How have neuropsychological patient studies contributed to the understanding of brain lesion effects on behaviour?

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**Abstract**

Neuropsychology is the study of behavioural and cognitive deficits in patients with brain lesions, comparing task performance between healthy controls and those with brain damage to infer the link between brain anatomy and behaviour. The discipline’s three most popular tools – association, dissociation, and double dissociation studies – have yielded a vast amount of valuable experimental and clinical insight for neuroscience’s understanding of the brain-behaviour connection. Here, specific contributions from each type of study are discussed in relation to the diagnosis and treatment of three neuropsychological impairments – Bálint’s syndrome, visual form agnosia, and aphasia. The inherent limitations of neuropsychology as a discipline are considered, including the problem of low generalizability, the debatable fractionation assumption, poor temporal resolution and its relative obsolescence in comparison to contemporary brain imaging techniques. It is concluded that the combined approach of converging traditional neuropsychological techniques with modern neuroimaging methods, is most efficient at providing insight on brain function and localisation, leading to brain-behaviour conclusions that would be impossible to discover using solely patient studies.

Keywords: Neuropsychology; Neuroscience; Brain; Behaviour; Lesions; Associations, Dissociations, Double Dissociations

**Background**

Neuropsychology is a branch of cognitive neuroscience that is of critical value for relating brain anatomy to behaviour and rests on the assumption that all behaviour is mediated by the brain, i.e. the brain hypothesis (Heilman & Valenstein, 2003). It often involves the study of patients with brain lesions and compares task performance between patients with brain damage and healthy controls.

Firstly, association studies in neuropsychology show how damage to a brain region results in multiple neuropsychological deficits that impact behaviour. Here neuropsychological deficits act in a syndrome, meaning that a set of symptoms act in a typical combination due to a single cause. In association studies, the patient shows impaired performance in task X, but unimpaired performance in task Y, suggesting that the two impairments are associated as they both affect the same person (Coltheart, 2015). Association studies have been used in research on Bálint’s syndrome – a neuropsychological impairment caused by bilateral lesions to the parieto-occipital junction.

In addition to associations, neuropsychology investigates single dissociations, leading to an improved understanding of how damage to a region leads to impaired performance in one task but unimpaired performance in another. According to this neuropsychological approach, difficulty in one task parallel to an absence of difficulty in a different task signifies that the two behaviours are controlled by domains independent of each
other (Ward, 2019). Single dissociation studies have been used in research on visual form agnosia, characterized by a deficit in visual object recognition, following a ventrolateral occipital lesion.

Lastly, neuropsychology incorporates double dissociation studies which require the presence of two patients – one of which is impaired in task X but shows unimpaired performance in task Y and one patient who is impaired in task Y but unimpaired in task X (Coltheart, 2015). When the dissociation between two patients is reversed, it becomes a double dissociation. This neuropsychological approach can be utilized in the comparison of two language disorders: Broca’s aphasia and Wernicke’s aphasia.

This essay explores the valuable clinical contributions of three types of neuropsychological patient studies: associations (Bálint’s syndrome), dissociations (visual form agnosia), and double dissociations (aphasia) (Coltheart, 2015). The limitations and strengths of neuropsychology are discussed, showing how it is a methodological, though slightly outdated, powerhouse in its contribution to neuroscience’s understanding of the brain-behaviour connection.

Discussion

Association studies help neuropsychologists achieve the brain-behaviour-related subgoal of mapping behavioural deficits to damaged regions and thus finding a causal relationship, possibly leading to the creation of new treatments. Association studies can be used in the clinical investigation of Bálint’s syndrome, which is characterized by the following behavioural symptoms: simultanagnosia (inability to perceive more than one object at the same time, i.e. object-based neglect), oculomotor apraxia (inability to make eye movements), and optic ataxia (inability to reach accurately towards a perceived target) (Rafal, 2001). For example, patient RX displayed signs of simultanagnosia, as he could only see the ruler or the comb, but not both objects when they were shown concurrently. The association study of Bálint’s syndrome demonstrates the link between brain anatomy and behaviour by illustrating how damage to the parieto-occipital brain region leads to impairments in spatial attention and the processing of visual information.

This association study on Bálint’s syndrome (among others) has had important implications for research purposes, as well as for clinical settings. It has proven valuable in visual attention clinical studies – simultanagnosia that occurred independently of location showed major support for the object-based model, suggesting that visual attention acts by selecting objects and not necessarily locations (Rafal, 2001). Although insufficient research has been conducted on the treatment of Bálint’s syndrome and it must be an area of investigation in the future, the available approaches propose that a certain degree of rehabilitation for Bálint patients exists (Heutink et al., 2018). Currently, the most effective method is restorative training aiming to develop and advance a particular cognitive function by exercising it continuously and repetitively over time. This restorative training method shows how association studies not only contribute to the comprehension of the brain-behaviour dynamic but also offer useful guidance for clinicians regarding patients’ ability to lead normal lives in spite of their impairment. One might assume that the tasks assessing simultanagnosia, oculomotor apraxia and optic ataxia all require the same neural circuit that is damaged, but this might not necessarily be the case. An alternative approach is that separate functional regions are responsible for each of these symptoms, and they are anatomically proximal to each
other, making it impossible for only one of them to be damaged (Coltheart, 2015).

