# Discussion

[Deficits in Neglect go beyond attention] The inability to orient spatial attention to left visual space has long been considered the hallmark deficit of unilateral neglect [@Danckert2006]. As outlined earlier, research has increasingly questioned the notion that this particular deficit characterizes the primary, or even cardinal characteristic of the disorder. The damage that often leads to neglect happens to straddle the border between the two visual systems as they differentiate dorsally and ventrally [@Danckert2010]. It is therefore perfectly placed to not only interfere with both systems, but potentially corrupt late-stage communication between the dorsal and ventral streams, producing deficits that cannot be accounted for by simplistic single-system, or single-domain, models.

In chapter 1, patients with neglect demonstrated complex deficits in visual working memory. Namely, when compared with controls, they failed to successfully recall and report the colour of stimuli after a delay. They also mis-reported colours when asked to recall stimuli from a given location, instead reporting colours of stimuli from other, competing, locations. While the first deficit appears to demonstrate a simple deficit of visual working memory, the latter probably represents a somewhat more complex problem of binding visual information (colour and location) in working memory. The experiment also supports the notion that these working memory deficits are not likely to be down-stream effects of more basic spatial attention deficits. The severity of the visual working memory deficits from one patient to the next did not correlate with the magnitude of deficits observed on covert orienting, but appeared to be relatively independent.

[Prisms are limited] Thus far, one of the most promising treatments for rehabilitating neglect has been prism adaptation [tk "the most" too strong?]. The reason prism adaptation has appeared so successful, however, may have been a result of the fact that much of the research has been restricted to tests that effectively measure deficits of spatial attention. Besides the popular covert orienting task, researchers have often used clinical paper-and-pencil tests such as object cancellation, figure drawing or copying, tasks that are, by their very nature, sensitive to an inability to orient to the left. Chapter 2 investigated whether or not prism adaptation would produce a measurable effect on tasks thought to measure ventral-stream dependant processing – spatial working memory and temporal estimations – tasks that would presumably not be improved by remediation of spatial attention in the dorsal stream, the apparent target of prisms [@Danckert2008, @Clower1996]. The experiment replicated the finding that prisms produced a change in line bisection performance, a deficit that is likely driven, at least in part, by an inability to orient leftward, though the effect was far from clear-cut. However, when examining the deficits of spatial working memory in right space, and temporal estimation, two tasks presumably unaffected by deficits of leftward orienting, prisms appeared to lack any significant rehabilitative function. Patients demonstrated extreme deficits on these two tasks both before and after prism adaptation.

[SA failed as a replacement.] It was speculated that an alternative treatment of neglect might be saccadic adaptation, a task not that different from prism adaptation, but one that has been demonstrated to produce subtle changes in perception for healthy individuals (ref). Chapter 3 began with an examination of healthy performance on the landmark and line bisection tasks. The two tasks have been used before in neglect research as they comprise largely similar perceptual properties but likely rely heavily on distinct visual systems [@tk?]. Healthy participants typically demonstrate very small biases, compared with neglect patients, on these tasks. It was therefore suspected that if saccadic adaptation produced changes in perception of spatial extent and spatial attention, it may show up as small changes on the landmark and line bisection tasks, respectively. Unfortunately, though the participants demonstrated adequate saccadic adaptation, the effect did not appear to influence either task. At the same time, a single case study attempting saccadic adaptation in a neglect patient was unsuccessfully because the task demands proved too difficult.

The results of the first two chapters involved small groups of patients with unilateral neglect. As with any research examining such restricted population sizes, this limits the confidence that can be placed on the external validity of the results. It cannot be realistically assumed that such a small sample can exactly represent the population as a whole. Further, the heterogeneity of unilateral neglect, both in terms of the extent of brain damage, and in terms of the particular type and severity of deficits, makes extrapolating from a small group problematic. Further research with larger groups of patients are required to verify the reliability and validity of the conclusions made here.

[SA healthy] Saccadic adaptation failed to produce a measurable change in landmark and line bisection results, but there are avenues left unexplored in examining the possible reasons for this. First, most of the perceptual after-effects that have been demonstrated post-saccadic adaptation have been restricted to spatial illusions immediately before or after saccades, similar to those which were adapted [@Awater2005, @Collins2006]. Longer lasting effects appear to be possible, but it may require careful task design to produce them. The types of parameters used are likely to be important, as research has demonstrated that the type of saccade [@Schraa-Tam2009,@Johnston2008,@Müri2008], or even the magnitude of the adaptation direction [i.e., +- gain, @Catz2008, @Golla2008, @Panouillères2012] can result in very different patterns of brain activation. @Garaas2008 was able to identify long-lasting perceptual effects of saccadic adaptation, but this involved developing a new, whole-field adaptation protocol. Future attempts to change perceptual biases with saccadic adaptation should consider these parameters, especially the potential use of whole-field adaptation (@Garaas2008).

Beyond the type of adaptation used, it is possible that the landmark and line bisection tasks were insufficiently sensitive to reliably measure any effect of the adaptation procedure. Introducing a horizontal jitter to the bisection stimuli may remove the participant's ability to rely on the body mid-line as a reference point and may increase task difficulty, and thus the sensitivity to any subtle biases, where they exist. It may also prove fruitful to calibrate line length to maximize sensitivity to the participant's own spatial bias established at baseline.

The saccadic adaptation case study demonstrated that the task demands of visually following a rapidly perturbed target on a screen may be too difficult to be a useful tool in rehabilitating patients suffering from neglect. However, the parameters used here placed the second target somewhat to the left of centre. Placingall targets in right space may improve a patient’s chance of successfully performing the task. Further, increasing the salience of the targets, by, for example, increasing their size, brightness, or flashing them at onset, may improve the patient's ability to orient and saccade toward them. There are also paradigms that utilize self-paced, voluntary saccades rather than the voluntary saccades used here, and there is evidence that adaptation of voluntary saccades may rely more heavily on cortical as opposed to cerebellar, circuits [@Schraa-Tam2009, @Müri2008], which may prove promising for the rehabilitation of unilateral neglect. Finally, the durations that targets remain on the screen could be carefully calibrated to the particular abilities of the patient, again maximizing their chances of completing the task and adapting to the direction and magnitude of shift desired.

It remains possible that improved methodologies may enable neglect patients to successfully undergo saccadic adaptation. However, the results presented here do not, in any strong way, suggest that saccadic adaptation appears to be a strong contender to replace prism adaptation in the remediation of neglect. In practice, it appears that prism adaptation more closely accommodates the abilities of neglect patients, and the existing body of positive research makes turning away from prisms appear to be a poor choice. Instead, future research should remain considerate of the limitations of prism adaptation, and the particular domains where they do and do-not appear to be effective. Research should concentrate on combining other techniques with prisms to more completely rehabilitate the disorder. For example, the working memory results presented here demonstrate severely degraded abilities. Considering the importance of working memory in self-care and everyday functioning, it seems imperative that prism adaptation be supplemented with some form of working memory training to maximize recovery.