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APPLIED IT

IS EAR DIRECTION OR INTEGRATED PERCEIVED DIRECTION DOMINANT FOR SPEECH PERCEPTION?

Head rotation effects on the right ear advantage

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Abstract

There is a well-documented asymmetry in speech perception, known as the right ear advantage (REA), where speech sounds are better recognised when coming from the right than from the left. This asymmetry is sensitive to multisensory integration, as seen in José Morais' ventriloquism study. The aim of the present study is to investigate whether speech perception is affected by the integrated perceived direction of self or only by the direction of the ears. Dextral participants (N = 35) were tested in a single response diotic listening task with consonant-vowel-syllables presented in 144 pairs, while instructed to listen in one direction. Each participant was tested in three head direction conditions: straight, left, and right, with the gaze held straight in relation to the seating position in all conditions. A one-way repeated measures ANOVA was run but the null-hypothesis could not be rejected. Stimulus dominance is presented as a likely confounding factor, although other methodological and theoretical errors are certainly possible.

Keywords

REA, right ear advantage, speech perception, attention, dextrals

Titel

Är öronens riktning eller en integrerad uppfattning av riktning referens för språkperception?: Inverkan av huvudets vridning på språklig perceptionsasymmetri

Sammanfattning

Right ear advantage (REA) är ett inom språkperception välkänt fenomen där språkljud bearbetas effektivare när de kommer från höger än när de kommer från vänster. José Morais demonstrerade att visuospatial information om ljudkällors position kan påverka REA och att multisensorisk integration således har ett visst inflytande över fenomenet. Syftet med denna studie är att fastslå huruvida REA i huvudsak bestäms av en multisensoriskt integrerad riktning av jaget, eller om endast öronens riktning är av betydelse. Högerhänta deltagare (N = 35) testades på 144 konsonant-vokal-par i en diotiskt lyssningsuppgift med styrd uppmärksamhetsriktning. Varje deltagare testades i tre huvudriktningsbetingelser: rakt, vänster, och höger. Blickens riktning var under samtliga betingelser rakt fram gentemot kroppens position. Resultaten analyserades med en inomgrupps-ANOVA men nollhypotesen kunde inte förkastas. Stimulusdominans pekas ut som en störande faktor och granskas tillsammans med andra möjliga metodologiska och teoretiska misstag.

Nyckelord

REA, right ear advantage, språkperception, uppmärksamhet, högerhänta

Foreword

All tasks were shared between both writers, Alfred took the main workload in writing the introduction and discussion, Anton in method and results.

We would like to thank our supervisor Pierre Gander and everyone who participated!

Table of contents

1 Introduction

When making sense of the world, the brain must continually integrate a whole host of different sensations into a unified perceptual experience, a living, moving, three-dimensional world of objects and relations – an impressive feat that requires efficient mediation of competing sensory inputs. How does the brain coordinate this abundance of information? Imagine listening to a radio in your kitchen. As you walk about the room your body, head, and eyes all move, quite independently. Your eyes may dart around the room while you turn your head and walk in different directions, yet you experience the sound source as being perfectly static. You perceive the audio as emanating from the same point in space. What processes govern this multisensory integration? How are competing impressions negotiated? For instance, if you move your head in relation to the sound source, will the audio be processed as coming from a direction set by your ears or a direction set by some cognitive map, a unified environmental representation determined by multiple senses?

The efficiency of verbal processing has been shown to depend on the location of the sound source (Hiscock & Kinsbourne, 2011). If this location is processed according to an integrated cognitive map, it might be possible to affect performance on verbal tasks by manipulating visual and proprioceptual conditions.

1.1 The right ear advantage

When two verbal stimuli are presented simultaneously and *dichotically*, meaning separately to each ear, the stimulus presented to the right ear is generally better recognised. This tendency is known as the right ear advantage, or REA, and provides behavioural evidence for the lateralisation of function in the brain (Hiscock & Kinsbourne, 2011).

Stimuli are in certain circumstances expected to be processed more efficiently when presented to the input channels contralateral to the hemisphere specialised for the processing of such stimuli. These input channels need not correspond to physical structures, e.g. that which is anatomically opposite, but might also refer to functional relations, e.g. that which is "mentally opposite", such as visual and auditory hemifields (White, 1969). Clinical findings show that most humans have a left-hemispheric specialisation for language processing and the REA consequently provides behavioural evidence in support of the clinical data (Corballis, 2014).

