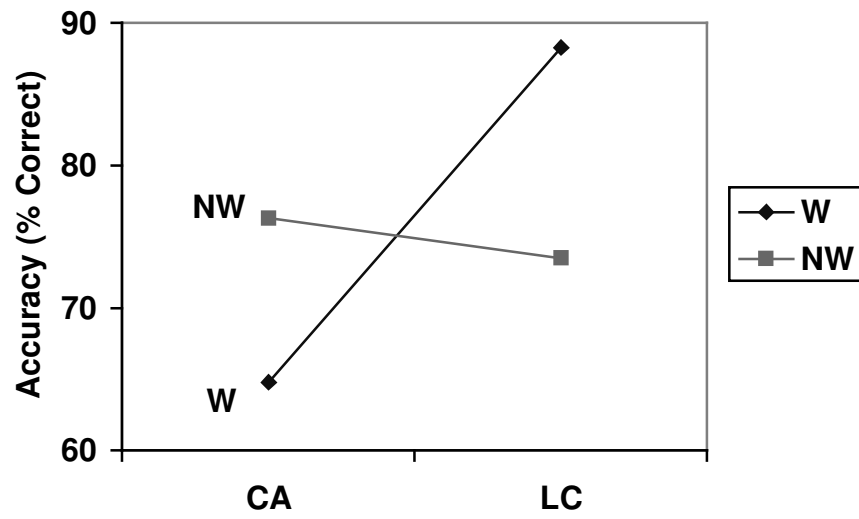
Figure 1. Case x Lexicality accuracy interaction. CA, case alternation; LC, lowercase. W, word; NW, nonword.

Figure 2. Case x Lexicality reaction time interaction.

Figure 3. Case x Visual Field reaction time interaction. LVF, left visual field; RVF, right visual field.

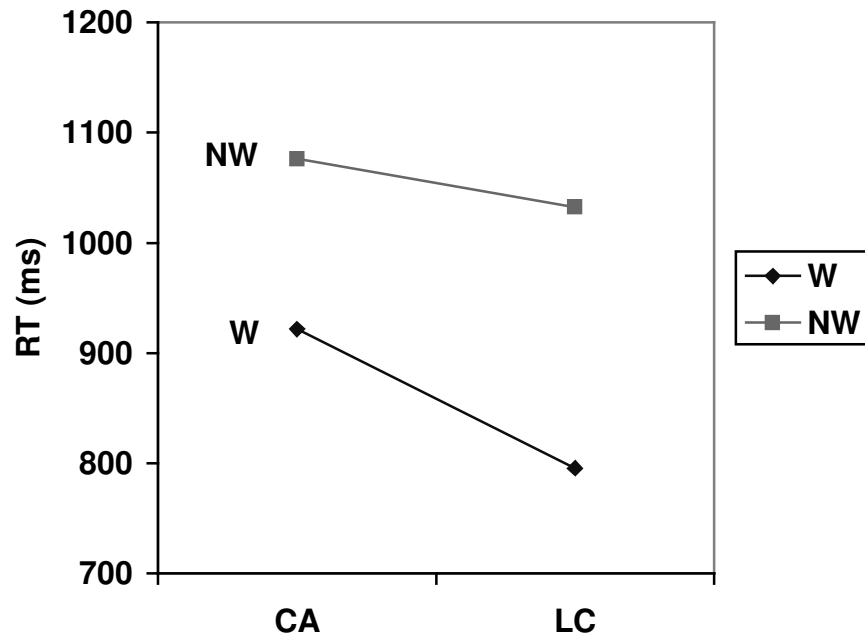
Figure 4. Case x Visual Field accuracy interaction.

