Functions of dorsal and ventral visual processing streams

Visual process is the capability to generate, perceive, analyse, synthesise, manipulate, transform and think with spatial patterns and stimuli (WISC–IV - 2008). Visual processing poses a huge computational challenge for the brain. The brain has evolved to well-ordered and effective neural systems to reach the demands. Over the past many years, in order to understand this neural system and complicated pathway, immense research has been done (Prasad & Galetta, 2011). Research suggests that, visual processing undertakes two fundamental objectives; to identify the visual stimuli and its location. Originally these objectives are known as " what" and " where" (Ungerleider & Mishkin, 1982). Whereas currently, terms such as " what" and " how" or " form and " motion" perception (Klaver et al., 2011) are used to objectify the functions of the two streams. The in-depth insight of the anatomy of the visual system along with skilled examination, recognizes the specific localization of the neuropathological processes. Moreover, these findings help in efficient diagnosis and treatment of visual processing, neuro-ophthalmic or neuropsychological disorders. There have been decades of research from a variety of sources like physiological studies in monkeys, neurophysiology, neuropsychology, neuroimaging and behavioural psychophysics to determine and describe functions of the two visual processing streams (for review see, Creem et al., 2001; Freud et al., 2016; Goodale et al., 2005; Milner & Goodale, 1995). The current essay will evaluate non-primate and neuropsychological patients' studies to discuss the functions of both visual processing streams.

In 1975, Mountcastle worked with 11 monkeys to report behavioural difficulties that are noticed in humans and monkeys with lesions of the posterior parietal lobe. It was suggested that various different types of neurons in the dorsal stream of the monkey were activated while the monkeys were performing a specific visually guided act (Mountcastle et al., 1975). Several class neurons were noted to be active when the monkey reached the object, while others were active when there was saccadic eye movement to the object. Neuronal activity was also noted when the monkeys seek after a target in motion. Since the neuronal activity seemed to be in relation with the location of the target, therefore the interpretation of this study helped in the future reflection of the where function of the dorsal stream (Ungerleider & Mishkin, 1982).

What and where

Research demonstrates that the two objectives are accomplished by two independent anatomical systems (Ungerleider & Mishkin, 1982) from primary visual cortex (V1) known as the *Ventral* (what) visual processing stream which extends into the inferior temporal lobe and the *Dorsal* (where, how) visual processing stream which extends into the parietal lobe (Goodale & Milner, 1992). This stream existence was proposed from a monkey study, wherein lesions found within the ventral stream correlated with a decline in the monkey's ability to identify stimuli/object. A lesion in the dorsal stream was correlated with declined spatial localization (Ungerleider & Mishkin, 1982). This is when the terms ' what and ' where' became popular. Similar evidence of independent streams was noted in lower vertebrates, frogs and gerbils (Goodale, 1983). Resembling dissociations were noted in studies on humans by measuring the PET scan activity (Haxby et al., 1994). It confirmed the functional difference between two pathways while participants performed object recognition and spatial location task. It suggested that occipitotemporal region, a part of the ventral pathway associated with the face recognition, while the occipitoparietal region, part of the dorsal pathway correlated with the spatial location. Additionally, the ventral and dorsal stream was also activated for the face and spatial location task respectively. These results suggest the presence of two independent functional and anatomical visual processing streams in humans just as the monkeys. Another study depicted a double dissociation of visual recognition (face perception concealed with shadows) and visuospatial performance (maze learning) in two participants having lesions in the occipitotemporal and occipitoparietal cortex respectively. This was confirmed by a post-mortem examination (Newcombe et al., 1987)

The existence of two streams was proven from the monkey study, however it was argued that there is notable difference between the human and monkey brain and the functional cortical area would not be noted in the same locations (Schenk & McIntosh, 2010). The visual modality is notably more developed in primates and it holds a great amount. Around 50% of cerebral cortex in macaque and about 20-30% in humans is adhered to visual processing (Van Essen, 2004).

