Final report: Lateralisation of cognitive functions in the brain: Typical vs. atypical patterns. Reference 376/14.

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Project: Introduction and Aims

In this research project, we evaluated the functionality of the hemispheres for cognitive functions in individuals with different types of brain organisation. Moreover, we studied hemispheric lateralisation that captures the dominance of one cerebral hemisphere over the other for information processing. This is based on the argument that hemispheric lateralisation has advantages at the individual level because it increases brain efficiency, and at the population level as it facilitates social coordination and synergistic behaviours between individuals.

We studied typical and atypical lateralised individuals and their association with handedness preferences, i.e., right- and left-handers who differ in their use of processing mechanisms within as well as between hemispheres. In this respect, handedness is a distinct form of individual differences and hemispheric specialisation for hand movement control, with the left and right hemisphere hosting right- and left-handedness, respectively.

We investigated the processing resources of both hemispheres for tasks with different cognitive functions. We focussed on language, spatial attention and timing - core cognitive functions that underlie many everyday life activities.

Use was made of various neuropsychological tests to characterise the participants' behaviour such as cognitive performance measurements, self-report inventories and the visual half-field technique, which is a validated behavioural method that permits to selectively bias hemispheric processing. Accordingly, left visual field advantages can reveal right hemisphere specialisation whereas right field advantages are linked to left hemisphere specialisation. In addition to providing a reliable means to explore lateralised cognitive processing in each hemisphere, divided visual field studies can be used to investigate interactions between both cerebral hemispheres. The interactive aspect is relevant in order to uncover the mechanisms that steer sharing of information resources across the hemispheres.

The research aims of the project were to (1) to study the brain's processing abilities in individuals with typical and atypical lateralisation; (2) to determine the effect of hemispheric asymmetries on cognitive performance.

Study 1

Introduction and Methods

In a first study, we assessed the processing of time**,** which is a fundamental dimension of our behaviour and plays an essential role in guiding our everyday activities. In particular, time is important for motor skills but also in the context of time perception by which we structure our mental time experiences such as keeping appointments. To this purpose, we used in this work two complementary approaches: (1) questionnaires that enabled participants to rate their abilities and preferences; (2) experimental tasks that provided behavioural accuracy and consistency performance data. In particular, we examined how participants performed a range of experimental assignments that involved timed manual responses during externally-paced motor tasks (which included no time shifts, subliminal time shifts = are not noticed consciously, or supraliminal time shifts = are noticed consciously) and internally-paced tasks (which included preferred movement rate and maximum movement rate). In addition, we evaluated how participants mentally experienced the duration of time intervals (which included internally generating interval durations, and identifying when they thought the time had lapsed).

Results and Discussion

The results of this study showed that behaviour of the participants was influenced by the time-shift perturbations of the externally-paced motor tasks. In particular, their timed responses were similar during the no and subliminal perturbation conditions (requiring behavioural stability) whereas they deviated during the supraliminal perturbation conditions (requiring behavioural flexibility). However, noteworthy is that we observed that left- and right-handers differed in their ability to deal with the supraliminal perturbations. In particular, left-handers as compared to right-handers showed an enhanced degree of adaptability in managing the perturbations, suggesting enhanced cognitive flexibility in these situations. Thus, handedness guides motor control abilities in contextual situations that particularly necessitate cognitive intervention, which is in line with the dynamic nature of lateralised brain functions and the expression of dominance in skill use (Serrien et al. 2006, Nature Neuroscience Reviews 7, 160-166).

The findings from this study further showed that there were no group differences when the participants moved at preferred motor rate, or, mentally experienced time intervals. This suggests that these behaviours are guided by general processing abilities. The latter premise is supported by our result that the adopted preferred movement rate positively correlated with the time perception tasks across left- and right-handers. Such stability of an individual's timing ability suggests the existence of common mechanisms across domain for the processing of interval durations. Therefore, cross-domain coupling of timing abilities occurs when there is reliance on rates that are spontaneously adopted for motor behaviour and for those we perceive. In particular, both timing skills can be considered as counterparts that share an intrinsic (preferred) timescale and that take advantage of interwoven domain-general mechanisms in order to support behaviour. We further

observed a relationship between perceived interval duration and sense of the passage of time as assessed by questionnaires, which underlines a translation between measurements of internalised timekeeping.

Conclusion

Overall, our results highlight that individual factors through domain-general and domain-specific levels of organisation play a steering role in how one predicts, perceives and experiences time, which accordingly impacts on cognition and behaviour.

Study 2

Introduction and Methods

In a second study, we examined hemispheric functioning of two vital cognitive functions; language (lexical decision making of words) and spatial attention (landmark; judging whether or not a presented line is correctly bisected), which are argued to be asymmetrically distributed in the brain, i.e., language to the left side and spatial attention to the right side. The processing demands of both functions were evaluated by means of a careful presentation of target stimuli to the left or right visual field. The design of our study was implemented within a manual reaction time experiment, and the participants were required to respond when they recognised the target stimulus using bimanual responses in order to avoid stimulus-response compatibility effects.