The REA is considered a robust finding in experimental psychology, corroborated by clinical evidence as well as neuroimaging techniques, but what accounts for this lateralisation? What are the physiological and neurological underpinnings of the REA? Although more than 50 years have passed since Doreen Kimura first discovered the phenomenon, the underlying mechanisms remain elusive and disputed (Hiscock & Kinsbourne, 2011).

Since the ascending neural pathways from each ear projects bilaterally, i.e., to both auditory cortices, ear of entry alone cannot provide the complete picture. Kimura nevertheless advocated an anatomical explanation where the physiological organisation of the auditory system favours information from the contralateral pathways. According to this account, the contralateral pathways are given superior representation in the auditory cortices whereas the ipsilateral pathways are suppressed. Input from the ear *contralateral* to the dominant hemisphere therefore projects to the dominant auditory cortex directly, whereas information from the ear *ipsilateral* to the dominant hemisphere travels via the minor hemisphere and the corpus callosum, thus reaching the verbal processing centres later and with greater loss of information (Hiscock & Kinsbourne, 2011).

This interpretation, which came to be known as the structural view, predicts that ear of entry is indeed the deciding factor. However, the view was soon challenged by researchers suspecting that attentional and spatial factors may play an important role. As José Morais (1975) put it, “channels in the mind may not correspond exactly to channels in the brain” (p. 128). Kimura's dichotic presentations do not, in fact, provide sufficient evidence for the structural claim; a stimulus presented to the right ear could also be perceived as originating from the right side of external space, in which case, the REA may in fact reflect a spatial advantage rather than an ear advantage.

By presenting two verbal stimuli *diotichally*, i.e., the same stimulus is presented to both ears (as opposed to the *dichotic* method referenced above), and producing interaural time differences artificially so that volume is kept constant, Morais and Bertelson (1975) found that the apparent spatial position of the stimuli sufficed to cause a right-side advantage. Morais (1975) also demonstrated a ventriloquism effect where the positions of fake loudspeakers could reduce the right-side advantage if participants falsely believed that the sounds came from a position closer to the median plane. He proposed that spatial beliefs could affect the distribution of attentional activation, causing REA to decrease when speech sounds were perceived to emanate from more centrally placed sources. Some structural propensity for favouring information channels associated with one side of space is still plausible but a purely structural account of the REA is evidently inadequate.

Current researchers widely regard attention as a key factor in the REA with many adhering to a combined account involving attentional as well as structural aspects (Hiscock & Kinsbourne, 2011). The concept of attention is, however, rather vague; it can basically be construed as the allocation of limited mental resources, but this allocation can seemingly be induced by both automatic and voluntary processes. Elaboration on such matters has proven to be valuable for the methodology surrounding the REA (Hiscock & Kinsbourne, 2011) and will be discussed in the next section.

The ventriloquism study indicates that speech perception can be affected by the perceived location of sound sources, i.e., by beliefs and visual input, and not exclusively by the sources' locations relative to the ears. Assuming that speech perception is dependent on integrated positioning, is it processed in relation to the direction of the ears or to a perceived direction of self? If ear direction is not the sole reference for speech perception, different head positions might affect the way in which activation is distributed and thus affect REA-measures, even when the source location is constant in relation to the ears. We therefore hypothesise that the REA is significantly affected by head positions in diotic verbal listening tasks.

1.2 Methodological advances

Several methodological issues have emerged since Kimura's research in the 1960s and the methods employed in this study have been chosen to reflect the best current understanding of elements that may confound REA-research. Some changes aim to minimise the impact of bottom-up, or stimulus driven, factors. Consonant-vowel-syllables (CV-syllables) using the six stop consonants (b, d, g, k, p, and t), typically in combination with a short *a*, are considered more reliable as stimuli than the digit names used in some of the early REA-studies, leaving less room for confounding effects of volitional factors (Hisckock & Kinsbourne, 2011; Voyer & Techentin, 2009). The CV-syllables have later been shown to introduce confounding elements of their own, notably in the form of voice onset time (VOT), the time it takes for the voicing to follow the release of air that initiates the sound. CV-syllables with long VOT (k, p, and t) are better recognised than syllables with short VOT (b, d, and g), accordingly, the CV-pairs used to study REA should preferably be a combination of either short VOT-syllables or long VOT-syllables (Rimol, Eichele, & Hugdahl, 2006).

