# Cerebral lateralization of local/global visual processing and correlations with dual-task performance : A divided visual field study

Anshul Bawa

HUV886 - Special Module in Cognitive Psychology
Project Report

13 May 2016

Investigator : Anshul Bawa, CSE IITD

Supervisor : Varsha Singh, HSS IITD

## Abstract

A within-subject divided-visual field experiment was conducted that investigated correlations of raw performance with degree of lateralisation of processing in a Navon-type hierarchical visual task with stimuli as letters. This experiment investigated interference effects between local and global visual processing among right-handers and left-handers, and found that higher lateralisation degrades raw performance in both cases, though lateralisation of global processing interferes with dual-task performance in right-handers whereas lateralisation of local processing interferes with dual-task performance in left-handers. Interesting differences in the raw performance of left-handers and right-handers were also observed across tasks and sub-experiments.

## Introduction

Hemispheric asymmetry in local and global processing of visual stimuli has been extensively studied. In humans, the right hemisphere is known to be specialized for processing the global aspects of visual patterns, whereas the left hemisphere is specialized for analyzing local details (Blanca, Zalabardo, Garcia-Criado, & Siles, 1994; Delis, Robertson, & Efron, 1986; Dernelle & de Schonen, 1991, 1995; de Schonen & Dernelle, 1994; Martin, 1979b; Sergent, 1982; Van Kleeck, 1989). While both hemispheres are capable of processing both global and local information, there is a bias for global processing in the right hemisphere (RH), and for local processing in the left hemisphere (LH).

The effects of global advantage and global-to-local interference have also been documented in Navon, 1977 and replicated in many studies. Global advantage refers to the fact that global processing is faster than local processing. Global interference is the effect that the global stimulus affects the processing of the local stimulus, but not vice-versa.

Lesion studies (Robertson and Lamb, 1991) have shown that different neural systems are implicated in the processing of global (*gl*) and local (*lo*) levels of nested hierarchical visual stimuli in which large forms are constructed from smaller forms, a large '**A**' made of smaller '**A**''s, for example (Navon, 1977). Patients with right temporo-parietal damage are impaired in identifying *gl* forms, while patients with left temporo-parietal damage are impaired in identifying *lo* elements (Delis et al., 1988; Robertson et al., 1988).

The Divided Visual Field Paradigm is an experimental technique that involves measuring task performance when visual stimuli are presented on the left or right visual hemifields. If a visual stimulus appears in the left visual field (LVF), the visual information is initially projected to the right cerebral hemisphere (RH), and conversely, if a visual stimulus appears in the right visual field (RVF), the visual information is initially received by the left cerebral hemisphere (LH). In this way, if a cerebral hemisphere has functional advantages in a particular task like gl or lo processing of visual stimuli, improvements in task performance may be observed (as measured by accuracy or response time) when the visual information is presented on the contralateral visual field.

There is significant research on the origins and advantages of localisation of function in the brain, and also specifically on localisation by lateralisation. Advantages of lateralisation have been studied, but mostly for language production. Correlation of dual-task efficiency with hemispheric asymmetry has been established in fish [Dadda et al 2006]. In humans, a positive correlation was observed if both the individual tasks are significantly lateralized [Lust et al 2011]. [Delis et al 1986] have studied lateralisation using hierarchical visual stimuli in unilaterally brain-damaged patients, but no studies were found that have investigated dual-task efficiency using the hierarchical visual task.

We investigate if the strength of lateralisation of one or both visuospatial attention functions (global and local visual processing) leads to better performance on relevant tasks. The origins of lateralisation are poorly understood, and an analysis of the advantages and/or disadvantages conferred by lateralisation would be a first step in tracing its evolutionary origins. Do people with a more lateralised *lo* and/or *gl* processing do better or worse overall on tasks that involve both? In what specific subject groups and tasks is raw performance correlated with the degree of lateralisation?