In terms of single dissociation studies, visual form agnosia is a popular topic of research, as the ventrolateral occipital lesion impairs vision for object recognition but not for visuomotor skills (i.e. guiding movements), showing an action-perception dissociation (Ganel & Goodale, 2019). Neuropsychological and behavioural investigations of this on patient DF showed that she was in control of hand movements during reaching and could easily grasp tools (no sign of optic ataxia) but could not recognise any shape primitives and had problems visually selecting and grasping the target part of the object in order to use it (Milner et al., 1991; Carey et al., 1996). By utilizing current knowledge on action-perception dissociation, clinicians are able to accurately diagnose agnosias and discern agnosias from aphasias and other cognitive impairments, resulting in quicker and more effective rehabilitation and clinical treatment (Burns, 2015).

From cognitive impairment research, one could infer that the differences in behavioural tasks occur because the tasks are dependent on separate neuronal networks, e.g., vision for action is linked with the dorsal stream and vision for movement is linked with the ventral stream. However, an alternative explanation could be that both tasks are linked with the same neuronal network, but one task (in this case, recognising shape primitives) uses more neural resources (Ward, 2019). The task-resource artifact suggests that if the brain lesion diminishes this particular resource, then the task might be more challenging (Shallice, 1988; Ward, 2019).

It can be argued that double dissociation studies in neuropsychology are more valuable in drawing inferences about cognitive functions and behaviour than single dissociations. Therefore, they contribute significantly more to neuroscience’s understanding of how brain lesions affect behaviour. As mentioned in the “Background”, double dissociations are frequently used in the comparison between Broca’s aphasia and Wernicke’s aphasia. Broca’s aphasia (non-fluent aphasia) is a disorder of language production caused by a lesion of the inferior frontal gyrus, which is associated with difficulty in processing syntactic knowledge (Shankweiler et al., 1989), agrammatic speech and speech apraxia (difficulty speaking). These impairments result in low speech rate and poor performance on sentence repetition – both of which are deficits characteristic of Broca’s aphasia (Kolk & Heeschen, 2007). This is seen in patient Tan, Broca’s patient, who could only say the word “Tan” but could comprehend what others would say to him, showing how a frontal lobe lesion disrupted language production, but left language comprehension unimpaired. On the other hand, Wernicke’s aphasia is a disorder of language comprehension typically caused by a lesion in the superior temporal gyrus of the left hemisphere, resulting in speech characterized by paraphasias, neologisms, and incorrect use of grammar when speaking and reading out loud (Ellis et al., 1983). However, unlike Broca’s aphasia, language production is unimpaired.

From this double dissociation, it can be deduced that there are separate cognitive modules responsible for language production and language comprehension. One patient has damage to the language production module and the other has damage to the language comprehension module. This notion of brain modularity is supported by modern advances in brain imaging. Electroencephalography, as well as structural and functional MRI studies, have suggested that cognitive modules are functionally specialized, as neurons connect together when they process similar kinds of
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Information (Ward, 2019; Bullmore & Sporns, 2009). These methods are more popular than dissociation studies, as they refute the task-resource artifact found in single dissociations. The assumption that the dissociation found in Broca’s aphasia occurs due to a single language cognitive module, which finds language production more difficult than language comprehension, has been discounted, because in Wernicke’s aphasia, language comprehension is more challenging (Coltheart, 2015).

Neuropsychology is one of the most well-established methods in neuroscience (Vaidya et al., 2020) and has had significant contributions to the field’s knowledge on the causal effect of brain lesions on behaviour through the study of associations, dissociations, and double dissociations. In addition to this, neuropsychological lesion studies possess high ecological validity, as they allow scientists to connect experimental neuroscience with real-world behaviours by investigating the behaviour of people with brain lesions in naturalistic settings. An example of this is the semi-naturalistic Multiple Errands Test (MET), a strategy application task which was given to participants with damage to the VPMC sector (frontal lobe) and that simulated real world tasks, such as shopping for objects in a mall under different constraints (Vaidya et al., 2020). These tasks involved the process of planning which is hypothesized to be linked to the frontal lobe. Results showed that participants’ lesions in the VPMC sector showed significantly poorer performance compared to healthy controls, revealing executive performance errors in planning (Shallice & Burgess, 1991; Dawson et al., 2009). This semi-naturalistic experiment shows that successful behavioural navigation is connected to the VPMC region (Tranel et al., 2007), further supporting the brain hypothesis that the brain mediates behaviour. These conclusions about brain lesion effects in real world functioning would have been difficult to achieve in a more laboratory setting, using solely neuroimaging methods.