Since the REA may reflect structural as well as attentional components, many researchers advocate methods designed to disassociate structural effects from attentional effects. For instance, if participants are free to report stimuli in whatever way they choose, they could resort to improvised strategies, e.g. biasing attention to one side, which undermines causal interpretation of the data. To control for such top-down effects, participants could be forced to selectively attend to one side during stimulus presentations (Voyer & Ingram, 2005).

Another important finding concerns the large degree to which language lateralisation is connected to degree of handedness (Knecht et al., 2000) which puts greater demands on the recruitment of participants.

2 Method

2.1 Participants

35 dextral participants, 21 men and 14 women, where the age ranged from 22 to 64 years (M = 29.9, SD = 11.3) were included in the main study. The participants were chosen by convenience sampling and had Swedish as their first language. To obtain a reliable classification, handedness was determined via Dragivic's (2004) modified version of the Edinburgh handedness inventory questionnaire (all participants classified as dextrals). Since the effect, to the best of our then existing knowledge, had not been studied in this implementation before, we had no way to make good estimates of the effect size. The number of participants were chosen, together with the design (one-way repeated measures ANOVA with three conditions), to handle medium sized effects ($\eta_p^2 = .13$). For a power of .80 with alpha of .05, usable data from 35 participants was deemed necessary to detect medium sized effects as assessed with a statistical power analyser (Heinrich-Heine-Universität Düsseldorf, G*Power 3.1.9.2). As nine participants were excluded and replaced, a total of 44 participants started the test. The reasons for exclusions included discomfort caused by audio, insufficient visual field, insufficient hearing, inability to classify sound stimuli, audible equipment for cellular telephone and possibly confounding visually asymmetrical (lighting and colouring) and noisy room (reverberation). All used data was collected in a more symmetrical and slightly acoustically treated room.

The collected data was handled anonymously, to the highest degree that was still practical. To increase motivation, the participants were given the option to get their result sent to them by e-mail, therefore we had to keep the possibility to trace the given e-mail address to the matching set of data. The participants were made aware of this via the questionnaire and required to give consent before taking part in the study.

2.2 Materials

A questionnaire collecting participant data about age, sex, language and handedness was produced.

The CV-syllables *pa, ta, ka, ba, da,* and *ga* were recorded with a binaural microphone (3Dio FS XLR) and read in a speaking voice 90˚ to the side one meter from centre of the stereo microphone, to give the sound a socially acceptable perceived speaker position, in a dedicated recording studio (not heavily acoustically dampened). Only one recorded delivery from each CV-syllable was used to achieve more balanced priming, the CV-syllables were chosen manually to match in trios *pa/ta/ka* (long VOT) and *ba/da/ga* (short VOT). The recordings that were used were produced with the sound source positioned to the right and channel two corresponding with perceived sound direction. In combining the recordings into CV-pairs one stereo recording had channel one routed to the right earphone and channel two to the left and the second stereo recording channel one to the left and channel two to the right.

One project file per participant was produced in a digital audio workstation (Cockos Reaper 5.70), containing 19 blocks, the first block was designed to test the participants ability to classify each sound therefore containing each CV-syllable separately with microphone channel two in both left and right output channel, next six short blocks (four presentations each) to attenuate nonlinear training effects and were not used in the analysis, thereafter twelve blocks each containing all used CV-pairs (twelve sound presentation, block randomised). The sound presentations were separated temporally with five seconds and 15 seconds between the blocks.

The sound stimuli were replayed through the digital audio workstation on a personal computer and was delivered to the participant through audio interface (Cambridge Audio DacMagic XS) and closed circumaural headphones (Sony MDR-7506).

To control head direction and gaze, a tailor-made head gear was used. The head gear was constructed with three, low-power visible laser diodes mounted in a manifold which was placed on the forehead with an elastic head strap, with one laser placed in the middle of the manifold and directed straight forward, and one laser at each side rotated 38˚ away from the centre point. The lasers were activated separately via a switch on the power supply cable, operated by the test leader.

A circular target, 200 mm in diameter, was placed three meters in front of the table, see figure 1 as a reference for the lasers and gaze direction (figure 1).

