# Methods

### Participants

### The covert orienting task was performed by two groups, eight neurological patients who showed symptoms of neglect in pre-testing (3 male, 2 left handed, mean age =66; see Table x for details), and a healthy older control group (3 male, handedness untested, mean age=74). The two groups did not differ with respect to age (, ). The visual working memory task was performed by these same two groups and an additional control group of healthy young adults. FIXME: demographics missing.

Patients were also tested for signs of neglect using three standard clinical tests: line bisection, star cancellation, and figure copying (Wilson et al., 1987). Figure copying was coded qualitatively as exhibiting evidence of left-sided distortions or omissions – that is, signs of neglect. For line bisection, participant's bisection marks were recorded as deviations from centre as a percentage of the total line's length. Rightward deviations were scored as positive deviations whereas leftward deviations were scored as negative. Impaired performance was defined as a bias of greater than 5% of line-length. For star cancellation, the percentage of missed targets on the left side was recorded, and impaired performance was defined as > than 10% omissions of left-sided targets. Three of the patients scored as impaired on all three tasks, and these participants also scored highest quantitatively on the bisection and cancellation tasks (see table tk). Only one participant failed to show signs of neglect on any task (Table x).

### Apparatus and Procedure

#### Visual Working Memory Task

The visual working memory task was a modification of the one used by @Emrich2012. It was presented on a Dell Latitude D820 Laptop with Windows XP and executed by Matlab on the built-in 8.5x13" screen. Instead of targets and a colour wheel surrounding central fixation, the colour wheel was replaced with a vertical colour bar and it, as well as the targets, always appeared to the right of centre in order to minimize the impact of spatial attention deficits on WM performance (see Figure tk). A trial sequence for the VWM task was as follows: a fixation cross was presented for 500ms, followed by a target array which consisted of either 1,2, or 3 targets of different colours presented vertically aligned on the right side for 500ms. Targets could appear in one of 16 different locations in the vertical column. Following target presentation there was a delay of 1000ms, followed by the appearance of the vertical colour bar and probe stimuli. The probes occupied the same locations occupied by the targets but were unfilled (i.e., probes did not contain any colour information; Figure tk). One of the probes was highlighted by by a bolded outline (Figure x). Participants were asked to indicate, by external mouse input, the colour of the target indicated by the bolded probe location (Figure x). Unlimited time was given, and the participant could make changes to their response an unlimited number of times until satisfied they had accurately indicated the target colour. Note that in the single target condition, there would only be one outline, and the task was essentially to remember the colour of the target. In the two and three target conditions, only one of the two or three probes was highlighted, and the participant would be required to recall the colour of the target that had been presented at that particular location (Figure x).

#### Covert Orienting of Attention Task

The covert orienting task (Posner, 1978, 1980) was identical in design to that of @Striemer2007 and was run on the same computer as the VWM task described above. It was programmed and run in Superlab (Cedrus Software). Participants were presented with 100 trials. A single trial sequence consisted of a fixation cross (1050 to 1550ms), followed by the appearance of a peripheral cue which consisted of the brightening of one landmark (Figure x). Targets, which consisted of red circles presented within the landmark, appeared either at the cued location (valid trials) or at the opposite location (invalid trials; Figure tk). Two stimulus onset asynchronies (SOA; the time between cue and target onset) of 50 or 150ms were used. Cues were non-informative (i.e., 50% of cued trials were valid and 50% were invalid trials). There were also no-cue trials in which the target appeared without any preceeding cue. Targets appeared equally often on the left and right sides. Participants maintained fixation throughout the task. This was monitored by the experimenter and verbal feedback was given periodically to encourage participants to maintain fixation.

FIXME: Add more details, such as the stimuli size, shape, and eccentricity (in visual angle)

### Data Analysis

The visual working memory task recorded the exact colour value selected by the participant. From this several measures were calculated. Precision of a response was calculated in terms of the distance between the true colour of the target and the participant’s selection. Further, for each trial, the probability that the response represented an attempt at selecting the correct target colour (), one of the distractor target colours (, in the two and three target conditions), or simply represented a guess (), was calculated with the distribution-based model described in @Emrich2012. In short, this method tk (figure tk)… The values sum to one, so in the one-target case, the probability of guessing is simply the inverse of the probability of correctly selecting the target.