Despite patient studies’ historic value and critical effect on the understanding of behavioural deficits, it is flawed as a technique and its limitations must be considered when evaluating its contribution to neuroscience. Firstly, group studies are particularly difficult to conduct due to variability in the location and size of lesions. As described by Buxbaum (2006), “each patient might be as unique as a snowflake,” which implies that it is challenging to find a group of patients with the exact same lesions without having to use spatial normalization across the group, which can lead to inappropriate solutions and decrease anatomical precision (Crinion et al., 2007). The uniqueness of patient studies makes it particularly difficult to generalize the effects of specific brain lesions on behaviour. Single case studies are frequently used in the field because it is argued that individuals represent the general population which allows researchers to generalise findings to normal cognition (Ward, 2019). However, it is argued that single case studies are the only appropriate method to use in neuropsychology (Caramazza & McCloskey, 1988). Here within-patient replicability is of more use than across-patient replicability (Coltheart, 2015). Nevertheless, an inevitable limitation of this technique is its low generalizability, as humans are idiosyncratically different from one another and it is experimentally impossible to replicate brain lesions (Adolphs, 2006).

Furthermore, neuropsychology suffers from the modality assumption which claims that discrete cognitive modules in the brain are associated with different cognitive functions (Rorden & Kannath, 2004), in practice meaning that damage to one region does not alter the function of other brain areas. This idea rests on the fractionation
assumption: damage to the brain results in independent and cognitive impairments (Ward, 2019). Although this assumption is true at one level, as selective cognitive deficits have been found in the past, it is not entirely empirically valid. Research on visual imagery has proposed that selectivity in cognitive deficits is dependent on neuronal architecture, so it is more likely to occur if neurons are grouped together, as opposed to being spaced out during an operation (Ward, 2019; Kosslyn et al., 1990). Moreover, evidence suggests that the brain is not domain-specific and its regions operate distributionally and plastically as opposed to being mapped to only one function. The fractionation assumption is also challenged by the brain’s neuroplasticity, so its ability to change and reorganize its structure and functions in different situations (Cramer et al., 2011). Miller (2000) found that behaviour adaptation in neurons in the prefrontal cortex is dependent on task demands (Rorden & Kannath, 2004), making it inherently difficult to map behaviour to specific brain regions.

Moreover, lesion studies possess low temporal resolution, as researchers are unable to appraise the lapse of time of informational processing given that brain injuries are permanent from their onset and no activation sequences can be recorded (Rorden & Kannath, 2004). Other brain imaging methods, such as fMRI, can measure blood flow in seconds, offering higher temporal resolution than lesion studies. Neuroimaging techniques also display every neural network that is activated during a specific behaviour and the simplicity of the fMRI in its ability to connect blood flow patterns to behaviour, is an attractive concept. The flaws of neuropsychology and advantages of new methods have led to the belief that patient/lesion studies are outdated in the field of neuroscience and pale in comparison to new technological advancements that are more efficient at studying the link between human neural activity and psychological processes.

Although neuropsychology is admittedly limited in its explanatory power, this does not mean that modern neuroscience techniques are faultless. The greatest good can be yielded by using different techniques to tackle the same theoretical question. Neuropsychology’s leverage over fMRI, for example, is that it shows a necessary causality of brain functions on behaviour, not just a mere correlation between neuronal activity and psychological processes which possess heavy inferential limits (Adolphs, 2016). By investigating the effect of brain damage on neuronal activity, it is possible to find the causality of lesions of specific cortical regions to the processes found in other regions, possibly combating the modality assumption (Vaidya et al., 2019). This is illustrated in an fMRI study on patients with vMPFC lesions which showed that this lesion led to reduced ventral striatum activity when the patient was anticipating a monetary reward (Vaidya et al., 2019; Pujara et al., 2016). In addition, the conjunction of neuropsychology with other methods could compensate for neuropsychology’s poor temporal resolution and provide more insight into the architecture of the mind. For example, the blindsight phenomenon was investigated by lesioning the primary visual cortex (V1) of monkeys and then using fMRI to study its effect on extrageniculostriate pathways (Schmid et al., 2009). Because brain imaging methods usually provide higher temporal resolution, researchers are able to extract beneficial clinical inferences about the compensation of impairments and how to gradually resolve them (Adolphs et al., 2016).

In conclusion, neuropsychology has contributed to the understanding of brain lesion effects on behaviour by studying associations, dissociations, and double dissociations that have yielded important
experimental and clinical insights about the brain-behaviour connection and have contributed to the development of rehabilitation for neurological disorders. However, this field is also theoretically flawed and potentially antiquated in an age of new brain imaging developments. For neuropsychology to develop as a discipline, it should be used in conjunction with other neuroscience techniques, merging the classic and modern together. This convergence of methods would help advance the field’s understanding of the link between brain function and behaviour.

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