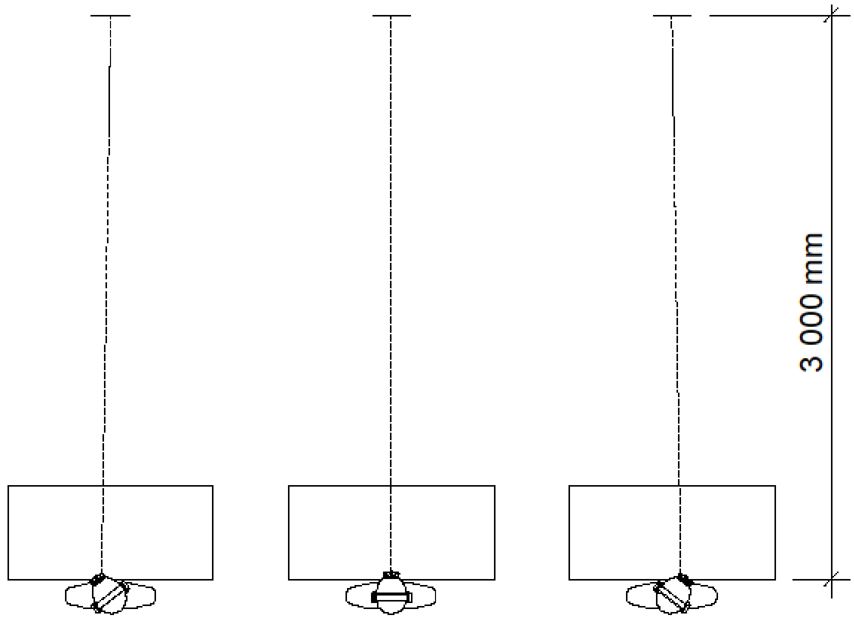

Figure 1. Head direction controlled with head gear and target: head rotated 37˚ to the left (measuring REA_{left}), head straight (measuring $REA_{straight}$) and head rotated 37˚ to the right (measuring REA_{right}).

2.3 Procedure

The participant self-reported its age, sex, hearing deficiencies, which hand they use different tools with (in a test of handedness) and were instructed in their task. Their task was to note, on an answer sheet, the consonant perceived as coming from the direction instructed to focus on while having the head rotated so that the active laser was directed toward the target with the gaze toward the target.

Each participant was tested in two blocks of each combination of attended listening direction and head direction, of which order was randomised and ABBA counterbalanced. The task to direct listening is given to avoid effects on the data from conscious and unconscious attention directing strategies.

The test leader, placed approximately three meters behind the participant, gave verbal instructions, which gave spatial auditive reference to a fixed position in the slightly acoustically treated classroom. For each block the participant was given verbal instructions by the test leader complemented by a written instruction with a direction for the head and a direction of attention.

In addition to assigning a direction for the head, matching laser diodes lit up on the head gear whose beam along with the participant's gaze were to be directed towards the target at every sound presentation. The turning of the head was in practice estimated to 35 – 37˚.

The participants wrote one consonant per sound pair in the corresponding square of the answer sheet while doing this they could move their gaze and the laser beam from the target as long as they were in correct position before the next sound. If the laser and the gaze were not directed onto the target again before the next sound presentation the square on the answer sheet should be left empty. The procedure was practiced on four blocks with three sound presentations each before the test started. The test was started with a control block where all of the six CV-combinations were played one after the other (not stereoscopic), and thereafter six blocks with four sound presentations each which were not included in the result to minimise the nonlinear training effects. Lastly twelve blocks, all six directions of the head and listening combinations twice, randomised for each participant and balanced in ABBA-configuration, each block containing all twelve sound presentations.

The digitalisation of the participants response forms was performed without comparison with the corresponding presented stimuli, to avoid biased data in the event of ambiguous handwriting.

2.4 Data transformation and analysis

For every participant and every head direction, the number of responses corresponding to the stimuli presented to the right or left auditory hemifield were counted. An index for REA was calculated, REA = (right side responses – left side responses) / (right side responses + left side responses) for each condition (figure 1), giving $REA_{straight}$, REA_{left}, REA_{right} and the result from all conditions, REA_{total}.

3 Results

There were four outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The difference in result was compared between three one-way repeated measure ANOVAs with one keeping the outliers, one excluding them and one replacing the extreme values with data points almost equal to the nearest non-outlier. The results were not found to differ sufficiently to have appreciable effect on the analysis.