FIXME: Was response precision calculated based on all trials, or only trials likely to be correct target selection? I assume the former. But should check.

For the covert orienting task, response times were recorded and means were calculated for each trial category for each participant. Cue-effect sizes (CES) – the different in RT between valid and invalid trials – for leftward and rightward shifts of attention for each participant at each level of SOA were calculated. For leftward shifts, RTs to validly cued right targets were subtracted from invalidly cued left targets (i.e., in both cases, the cue is on the right, and the magnitude of the difference comes from the extra time taken re-orienting to the left invalid target). The rightward CES was calculated in the inverse way – RTs to validly cued left targets were subtracted from invalidly cued right targets.

FIXME: I don't know if trials were dropped for extreme rt values.

Significance was defined as throughout. Where tests are used, unless otherwise specified, the Welch approximation of the degrees of freedom for unequal variance was used.

# Results

### Visual Working Memory

#### Single Target Condition

The single target condition of the VWM task was analyzed separately as it represents a distinct challenge to participants, and the outcome variables are different (lacking a measure) when compared with the two and three target conditions. Unlike those conditions, a the single target does not require the participant to encode spatial location, or any binding of colour and spatial location. It is purely a measure of the person's ability to precisely encode and recall a colour.

[Response Precision] Response precision for the single target condition was compared between the three groups using a mixed design ANOVA (or whatever you did – I think for the precision data point the full omnibus ANOVA might be asked for – so group as between and level of WM task (1, 2, 3 targs) as within). There were no significant differences between the group means, despite an apparent advantage for the young controls (tk anova). Removing one or both extreme outliers from the two older groups may result in a significant effect of age, but would make the two older groups even more homogeneous, which would not support the notion that neglect reduces precision on this task . It's also worth noting that the least-precise patient responded more accurately on average than least-precise members of the two control groups.

[pTarget] Because the single target condition has no non-targets, and therefore no PNT (i.e., ), there is effectively only one dependent variable and the choice of which to probability to use is arbitrary. For convenience, is used here as the dependant variable. As can be seen in figure tk, the two healthy groups perform nearly perfectly by this metric. A one-way ANOVA containing all three group means was significant (, ). Tukey HSD tests were performed to compare the means, and the two healthy groups, who appear to have been performing at ceiling, are not shown to be different (, ). However, both young adults and older control groups were significantly different from than the patients (, , and , , respectively).

#### Two and Three Target Conditions

[Approach] In the multi-target conditions, three outcome probability estimates were produced. As was the case for the one target condition, these probability estimates sum to one, and as such represent only two unique values. Here, the two types of failures chosen for the analysis were the , defined as…. and the probability of indicating a non-target (), defined as ... The two dependant variables were analyzed separately, rather than in a multivariate analysis, as the characteristics of the data violate many of the assumptions of standard multivariate tests and the limited sample size would render any result tenuous at best. This limits the ability to compare the two outcomes, but provides clearer answers to the distinct questions each measure addresses.

[Guessing 1] First, guessing, or indicating a colour that was not represented in any of the target distributions (see Figure a). The restricted range of probability scores, and high frequency of near-zero outcomes produced a highly skewed and non-normal distribution that even with data transformations, was not sufficiently normal for parametric analysis to be appropriate. The means of the three groups and two target conditions can be seen in figure tk. As an attempt to analyse the data, the two target conditions were collapsed to produce means for a more generic "multi-target" performance metric.

[Guessing 2] The Kruskal-Wallis rank sum test was used for the non-parametric omnibus model of , and it did not indicate differences (, ). Non-parametric relative effects using Tukey contrasts were performed in a "one-sided" fashion, assuming age and injury would only impair performance. The Patients did not significantly differ from either the young adults (, ), or older controls (, )). The two healthy groups did not differ from one another (, )).

[Non-target/binding errors] As was the case for the , the data is highly non-normal and transformations are ineffective in correcting for the nature of thhe data. Figure tk presents the means for the two multi-target conditions (2- and 3-targets). As was done for the guessing data, analysis was performed on the collapsed means of the two conditions. Here, however, the Kruskal-Wallis test was significant (, ). Multiple comparison tests yielded significant differences between the patients and the two healthy groups (, for older controls, and , for young adults). The two healthy groups did not differ from one another (, ).