## Method

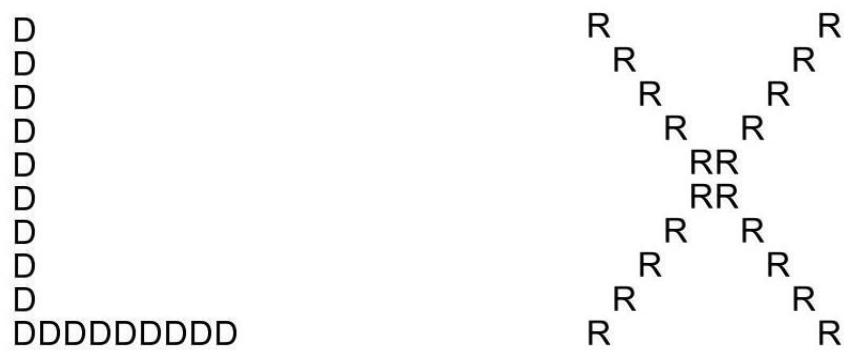
### *I. Subjects*

Sixty male undergraduate volunteers of age 20±1 years ($M$=20, $SD$=1, $n$=60) were recruited. All subjects had normal or corrected-to-normal vision. Informed consent was obtained from the participants. The sample had 43 consistent right-handers and 4 consistent left-handers, with the other 13 participants being mixed-handed. Handedness was reported by subjects on a simplified Edinburgh Handedness Inventory.

### *II. Stimuli*

Navon figures (large letters made up of smaller letters) were created within a 9x10 matrix. Four different letters ('L', 'D', 'X', 'R') were used to create the stimuli, creating a total of 16 distinct stimuli. 4 of these stimuli were congruous (i.e., the small letter matched the large letter). The other 12 were incongruous, with different small and large letters.

Letters, in Arial font, were displayed in black against a white background. Stimuli were presented unilaterally in the left or right peripheral visual hemifield while a fixation cross was presented centrally. Viewing distance was 25 cm. Two sample stimuli are shown below.



*III. Procedure*

The average duration of the entire experiment was 24 minutes per subject on average. This was a within-subject design, so all subjects were presented the trail blocks in the same order subject to intra-block randomisation. There were a total of 10 trial blocks, each separated by an enforced rest of 30 seconds. The experiment was divided into two sub-experiments, *E1* and *E2*, consisting of 6 and 4 trial blocks, respectively. A trial block in *E1* had 16 trials and a trial block in *E2* had 24 trials. Each trial consists of a visual stimulus presented to a randomly picked hemifield for a brief duration of 130 ms, immediately followed by a yes/no question about the stimulus. Each of the stimuli appeared with equal probability across the experiment and were presented in a pseudo-random sequence that prevented the same correct response from appearing in more than three consecutive trials.

There were three kinds of questions that could follow any stimulus :

1. Was the smaller letter one of these : L,D?

2. Was the larger letter one of these : L,D?
3. Were both letters one of these : L,D?

The questions (call them *Q1*, *Q2*, *Q3*) were set-membership queries on the letters. Out of the 4 letters seen (L,D,X,R), 2 of them would constitute a yes answer, and 2 would constitute a no answer. The membership set was kept fixed to control for any orthographic effects of stimuli on RTs.

In sub-experiment *E1*, the trail blocks were divided across the kind of question asked, and there were two blocks each for *Q1*, *Q2* and *Q3*, each divided across the letters of the visual stimuli. The type of question to be asked was communicated at the beginning of each trial block. The blocks corresponding to *Q1, Q2* and *Q3* are referred to as Task *Lo,* Task *Gl,* and Task *LoAndGl,* respectively.

In sub-experiment *E2*, the questions were randomised over four blocks, each block being divided on the basis of letters of the visual stimuli. One of the four trial blocks had congruous presentation of smaller and larger letters, and the other three had an incongruous presentation. All the analysis has been limited to the three blocks with incongruous presentation. Note that in *E2*, the kind of question was known only after the stimulus had vanished from the screen, so *E2* did not aim to isolate *Lo* and *Gl* processing but instead meant to study the effects of their interaction and interference across hemifield presentation and type of question.

For reference, the actual study can be found at
http://www.psytoolkit.org/cgi-bin/psy2.0.7/survey?s=TWrJu

## Analysis

To evaluate performance in dual-task, the mean response time (RT) was used as a metric in five different dual-task settings within the experiment. The five settings are as follows :

1. Experiment *E1*; Task *LoAndGl*. (n=32)
2. Experiment *E2*; Question *Lo*; Incongruous presentation. (n=24)
3. Experiment *E2*; Question *Gl*; Incongruous presentation. (n=24)
4. Experiment *E2*; Question *LoAndGl*; Incongruous presentation. (n=24)
5. Experiment *E2*; Incongruous presentation. (n=72)

Note that these settings include presentations to both the hemifields. In the first setting with experiment *E1*, all 16 visual stimuli (4 congruous and 12 incongruous) were counted. In the rest 4 settings with experiment E2, just the 12 incongruous image presentations were counted. Let the mean RTs for each setting above be denoted by *T1*, *T2*, *T3*, *T4* and *T5*. Performance would then be defined as the inverse of mean RT.