$REA_{straight}$ data is positively skewed and not normally distributed, as assessed by Shapiro-Wilk's test ($p = .012$). An inverse transformation of the data was made to attenuate the positive skewness. The REA index has possible values ranging from minus one to plus one, therefore the value one was added before inversing the data (1/(REA+1)). The results, from using transformed and non-transformed data in one-way repeated measure ANOVA, was compared and not found to differ appreciably (*F*-value differed less than two per cent, significance and effect size would have been presented identically).

A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in REA for the three head direction conditions, the four outliers were concluded not to have appreciable effect on the analysis and were included. The assumption of normal distribution was not met but concluded not to affect the analysis. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 3.872$, $p = .14$. The different head directions did not elicit any statistically significant differences in REA, $F(2, 68) = 1.21$, $p = .31$, $\eta_p^2 = 0.034$, with $REA_{straight}$ ($M = .070$, $SD = .094$), REA_{left} ($M = .057$, $SD = .11$) and REA_{right} ($M = .043$, $SD = .093$).

A one-sample *t* test was run to determine if there was a REA_{total}. The REA_{total} data were normally distributed, as assessed by Shapiro-Wilk's test ($p = .17$). There was one outlier in the data, as assessed by inspection of a boxplot, which was replaced by a less extreme value just over the second largest. Mean REA ($M = .055$, $SD = .012$) in the experiment is statistically significant over zero, 95% CI [.030, .079], $t(34) = 4.52$, $p < .001$, $d = .76$.

Dominant CV-syllables sounds within the CV-pairs are a possible explanation of the relatively low REA measurements. A set of paired *t* tests were run to visualise these possible significant asymmetries. Outliers were detected in a boxplot, but they were found not to have appreciable effect on the analysis and were kept. The assumption of normality was violated, as assessed by Shapiro-Wilk's test ($p < .05$)

within multiple pairs, non-normality does however not affect Type I error rate substantially in paired-samples *t* tests and no action was taken. Significant asymmetries were found in all but two CV-pairs (table 1). Stimuli dominance do however variate between participants and another set of paired *t* tests were run between the participant specific dominant syllable and the participant specific non-dominant syllable for each CV-pair. Outliers were again detected in a boxplot and were kept as they were found not to have appreciable effect on the analysis. The assumption of normality was violated, as assessed by Shapiro-Wilk's test ($p < .05$) within multiple pairs and no action was taken. Bigger asymmetries were found in all but the most extreme CV-pair and asymmetries were significant in all CV-pairs as seen in table 2.

Table 1

Asymmetry within CV-pairs (paired t test).

Consonant (within pair)	M	SD	t	df	p
p(pt) – t(pt)	47.1 %	.59	4.71	34	< .001
p(pk) – k(pk)	48.9 %	.71	4.05	34	< .001
k(kt) – t(kt)	41.7 %	.70	3.48	33	.001
d(db) – b(db)	0.70 %	.86	0.049	34	.96
g(gb) – b(gb)	5.11 %	.83	0.36	34	.72
g(gd) – d(gd)	98.1 %	.070	82.6	34	< .001

Table 2

Asymmetry within CV-pairs Subject dominant consonant – subject non-dominant consonant (paired t test).

Consonant pair	M	SD	t	df	p
pt	67.6 %	.33	12.1	34	< .001
pk	80.4 %	.30	15.7	34	< .001
kt	74.8 %	.30	14.5	33	< .001
db	78.8 %	.31	15.1	34	< .001
gb	74.5 %	.35	12.7	34	< .001
gd	98.1 %	.070	82.6	34	< .001

To give a rough estimate of the possible expected effect size (for difference in REA between the three head directions) with lower stimuli dominance, a one-way repeated measures ANOVA was conducted for the ten participants with the highest number of non-dominant stimuli answers, while acknowledging that this sub-group might not be representative. The data has no outliers and is normally distributed at each head direction, as assessed by boxplot and Shapiro-Wilk test ($p > .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi^2(2) = .510$, $p = .068$. The different head directions did not elicit any statistically significant differences in REA $F(2, 18) = 1.87$, $p = .18$, $\eta_p^2 = 0.17$, with $REA_{straight}$ ($M = .12$, $SD = .14$), REA_{left} ($M = .098$, $SD = .13$) and REA_{right} ($M = .040$, $SD = .12$).