FIXME: plot of the collapsed means over the the 6 means plot. Combined somehow?

FIXME: Table of , means, and Cohen's d. effect size

### Covert Orienting Task

Analysis of the covert orienting data was extremely limited given that 3 of the 8 patients failed to respond to any left-sided targets. Not only does this prevent any measure of leftward orienting deficits in almost half the sample, but those three participants exhibited the strongest symptoms of neglect on the clinical measures. This means that not only is the power of any analysis reduced, but that analysis will necessarily be performed only on moderately neglecting participants.

FIXME: Applicable to above and discussion if the “3” were also worst on VWM task.

Leftward cue-effect sizes (CES) were calculated for each participant in the patient group and older controls. Both groups exhibited significant cue effects, indicating significant cost for reorienting attention to invlidely cued targets (, for the patients, and , for the older controls). To examine group differences in covert orienting, a mixed Anova was performed with group as the between-subjects factor and SOA as the within-subjects factor. An effect of group approached significance (, ), while SOA and the interaction were non-significant (, , and , ).

[Compare directly to normative data] Figure tk depicts the CES of the 5 neglect participants over the range of performance observed in the healthy controls. As can be seen in the figure, three of the patients performed well within the range of healthy controls. In contrast, the final two patients demonstrated leftward CESs that were well outside the range of the healthy older controls. It is also worth noting that one of the two, Patient 171, did not show any signs of neglect on the clinical tests, and the other, Patient 454, exhibited only weakly neglecting symptoms when compared with their cohort. The patient produced a bisection bias above our threshold, though only at 6%, a near median performance for the group, and produced errors in figure copying, but did not miss any left-sided targets in the stars test. It also should be noted that Patient 171 did not show similarly large rightward CE sizes, so it cannot be said that the result was a deficit of general covert re-orienting, but, indeed, a lateralized deficit ( of -22 and 11 for 50 and 150ms SOA respectively). For Patient 454, it was less clear ( of -263 and -21 for 50 and 150ms SOA respectively; negative values indicate faster invalid trials).

Comparing TE and SWM

The reduced group size as a result of the inability of three patients to orient to leftward targets prevents reliable statistical analysis of the relationship between the covert orienting and visual working memory tasks. The two patients that performed well outside of the range of healthy performance on the covert orienting task did not stand out with extreme performance deficits on the visual working memory task. When compared with the rest of the neglecting group, Patient 454 performed slightly worse than the median on both measures, while Patient 171, who, incidentally was the only one in the group to score negatively on all three clinical measures of neglect, was actually the most accurate participant, again, on both measures. This lack of reliably similar performance between the two tasks hints at the decoupled nature of the two domains suggested earlier.

TODO: table with performance on both tasks and clinical measures. Group medians in margins.

FIXME: Above two paragraphs could be mostly moved to Discussion

# Discussion

[VWM single] The response precision data indicates that the patients were able to perform the basic task of indicating a colour to a similar degree of proficiency as the two control groups, demonstrating that basic perceptual representations are in-tact, and that they are able to respond as well as controls when they are able to recall the correct visual information. However, the data appears to indicate that neglect patients fail to recall the colour of targets and respond in a way that indicates more prevalent guessing.

[VWM Multiple -guessing] When participants were asked to perform the same VWM task in the presence of distractors, two things change: there is an increase in memory load, and patients must now bind colours to locations. That is, in addition to remembering more than a single colour, patients needed to remember the relative spatial arrangement of those colours in order to answer correctly. As a result, two types of errors can be committed. A failure to recall a colour (a guess), or a mis-identification of one of the distractors as belonging to the indicated spatial position (non-target selection). Interestingly, in contrast to the single target condition, the patient group does not appear to guess more frequently than the other groups. This may reflect a problem of binding colours to locations leading to an increase in selecting a non-target colour. That is, a guess represents the choice of a colour not included in probable distributions for either the target or distractors (Figure x). In contrast, selecting a non-target (distractor) colour may represent a biding error associating a distractor colour with a target location. (tk Binding errors citation: Treisman, Behrmann or Humphreys and Riddoch)