The degree of lateralisation was measured across six different settings within the experiment. The six settings are as follows :

1. Experiment *E1*; Task *Lo*. (n=32)
2. Experiment *E1*; Task *Gl*. (n=32)
3. Experiment *E1*; Task *Lo* and Task *Gl*. (n=64)
4. Experiment *E2*; Question *Lo*; Incongruous presentation. (n=24)
5. Experiment *E2*; Question *Gl*; Incongruous presentation. (n=24)
6. Experiment *E2*; Question *LoAndGl*; Incongruous presentation. (n=24)

To evaluate the extent of lateralisation, two different metrics were employed on relative response times across hemifield presentation (all other parameters kept constant).
Let $T_l$ denote the mean RT for LVF presentation in a setting, and $T_r$ denote the mean RT for RVF presentation in the same setting. The two metrics are then as follows :

1. Ratio :

$$max(T_l,T_r) / min(T_l,T_r)$$

2. Normalised unsigned difference :

$$| T_l - T_r | / (T_l + T_r)$$

Both metrics have a higher value when the relative difference between the two averaged RTs is high, and both have been normalised for effects of magnitude to discount faulty and coincidental correlations. The two metrics are very strongly correlated within themselves ($r > 0.97$, $p < .0001$) across all settings tested below.

Let the degree of lateralisation in the six settings above be denoted by *L1, L2, L3, L4, L5* and *L6*, respectively. Note that *L1* and *L4* measure the extent of lateralisation of local visual processing; *L2* and *L5* measure the extent of lateralisation of global visual processing.
Let an additional suffix a denote the first metric, and b the second metric. For instance, *L2b* denotes the extent of lateralisation in the third setting (Experiment *E1*; Task *Gl*) as measured by the second metric, normalised unsigned difference.

We therefore arrived at 5 measures of performance and 12 measures of the degree of lateralisation. Pearson product-moment coefficients of correlation (Pearson's *r*-values) were calculated for each combination (a total of 60) of pairs of a measure of performance and a measure of lateralisation. All the correlations that are statistically plausible (with *p*-values less than 0.1) are reported in the results section, and the statistically significant ones (with *p*-values less than .05) are highlighted.

These correlations were calculated across different groups of subjects (e.g., consistent left-handers, consistent right-handers, high-performance subjects with low average RTs, high-accuracy subjects, etc.). The specific groups, for which results are reported below, are as follows:

1. All subjects ($n$=60)
2. Consistent left-handers ($n$=4)
3. Consistent right-handers ($n$=52)
4. Consistent right-handers, fast responders (average RT < 2.7 seconds) ($n$= 42)
5. Consistent right-handers with non-high accuracy (accuracy < 93%) ($n$=19)

These groups are hereby referred to as *C1, C2, C3, C4* and *C5* respectively.

Note that since *T1* to *T5* are measures of averaged RTs, they are an inverse metric of performance. A positive correlation implies that subjects with a higher degree of lateralisation took longer to complete the task than subjects with a lower degree of lateralisation.

## Results

For each of the 5 groups, we report the correlations between the metrics of performance and lateralisation. For the first two group (all subjects and consistent left-handers) we also report statistics on RTs across different settings, and for all subjects, the statistics on the two metrics.