The test was followed with a one-sample *t* test of the REA_{total} for the same group, no outliers were found and the data was normally distributed as assessed by boxplot and Shapiro-Wilk test ($p = .88$). A statistically significant REA was found ($M = .085$, $SD = .10$), $t(9) = 2.59$, $p = .029$, $d = .82$

A potential source to systematic variance between subjects is initial listening direction (Hiscock & Stewart,1984; Jäncke, 1994). A one-way ANOVA was conducted to determine if the instructed listening direction of the first block had any possibly confounding effects of on the REA_{total} even after the multiple discarded blocks. Starting with listening to the right ($n = 17$), listening to the left ($n = 18$). There were two outliers, as assessed by boxplot, inspection of their values did reveal one to be extreme, which were replaced by a less extreme value just over the second largest. Data was normally distributed for each group, as assessed by Shapiro-Wilk test ($p > .05$), there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances ($p = .91$). REA_{total} was higher for participants which started with listening to the right ($M = .077$, SD = .065), then those starting with listening to the left ($M = .031$, $SD = .069$), the effect was however not statistically significant, $F(1, 33) = 4.13$, $p = .050$.

4 Discussion

4.1 Results

The aim of this study was to determine if speech sound processing is done in regard to the direction of the ears or the participants integrated perceived direction of self. The mean value of REA was highest for head in straight position followed by head turned to the left and lowest in the head to the right condition, the differences were however not statistically significant. Our results do not give support to our hypothesis that the REA is affected by an integrated perceived direction, as the null hypothesis could not be rejected. The results show a total REA, but most participants show total or almost total signal advantage within the majority of the CV-pairs (irrespective of listening direction and direction of perceived stimuli), which affects the result toward no ear advantage (NEA). The fewer data points successfully measuring ear advantage is also giving higher variance in relation to mean value differences. Only looking at the data from the ten participants with highest number of answered subject non-dominant CV-syllables within all presented CV-pairs. This subset gives higher mean values for REA (again, $REA_{straight} > REA_{left} > REA_{right}$) and effect size values matching what the study was designed for, but these participants might not be representative of the dextral population.

4.2 Earlier research

4.2.1 Recognition of similar study

A study was made by Asbjørnsen, Hugdahl, and Hynd (1990) that in many ways resembles this study. We had no knowledge of their paper while conducting our study and would presumably have benefitted greatly from reviewing their ideas and results. Both studies used single response verbal listening tasks with headphones for studying differences in REA between head directions, while keeping the gaze straight in comparison to the body position. However, the method of controlling head direction differed, we used binaurally recorded CV-syllables sorted by VOT and presented *diotically* whereas they used *dichotic* stimuli with no consideration of VOT, and we tested our participants with directed attention.

4.2.2 Findings and conclusions

The effects of gaze and head position on the REA have been examined in earlier studies but the data has so far been notably inconclusive or even contradictory

(Asbjørnsen et al., 1990; Boliek, Obrzut, & Shaw, 1988; Dawe & Corballis, 1986). This may reflect fundamental theoretical misconceptions regarding the interplay of sensory processes, as well as methodological deficiencies. In the case of the former, Asbjørnsen et al. (1990) interpreted their data as evidence against the attentional view that had gained support since the 1970s. Comparing REA-scores generated from a standard dichotic listening test to REA-scores generated from dichotic listening tests with specific gaze and head instructions, they found no significant effect from either gaze direction nor head position and consequently assumed that attentional factors are, if anything, secondary to the structural elements of the REA. However, methodological concerns are still worth entertaining and the history of research surrounding the REA certainly suggests that experimental reliability could be improved upon. Possibly confounding elements have been identified, e.g. VOT, selective listening, etc., (see above and below) and the size of the REA is often inconsistent between studies (Hiscock & Kinsbourne, 2011). The typical prevalence of REA obtained from behavioural research, approximately 80 % (Hiscock, Cole, Benthall, Carlson, & Ricketts, 2000), also underestimates the actual prevalence of language lateralisation in the population, usually reported to be 95 – 99 % (Knecht et al., 2000; Corballis, 2014). Language lateralisation furthermore appears to be a matter of degree, rather than category, and there seems to be a strong linear correlation between degree of handedness and degree of lateralisation (Knecht et al., 2000) which could contribute to the discrepancy between clinical and behavioural data as well as the inconsistent sizes of REA found across studies.