In this work, we further examined complementarity of both functions. As left-hemispheric dominance for language and right-hemispheric dominance for spatial attention are present in the general population, it raises the question whether a relationship exists between both asymmetries. In this respect, research has investigated whether the complementary specialisation is due to a causal origin (the lateralisation of one function causes the opposite lateralisation of the other) or represents a statistical phenomenon (different functions lateralise independently). In the case of causal complementarity, a correlation exists between both functions as greater left-hemispheric dominance for language results in greater right-hemispheric dominance for spatial attention, whereas no correlation is evidence of a statistical origin as the functions would be largely statistically independent. Previous studies have provided evidence for both hypotheses.

Results and Discussion

Our results revealed that word processing was more accurate when presented in the right visual field (or left hemisphere) than left visual field (or right hemisphere), irrespective of word category and handedness group. This finding confirms the efficacy of left-lateralised mechanisms for word understanding. However, additional analysis highlighted that right-handers had stronger left-hemispheric proficiency than left-handers, suggesting that they have increased efficacy for the processing of verbal stimuli in the left than right hemisphere. Conversely, the left-handers showed a more mixed hemispheric proficiency balance, which can be due to a reduced right visual field

advantage, or, a lack of processing differences between both visual fields. Detailed analysis revealed that the majority of the right-handers demonstrated the typical profile of left-hemispheric lateralisation whereas a more balanced hemispheric pattern was noticed across the left-handers. That left-handers have a more equivalent language distribution involving both hemispheres, suggests that left-handers have different language functionality than right-handers.

For the spatial attention task, left- and right-handers differed in their accuracy profiles. Moreover, the findings denoted distinct processing advantages for both handedness groups, with right-handers showing a profile with preferred lateralisation to the right hemisphere and left-handers exhibiting a more bilateral pattern with shared functionality. The results suggest that the right hemisphere controls spatial tasks in right-handers whereas there is no hemispheric superiority in left-handers. Detailed analysis demonstrated that the majority of the right-handers showed typical right-hemispheric lateralisation whereas a more equivalent profile that involved both hemispheres was noted for the left-handers.

We also examined the complementary association of both language and spatial attention functions and observed that the relationship underlies processing efficiency of the respective dominant hemispheres (i.e., left hemisphere for language and right hemisphere for spatial attention); a pattern that was significant for the right-handers such that stronger left-hemispheric lateralisation for language coupled with stronger right-hemispheric lateralisation for spatial attention. This suggests that particular characteristics of information processing preferentially operate across hemispheres and cognitive domains. However, the data also showed atypical lateralisation patterns, including a combination that involved lateralisation of both language and spatial attention to the right hemisphere; a profile that was robustly observed for the left-handers. This observation again points to an increased role of the right hemisphere, resulting in a more dispersed language distribution across the hemispheres, for the left-handers. Accordingly, the results highlight that typical lateralisation is most prevalent for right-handers whereas atypical lateralisation is most apparent for left-handers.

Conclusion

Overall, our findings underline individual differences due to handedness as left- and right-handers showed distinctive responses in the language and spatial attention tasks. That is, whereas right-handers showed pronounced hemispheric lateralisation for both core functions, left-handers demonstrated reduced lateralisation, or, a bilateral distribution across hemispheres, suggesting a less defined organisation profile. Therefore, the mechanisms that guide handedness and the underlying brain asymmetries steer the behavioural outcomes as a function of the cognitive function involved.

The data from study 1 and 2 presented above have already been finalised and published. Alongside, we have conducted additional studies, building on our previous work: (1) to examine further how left- and right-handers dynamically balance the requirement of stability and flexibility of goal-directed behaviour in a changing environment, (2) to assess further the processing of cognitive functions of left- and right-handers during various processing stages, with a focus on the processing of language and spatial attention.

(1) We have run experiment that examined the processing of a target stimulus alongside prime/distractor stimuli, creating cognitive stability (to maintain existing goals over time) and cognitive flexibility (to update and switch goals in response to environmental demands). We used different task paradigms to assess cognitive stability (task performance in the presence of distractors) and cognitive flexibility (switching between task rules). This approach enabled us to study the opposite processing requirements of both control modes on behavioural performance, in line with the argument that adaptive behaviour requires a dynamic, context-dependent balance between maintaining and switching task rules. Our preliminary findings showed that individuals differ in their cognitive control functions of stability and flexibility. In particular, we noted that individual differences bias the cognitive system to one or the other control mode, i.e., maintaining the current task or switching to a new task. That is, left- and right-handers showed opposite trends with respect to the stability-flexibility balance, with left-handers demonstrating increased flexibility as opposed to stability of performance. The findings suggest that the coupling between these control modes depends on individual meta-control parameters that are driven by handedness and that regulate global features of information processing and cognitive control of behaviour.