| **Response Time (ms)** | | | **Group *C1*** | | **Group *C2*** | |
|---|---|---|---|---|---|---|
| | | | *M* | *SD* | *M* | *SD* |
| | | LVF ($n$=16) | 1927.0 | 952 | 1946.4 | 804 |
| | | RVF ($n$=16) | 1825.4 | 866 | 1725.8 | 731 |
| | Task *Lo* | Average ($n$=32) | 1876.2 | 909 | 1836.1 | 768 |
| | | LVF ($n$=16) | 1269.9 | 640 | 1345.0 | 716 |
| | | RVF ($n$=16) | 1292.1 | 700 | 1314.3 | 507 |
| | Task *Gl* | Average ($n$=32) | 1281.0 | 670 | 1329.7 | 612 |
| | | LVF ($n$=16) | 1654.5 | 985 | 1549.6 | 747 |
| | | RVF ($n$=16) | 1533.0 | 845 | 1300.7 | 559 |
| | Task *LoAndGl* | Average ($n$=32) | 1593.7 | 915 | 1425.2 | 653 |
| Experiment *E1* | Average | ($n$=96) | 1583.7 | 831 | 1530.3 | 678 |
| | | LVF ($n$=12) | 2996.1 | 1184 | 2886.2 | 1403 |
| | | RVF ($n$=12) | 2881.6 | 1088 | 2971.5 | 1278 |
| | Question *Lo* | Average ($n$=24) | 2938.9 | 1136 | 2928.8 | 1340 |
| | | LVF ($n$=12) | 2761.6 | 1016 | 3111.7 | 1333 |
| | | RVF ($n$=12) | 2768.0 | 950 | 2880.8 | 1144 |
| | Question *Gl* | Average ($n$=24) | 2764.8 | 983 | 2996.2 | 1239 |
| | | LVF ($n$=12) | 2688.8 | 950 | 2758.3 | 1114 |
| | | RVF ($n$=12) | 2735.8 | 1006 | 2861.8 | 1227 |
| | Question *LoAndGl* | Average ($n$=24) | 2712.3 | 978 | 2810.1 | 1171 |
| Experiment *E2* | Average | ($n$=72) | 2805.3 | 1032 | 2911.7 | 1250 |

**Table 1 : Response Time statistics for all participants (C1) and consistent left-handers (C2) across tasks and LVF/RVF presentations**

| **Metric** | | *M* | *SD* |
|---|---|---|---|
| *T1 (E1; LoAndGl)* | | 1301.6 | 753 |
| *T2 (E2; Lo)* | | 2938.9 | 1136 |
| *T3 (E2; Gl)* | | 2764.8 | 983 |
| *T4 (E2; LoAndGl)* | | 2712.3 | 978 |
| *T5 (E2)* | | 2805.3 | 1032 |
| *L1 (E1; Lo)* | *a* | 1.183 | 1.604 |
| | *b* | 0.079 | 0.22 |
| *L2 (E1; Gl)* | *a* | 1.246 | 1.952 |
| | *b* | 0.104 | 0.285 |
| *L3 (E1; Lo, Gl)* | *a* | 1.469 | 3.046 |
| | *b* | 0.091 | 0.253 |
| *L4 (E2; Lo)* | *a* | 1.226 | 1.859 |
| | *b* | 0.095 | 0.265 |
| *L5 (E2; Gl)* | *a* | 1.196 | 1.597 |
| | *b* | 0.085 | 0.232 |
| *L6 (E2; LoAndGl)* | *a* | 1.171 | 1.56 |
| | *b* | 0.074 | 0.201 |

**Table 2 : Metric statistics for all subjects (C1)**

| S.No | Performance Metric | Lateralisation Metric | *r*-value | *p*-value |
|---|---|---|---|---|
| 1 | *T2* | *L2a* | 0.32 | **.010** |
| 2 | *T2* | *L2b* | 0.29 | **.021** |
| 3 | *T2* | *L3a* | 0.24 | .055 |
| 4 | *T2* | *L3b* | 0.25 | .053 |
| 5 | *T3* | *L2a* | 0.26 | **.047** |
| 6 | *T3* | *L2b* | 0.23 | .075 |
| 7 | *T4* | *L2a* | 0.30 | **.018** |
| 8 | *T4* | *L2b* | 0.27 | **.031** |
| 9 | *T4* | *L3a* | 0.27 | **.036** |
| 10 | *T4* | *L3b* | 0.25 | **.048** |
| 11 | *T5* | *L2a* | 0.30 | **.016** |
| 12 | *T5* | *L2b* | 0.28 | **.029** |

**Table 3 : Correlations for all subjects (C1)**

| S.No | Performance Metric | Lateralisation Metric | *r*-value | *p*-value |
|---|---|---|---|---|
| 1 | *T2* | *L1a* | 0.95 | **.047** |
| 2 | *T2* | *L1b* | 0.95 | **.049** |
| 3 | *T3* | *L1a* | 0.98 | **.017** |
| 4 | *T3* | *L1b* | 0.98 | **.014** |
| 5 | *T4* | *L1a* | 0.97 | **.027** |
| 6 | *T4* | *L1b* | 0.96 | **.036** |
| 7 | *T5* | *L1a* | 0.99 | **.001** |
| 8 | *T5* | *L1b* | 0.99 | **.003** |