How and where

The key observations of the two streams and their functional differences of the two visual streams was observed on patient DF in the 1990's. Patient DF developed severe visual agnosia due to carbon monoxide poisoning resulting large bilateral lesions in her lateral occipital cortex (Goodale et al., 1991) and small bilateral lesions to her superior parietal occipital cortex (James et al., 2003). She had difficulty in object recognition based on the form, to an extent that she could not differentiate simple geometric shapes for example square and circle. Additionally, she also faced difficulty in object orientation. Despite DF lacked the ability to describe or demonstrate the orientation of a line or a slot, she was still capable to reach and post a card in the same slot with no mistakes. Additionally, even though she was not capable of gauging the width of a square block, she could adjust her hand grip size before picking it up. With these explorations, the dorsal streams function was adapted to ‘ how’ from ‘ where’ (Goodale & Milner, 1992). She was also capable to recognize objects from their characteristics like colour and surface features (Humphrey et al., 1994; Milner et al., 1991). This suggested that even though she had a profound problem in object recognition, she used visual cue to guide her movements. This leads to conclusion that DF’s the perceptual difficulty can be attributed to the severely damaged ventral stream whereas, the exempted visuomotor skills could be due to a functionally spared dorsal stream.

Perception and action

Recently an fMRI study, building on patient DF past research, helped understand the detailed perspective supporting the above study (Goodale et al., 2003). The study reported that anatomical MR images depicted the lateral occipital cortex (LOC) a part of the ventral stream, was acutely damaged causing difficulty in object recognition. There was no activation in different areas or the surrounding cortex when a comparison of activation was done with the line drawings of the object and the disintegrated version of the same drawing. Furthermore, activation was noted in the anterior intraparietal sulcus (AIP), a part of the dorsal stream, while DF held various objects in size and orientation. These results modify the previous model (Goodale & Milner, 1992) yet support the hypothesis of two separate visual processing streams i. e. one for visual perception (what) and other for visual control of action (how). Therefore, in the new ‘ perception/action’ model, the function of the ventral visual processing stream remains unchanged. However, the dorsal processing stream’s functions change. The visual information is processed by the ventral stream for visual perception (vision of perception). Meanwhile the dorsal stream processes visual information with the aim of movement implementation (vision of action) (Milner & Goodale, 2008; Sheth & Young, 2016). However. DF’s spared visuomotor abilities were challenged by (Schenk, 2012). It was argued that the visually guided ability could be due to haptic sensory information to compensate for impaired size-vision. This was tested using a mirror apparatus to form a dissociation of the image from the physical presence. The results suggested that DF’s performance was better when haptic feedback was provided in comparison to haptic feedback not being provided. This indicated that visuomotor control could possibly under the control of dorsal pathway where the stimulus condition of the study arises from multisensory interactions (Sheth & Young, 2016).

In the condition of optic ataxia (Bálint, 1909) wherein there is bilateral damage to the parietal lobes, patients faced issues in performing spatially accurate reach but are also face difficulties in wrist rotation. While trying to hold an object of different size or orientation, they faced difficulty in the configuring the hand beforehand. However, they were capable to report the spatial location of the objects around themselves and how the objects looked (Jeannerod, 1997). This suggests that there was damage to the dorsal pathway whereas the ventral pathway remained intact. This case was in contrast of patient DF.

Studies suggest that even though the ventral stream is mainly responsible for processing spatial details and high resolution visual features, it is now self-responsible for object recognition. The dorsal pathway also takes part in object recognition, not generally but in a few different situations for example, when the stimulus is unique or different in a manner. Object selective responses have been noted in the cortical areas of the dorsal pathway for objects with and without a semantic context (Konen & Kastner, 2008). The cortical region of the dorsal stream has been noted to be reactive to the feature of the stimuli which is to be monitored in the ventral stream. For example, in shape selectivity task, it was noticed that neurons of lateral intraparietal area in the dorsal stream were active of the monkey cortex (Sereno & Maunsell, 1998), transformation-invariant object selective response in the dorsal stream of human cortex (Konen & Kastner, 2008). Dorsal area also showed activation in the monkey cortex when there was a colour selection response task while the colour directed the eye movements (Toth & Assad, 2002) while in humans, colour discrimination caused dorsal area activation (Claeys et al., 2004).