(2) We have run experiments that investigated how the processing demands of target stimuli are affected by simultaneously presented prime and distractor stimuli. This approach enabled us to examine effects of interference and facilitation at the intrahemispheric as well as interhemispheric level. Our preliminary observations showed that the processing power of the brain is modified when interhemispheric interactions are promoted. We observed differences between unilateral and bilateral target presentations with distinct visual field differences in the latter performance conditions. It further indicates that bilateral compared to unilateral presentations reflect an optimal way to measure cerebral asymmetries as it influences hemispheric asymmetries, likely due to interhemispheric competition induced by two simultaneously presented stimuli or the control of attentional bias. The particular effects were more pronounced for language than for spatial processing, which indicates that the strength of lateralised processing is more dominant and engrained for language than for spatial functions. The observations indicate rich interhemispheric interactions that are driven by transcallosal pathways, and further point to an asymmetry in the transfer of information between the left and the right hemisphere for language and spatial functions. We further noted that left- and right-handers differed in their processing ability of

information, with right-handers being more influenced by the combined processing demands, suggesting that handedness guides intra- as well as interhemispheric processing.

The data analyses of the non-published work is being finalised and findings will be written-up and submitted for publication accordingly.

Discussion

Overall, our results show that mechanisms within and between hemispheres play a primary role in steering how we selectively process target stimuli. Furthermore, these processing mechanisms are specifically influenced by handedness, indicating distinct brain dynamics that drive information processing, not only within hemisphere but also from one hemisphere to another and as such interhemispheric communication.

Overall conclusion

The findings from the project support our hypothesis that handedness is an influential factor in guiding brain processing mechanisms. In particular, left-handedness underlies between-subject variability for the processing of core cognitive functions, including a less focal or a more distributed pattern that tends to facilitate flexibility of information processing. This is in line with the assumption that the two hemispheres operate in a more integrative way with greater interhemispheric communication in left- as compared to right-handers who rely more on the functioning of two independent hemispheres with stronger hemispheric lateralisation and asymmetries between hemispheres. In particular, typical lateralisation is most prevalent for right-handers whereas atypical lateralisation is more evident for left-handers. The findings accordingly illustrate individual diversity that associates with a dynamic account of brain organisation and underlines the brain's plasticity for the processing of goal-directed behaviour. Thus, the study of handedness allows us to better understand the behavioural variance and neural mechanisms related to changes in cerebral dominance, which is important for addressing potential rehabilitation and intervention strategies. A careful assessment of handedness for clinical purposes is important as the factor drives neural and behavioural functioning. This is the more important as throughout our experiments, we observed individuals with converted handedness due to an early and persistent environmental change; that is, individuals who were initially left-handed but switched hand use due to social expectancies. These individuals overall would have converted to right handedness for writing skills but maintained left handedness for other skilled manual activities. We also observed a family history of left handedness in left handers, which underscores the relevance of genetic factors to the individual manifestations of handedness. Taken together, the results underline that handedness distinctively modulates hemispheric processing and behavioural performance during cognitive tasks, and represents a key marker of functional lateralisation.

Significance

The conducted work has used a comprehensive approach for studying the functionality of both hemispheres within the healthy population. Moreover, increased insights into the brain's lateralisation patterns and relationships with handedness and cognition were put forward, increasing our understanding of the factors that affect heterogeneity of behaviour. The current findings have consistently shown that individual differences guided by handedness are an important basis of distinct cognitive control mechanisms. The results of our research work can be used as a foundation for future research initiatives.

Outcomes

Results from our research work have been published:

- O'Regan L, Serrien DJ (2018). Individual differences and hemispheric asymmetries for language and spatial attention. Frontiers in Human Neuroscience, 12, 380.
- O'Regan L, Spapé MM, Serrien DJ (2017). Motor timing and covariation with time perception: Investigating the role of handedness. Frontiers in Behavioral Neuroscience, 11, 147.

The produced research outputs have been published in open-access format, providing wide opportunity for the research community to access the papers, free of cost or any other embargo barriers. Specialised funding to cover the processing costs of the papers was obtained.

Findings from our research work have been presented at National and European conferences:

- O'Regan L, Serrien DJ (2018). Interhemispheric interactions during language processing: effects of handedness. 6th North Sea Laterality International meeting, Dundee, UK.
- O'Regan L, Serrien DJ (2018). Are pairs of identical stimuli processed more efficiently between or within the cerebral hemispheres? PG conference at the University of Nottingham, Nottingham, UK.
- O'Regan L, Spapé MM, Serrien DJ (2017). Motor experience and its impact on cognitive flexibility. 20th Conference of the European Society for Cognitive Psychology (ESCOP), Podsdam, Germany.
- O'Regan L, Serrien DJ (2017). Lateralisation of language and spatial functions in left- and right-handed individuals: a divided visual field study. PG conference at the University of Nottingham, Nottingham, UK.
- O'Regan L, Serrien DJ (2016). Lateralisation of cognitive functions: a behavioural study. PG conference at the University of Nottingham, Nottingham, UK.

Support of PhD studentship

- The research project supported a PhD student, which provided a post-graduate opportunity and training of a future researcher. The PhD student was offered all the post-graduate resources that are available at the School of Psychology.