**Table 4 : Correlations for consistent left-handers (C2)**

| S.No | Performance Metric | Lateralisation Metric | *r*-value | *p*-value |
|---|---|---|---|---|
| 1 | *T2* | *L2a* | 0.32 | **.020** |
| 2 | *T2* | *L2b* | 0.29 | **.036** |
| 3 | *T3* | *L2a* | 0.25 | .065 |
| 4 | *T3* | *L2b* | 0.23 | .097 |
| 5 | *T5* | *L2a* | 0.28 | **.040** |
| 6 | *T5* | *L2b* | 0.25 | .066 |

**Table 5 : Correlations for consistent right-handers (C3)**

| S.No | Performance Metric | Lateralisation Metric | *r*-value | *p*-value |
|---|---|---|---|---|
| 1 | *T2* | *L2a* | 0.43 | **.001** |
| 2 | *T2* | *L2b* | 0.40 | **.003** |
| 3 | *T3* | *L1a* | -0.25 | .072 |
| 4 | *T3* | *L1b* | -0.25 | .075 |
| 5 | *T3* | *L2a* | 0.32 | **.021** |
| 6 | *T3* | *L2b* | 0.29 | **.038** |
| 7 | *T4* | *L2a* | 0.36 | **.008** |
| 8 | *T4* | *L2b* | 0.33 | **.016** |
| 9 | *T5* | *L2a* | 0.39 | **.004** |
| 10 | *T5* | *L2b* | 0.36 | **.008** |

**Table 6 : Correlations for consistent right-handers with low RTs (C4)**

| S.No | Performance Metric | Lateralisation Metric | ***r*-value** | ***p*-value** |
|---|---|---|---|---|
| 1 | *T1* | *L4a* | 0.47 | **.039** |
| 2 | *T1* | *L4b* | 0.45 | .051 |
| 3 | *T1* | *L5a* | 0.43 | .066 |
| 4 | *T1* | *L5b* | 0.43 | .061 |
| 5 | *T2* | *L2a* | 0.53 | **.015** |
| 6 | *T2* | *L2b* | 0.49 | **.032** |

**Table 7 : Correlations for consistent right-handers with non-negligible error rates (C5)**

## Discussion

As expected, RVF performance is better for *Lo* task in *E1* and *Lo* questions in *E2*. LVF performance is better for *Gl* task in *E1*. *Gl* tasks and questions have a significantly lower RT than tasks and questions that involve *Lo* processing.

Among consistent left-handers, however, both *Lo* and *Gl* processing are better in the LH/RVF presentation, suggesting that both *Lo* and *Gl* processing is lateralised in the left hemisphere. Consistent left-handers perform significantly better in the *LoAndGl* task of *E1* compared to the rest of the population, since all the modalities supposedly involved (*Lo* processing, *Gl* processing and computing the logical AND operation) are dominant in the same hemisphere, and hence there is no need for interhemispheric communication.

At the same time, consistent left-handers perform worse than average in experiment *E2*, in which the form of the question is not known in advance. It can be hypothesised that switching between different modes of processing within the same hemisphere is more expensive than switching across hemispheres. In *E1*, there is no switching involved as the processing is goal-directed with the target question and processing known in advance. This cost of intrahemispheric indecision also manifests strongly in performance-lateralisation correlations for *C2*, as mentioned below.

The overall trend in correlations is that average RT is positively correlated with extent of lateralisation. For the group *C1*, performance in all trials of the sub-experiment *E2* is weakly correlated with the lateralisation of *Gl* processing in *E1*. A statistically significant correlation across measures from different experiments is a strong result. Not only is performance in *Lo* and *LoAndGl* type questions affected negatively by lateralisation of *Gl* processing, even *Gl* type questions are affected, though less significantly so. As *Gl* processing is in itself much faster than *Lo* processing, a more lateralised *Gl* processing seems to imply an even faster *Gl* response from RH/LVF which interferes with the slower processing of the incongruous *Lo* stimulus. Differences in processing by LH and RH manifest more as interference and hemispheric indecision than as constructive distribution of processing.