Figure 1



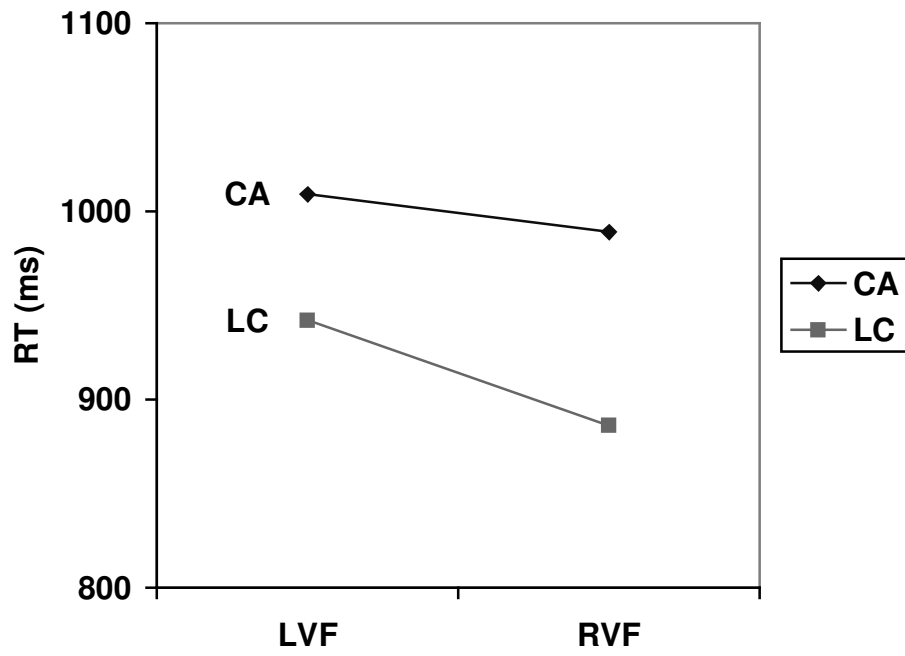
Case x Lexicality Accuracy Interaction

Figure 2



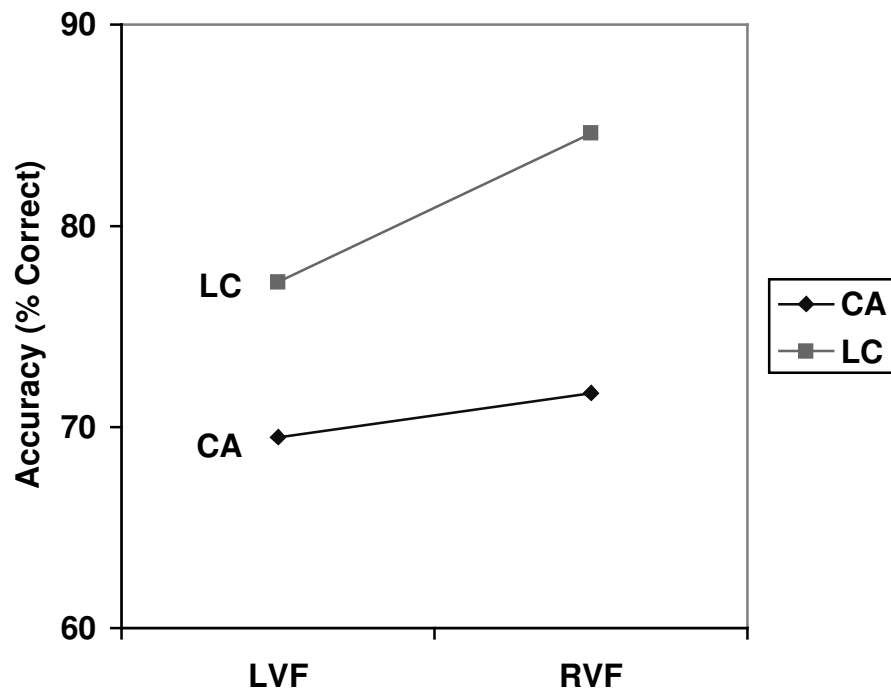
Case x Lexicality Reaction Time Interaction

Figure 3



Case x Visual Field Reaction Time Interaction

Figure 4



Case x Visual Field Accuracy Interaction