Object recognition

Patient RV (Goodale et al., 1994) was capable of visual object discrimination, however she could not use this visual information to help herself place the finger on the circumference of oddly shaped object when instructed to hold them. Dorsal simultanagnosia is a condition wherein the bilateral parieto-occipital lesions have an impact on the dorsal stream. In this condition, patients are capable of object recognition but are not capable of viewing multiple objects at a time and the attentional impairment is affected by the object boundary. An exception being when the objects are small, spatially close and foveal (Luria, 1959; Humphreys & Riddoch, 1993). This suggest the role of dorsal stream in particular manner of object recognition especially for the blend of figure and background typically for the visual periphery. Furthermore, in this condition deficits in spatial vision as well as spatial attention has also been noted (Sheth & Young., 2016). The what/where model interpretation of the two visual pathways began facing issues. It is noted that the ventral pathway is not solely functional for vision only, it also undertakes the processing of visual features. However, ventral pathway is not only responsible for object recognition, the dorsal stream plays a role in it too. Dorsal pathway undertakes object recognition in a few conditions and also bares the responsibility of spatial vision and spatial attention. It can be noted from Ungerleider and Misjkin, 1982, in the study of parietal lesion in monkey where they suggest “... contralateral neglect of auditory and tactile as well as visual stimuli…” it is considered more included in the spatial attention than the visual attention (Lynch & McLaren, 1989; Sheth & Young, 2016).

There are few points to consider as we build our knowledge and understanding of the two visual processing streams from all the studies conducted. In majority of the studies, it is important to consider the celebratory patient DF’s study contribution, results and contributions in shaping the segregation and understanding of the two visual processing pathways. However, constructing the understanding of the visual processing world on data obtained from only one patient DF and a few other neurological cased could possibly affect the reliability of this hypothesis and understanding, for example, Mr. S suffered from visual agnosia, the same condition as patient DF, due to carbon monoxide poisoning from faulty water heater while having a shower (Efron, 1968). While Mr. S and patient DF shared the same difficulties in visual processing, Mr. S was not as extensively studied over time as patient DF. Further, testable alternative hypothesis which reports the data inconsistent with the action and perception model need to be presented (Westwood et al., 2002). Another factor to note with regards to patient DF is during the fMRI study (James et al., 2003) it was noticed that there was a considerable reduced cortical thickness in the posterior intraparietal sulcus of both hemispheres (Bridge et al., 2013). However, a cortical area majorly suggests optic ataxia. However, these suggestive findings have not been verified. If these claims were to be confirmed, then it would suggest that DF was no more a study of pure ventral pathway damage (Hesse et al., 2014).

The present view of the visual processing systems is noted by the functional and anatomical difference between the ventral pathway specializing in perception and the dorsal pathway specializing in action (Pisella et al., 2006).

This has been concluded by studies conducted on non-human primates, patients suffering from damage to either of the visual pathway. While studying the patients with visual deficits or spared visual abilities, it suggested both pathways working separately however suggested nothing about the pathway interaction or overlapping. Additionally, it would be worth testing these hypotheses in healthy brain condition (Shmuelof1 & Zohary, 2006).

Though the work of Goodale & Milner, 1992; Haxby et al., 1994; James et al., 2003; Milner & Goodale, 2008; lends credence and further builds on to the theory proposed by Ungerleider & Mishkin, 1982 namely that the visual processing system is organized into two independent functional and anatomical pathways. It suggested that ventral visual pathway is associated with object recognition while the dorsal visual pathway is associated with spatial localization. The findings of (Schenk, 2012) would seem, at least in part to contradict this as it highlights the role of of dorsal visual processing pathway in visuomotor control. Thus, the only solid conclusion that can be drawn is that further research is needed before a conclusion can be drawn with regards to clear bifurcation of the functions of the two visual pathways. I suggest that such research could look deeper into the interaction of the two streams with each other and their functional understanding by studying more patients with visual deficits, maybe with emphasis given to healthy human participants and multisensory stimulus.

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