[VWM Multiple -mis-binding] Unlike guessing, patients were more likely to select non-targets in multi-stimulus arrays (i.e., with more than one item to remember). There are many potential explanations for this, the most obvious being a failure of binding. An error in the recollection of the spatial arrangement of targets and distractors would lead a participant to inaccurately associate colours and locations. If the colours were remembered perfectly, but their individual spatial locations lost, this would lead to this type of error half, and two-thirds of the time by chance, for the two and three target conditions respectively. The other event that can lead to this type of error is a simple failure to recall all of the target colours. If the target colour cannot be recalled, it is possible the participant may be inclined to select one of the other colours, or something close to it, by strategy or cognitive anchoring. While this experiment is not able to clearly disambiguate the two causes, if the large deficit observed here was caused by patients forgetting target colours, than it seems likely that such frequent recal failures would have also lead to a similar increase in the amount of guessing. As guessing didn't appear to increase, binding errors are the more likely culprit.

[Possible explanations] Without further research, it is unclear why neglect may induce visual recollection failures in the single target condition, and mis-recollection in the multi-target condition, but there are several possibilities. First, it is important to note that there are two changes from single to multiple target conditions. Besides the addition of the spatial task, there is the requirement to remember more visual information. If patients struggled to recall a single colour in the first condition, it is possible that, at least some of the time, they only remembered a single colour in the multi-target condition, either by strategy or necessity. This would appear to be a colour-location binding error, but would, in fact, be a simple visual working memory failure. A second possibility is that spatial binding errors in the multiple-target condition simply overwhelm simple colour-recollection errors, and produce an experiment that is insufficiently sensitive to the latter in order to be able to measure the deficit successfully. The two conditions may always be required to measure the two types of memory failures. Third, it should not be automatically discounted that a difference in the healthy control groups might account for the failure to identify group differences in guessing in the multi-target condition. The control groups perform almost perfectly on the single target condition, but fell away from this "ceiling" somewhat on the multi-target condition. The difference between neglect and healthy performance may simply be more accentuated when the task is calibrated such that healthy performance is near perfect and not highly variable.

[COVAT] The data also brings to light some difficulties with the covert orienting task in the study of neglect. Neglect is often defined in terms of attention, but in this case, for three patients, leftward re-orienting of attention appeared to be less sensitive a measure of neglect than the paper and pencil standard clinical measures. As used here, it appears to suffer from a restriction of range problem. While several of the most severely neglecting participants could not complete the task at all, several others, whom still exhibited signs of neglect on at least one clinical measure, performed well inside normal parameters. The apparent failure of the task to capture either subtle or strong deficits indicates that the task, as it was used here, may not be very effective for capturing the range of attention deficits in neglect, or useful for the comparison of attention and other deficits in neglect.

[Comparison of tasks] While a reliable statistical comparison of the two tasks was made impossible by the inability of several participants to complete the task, there is some information that may be gleaned from what remains, and provide hints toward further research. The two patients with strikingly poor ability to re-orient leftward did not stand out as being particularly degraded on either visual working memory or clinical measures of neglect. In fact, one of them didn't show clinical neglect at all. This should serve as a cautionary note, hinting that it's may be possible for some individuals to exhibit strong leftward covert orienting deficits in the absence of symptoms on clinical measures, (or visual working memory deficits?).

[Heterogeneity of neglect means within-subject is better] Despite the fact that 8 patients with neglect were recruited for this study, as can be seen from the results, there are several issues with making strong claims about group differences. Most notably, neglect patients are a highly heterogeneous group, with widely varying degrees of deficits, and different relationships between the deficits. Clinical measures such as those used here may not be sensitive enough, or cover enough domains of performance, to detect deficits still present in the individual. Further research, besides avoiding the covert orienting task as a measure of spatial deficits, would benefit from within-subject designs, such as before-and-after certain treatments, or longitudinally, as patients recover. Such designs would avoid some of the problems inherent in group-wise comparisons hamstrung by the heterogeneity of the disorder. The clinical symptoms, covert orienting deficits, and visual working memory deficits examined here may emerge from damage to un-related or weakly-linked domains of the neglect disorder, but further research with larger sample sizes, preferably making use of repeated measures designs, will be required.

Most rehabilitation techniques implemented in neglect focus on remediating the attention deficits. If these attention deficits are distinct from the working memory impairments discussed here and elsewhere (tk), than this rehabilitation strategy will fail to address this domain, and leave patients with untreated disorder. The next chapter addresses this question by examining the effects of a prominent rehabilitation technique on non-attentional biases.