Among consistent right-handers (group *C3*), the only statistically significant correlation observed is between *Gl* lateralisation in *E1* and *Lo* performance in *E2* ($r = 0.32$, $p = .020$), which mirrors the pattern of hemispheric indecision discussed above. The other correlations as observed in group *C1* are not very significant in *C3*, but they re-emerge in *C4*, which is a subset of *C3*. Among consistent right-handers with fast RTs, there is a weak-to-moderate correlation of lateralisation of *Gl* in *E1* to overall performance in *E2*. This correlation is higher than what is observed in *C1*.
When we limit our analysis to subjects that are getting a non-negligible proportion of the answers wrong (group *C5*; accuracy < 93%), we find that the correlation seen in *C2* becomes even stronger ($r = 0.53$, $p = .015$), which hints at the fact that hemispheric indecision also reduces accuracy along with mean RTs in the interfered task of *Lo* processing in *E2*.

Among consistent left-handers (group *C2*), a very different and significant result in correlations is observed. Performance in all kinds of tasks in *E2* are strongly correlated with lateralisation of *Lo* processing in *E1*, and not with the lateralisation of *Gl* processing as seen in all other groups. The correlations are very high (all *r*-values > 0.9) and all are statistically significant. As noted above, all modalities are lateralised towards LH/RVF for this group. Higher lateralisation of *Lo* processing in *E1* supposedly makes *Lo* processing compete more effectively with an already-faster *Gl* processing, and thus makes switching between these two modes even costlier. This also points to the fact that hemispheric indecision has more components than merely a global interference effect. Further studies on consistent left-handers would be helpful in teasing out more factors involved.

The broad conclusion is that the degree of lateralisation of one or more modes of processing negatively interferes with performance in a dual-task that involves both of two dichotomous processing modes. If lateralisation has any advantages, they are conclusively not advantages of raw performance, at least in tasks that involve dichotomous processing modes. Further extensions of this study could explore if lateralisation correlates with energy efficiency and/or fatigue. Also, correlations could be studied for non-dichotomous dual tasks.

## References


[Kleeck 1989] :
Hemispheric differences in global versus local processing of hierarchical visual stimuli by normal subjects: New data and a meta-analysis of previous studies
Michael H. Van Kleeck
Neuropsychologia Volume 27, Issue 9, 1989, Pages 1165–1178

[Hopkins 1989] :

Hemispheric specialization for local and global processing of hierarchical visual stimuli in chimpanzees (Pan troglodytes)

William D Hopkins

Neuropsychologia Volume 35, Issue 3, 7 February 1997, Pages 343–348

[Martinez et al 1997] :

Hemispheric asymmetries in global and local processing: evidence from fMRI

A. Martinez, P. Moses, L. Frank, R. Buxton, E. Wong and J. Stiles

NeuroReport 8, 1685–1689

[Robertson et al 1988] :

Effects of lesions of temporal-parietal junction on perceptual and attentional processing in humans

Robertson, L.C., Lamb, M.R., Knight, R.T.

Journal of Neuroscience Volume 8, Issue 10, 1988, Pages 3757-3769

[Johannes et al 1996] :

Hierarchical visual stimuli: electrophysiological evidence for separate left hemispheric global and local processing mechanisms in humans

Stnke Johannes, Bernardina M. Wieringa, Mike Matzke, Thomas F. Mtinte

Neuroscience Letters, Elsevier 210 (1996) 111-114

[Robertson et al 1991] :

Neuropsychological contributions to theories of part/whole organization

Lynn C Robertson, Marvin R Lamb

Cognitive Psychology Volume 23, Issue 2, April 1991, Pages 299–330

[Dadda et al 2006] :

Does brain asymmetry allow efficient performance of simultaneous tasks?

Marco Dadda, Angelo Bisazza
Animal Behaviour Volume 72, Issue 3, September 2006, Pages 523–529

[Delis et al 1986] :
Hemispheric specialization of memory for visual hierarchical stimuli
Dean C. Delis, Lynn C. Robertson, Robert Efron
Neuropsychologia Volume 24, Issue 2, 1986, Pages 205-214

[Lust et al 2011] :
Functional cerebral lateralization and dual-task efficiency—Testing the function of human brain lateralization using fTCD
J.M. Lust, R.H. Geuze, A.G.G. Groothuis, A. Bouma
Behavioural Brain Research Volume 217, Issue 2, 1 March 2011, Pages 293–301