The present study clearly failed to support its hypothesis in spite of changes made because of the methodological concerns specified above. Possible reasons for this are discussed in the following section.

4.3 Troubleshooting

4.3.1 Time and material

The nature of this study put considerable constraints on the time and resources available. Some factors were identified as possible sources of error early on but deemed to be outside of our immediate control. Firstly, in order to attain proper balancing, the test by necessity had to be somewhat taxing and we had limited means of incentivising the participants. This could impact test performances as well as the number of participants willing to participate. With this in consideration, a trade-off was made resulting in a relatively low number of stimulus presentations per head direction which contributes to higher than optimal variance. Secondly, since our aim was to study differences in REA, a preceding test, where participants showing a clear REA were selected for further testing, would have been preferable. We also lacked the time to properly test for hearing deficiencies and had to rely on participants' self-reported answers. Thirdly, the location of the experiment was suboptimal, chosen only as the best alternative, which led to a number of methodological concerns and compromises with regards to spatial asymmetries, disturbances, and stimulus presentation.

4.3.2 Stimulus fusion

The location of the experiment was not sufficiently sound-proofed. To combat disturbances, we decided on using closed headphones which unfortunately gave less distinct stereophonic positioning to the binaural recordings and presumably increased the degree of stimulus fusion. The degree to which competing stimuli fuse into a single percept impacts the participant's ability to assign location to the perceived sound. If the participant is asked to attend to one side of space, this stimulus fusion can introduce substantial variability to the data (Hiscock, Inch, & Kinsbourne, 1999).

Results from the ventriloquism study (Morais, 1975) lends further support to the notion that participants' ability to spatially differentiate sound sources affects the size of the REA. Our participants had no opportunity to perceive the possible locations of the stimuli sound sources before the test which might have rendered the competing CV-syllables harder to differentiate and increased the degree of stimulus fusion.

4.3.3 Stimulus dominance

The stimulus dominance within CV-pairs critically reduced the effective number of data points producing REA-values for each participant. For four participants, subject-specific stimulus dominance can explain 100 % of the data, however which syllables that were dominant varied between them. The stimulus dominance could in most cases likely be attenuated with individual calibration for each CV-pair, but stimulus dominance is still to be expected, as seen in the difference between table 1 and table 2, in some cases multiple calibration levels might be motivated.

4.3.4 Order of stimulus presentation

Although the difference in mean REA-scores between participants who initially listened to the left and participants who initially listened to the right were not statistically significant, such effects have been confirmed for digit stimuli (Hiscock and Stewart, 1984). Verbal priming effects on dichotic listening experiments with CV-stimuli have also been reported (Jäncke, 1994). Such priming effects should in our view be given some consideration and, if possible, be kept constant to avoid unnecessary variance in studies were REA is already established and only effects on REA are examined.

4.3.5 Additional factors

It is, of course, entirely possible that the hypothesised effect is non-existent, or so small that it is obscured by simultaneous mental processes. Aside from the possible confounding elements recounted thus far, the experiment may, in its present form, simply be too demanding and inducive to noise from unforeseen factors. One concern is that intruding activation from involved motor tasks is directionally biased and large enough to affect the data. The spatial task of directing a laser towards a target may also induce activation in the right hemisphere, which is generally associated with spatial orientation. This could reduce leftward activational asymmetry across all conditions, which would consequently reduce REA-scores according to activation-based models of verbal processing lateralisation.

4.4 Future research

Several improvements could be made for variations on this study.
With more focus on minimising the stimuli dominance within CV-pairs, pre-screenings to ensure balanced hearing and REA, more repetitions per controlled factor, bigger sample size and better controlled room. A controlled room would make versions of the test possible where three pairs of speakers could be used to compare REA between sounds from a point rotated in relation to the ears, but not to the perceived self direction, with sounds from a point rotated in relation to the ears and the perceived self direction.

5 Conclusion

The results of this study do not give support to our hypothesis that the REA is affected by the ears' position in relation to an integrated perceived direction, as the null hypothesis could not be rejected. A strong stimulus dominance and other methodological concerns made this study likely to commit a type II error. Lessons learned and collected in this report could be useful for students setting out to do related research.

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