



Differential shift in spatial bias over time depends on observers' initial bias: Observer subtypes, or regression to the mean?



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ARTICLE INFO

Article history:

Received 8 February 2014

Received in revised form

31 August 2014

Accepted 8 September 2014

Available online 16 September 2014

Keywords:

Alertness

Pseudoneglect

Spatial attention

Regression towards the mean

ABSTRACT

Healthy subjects typically exhibit a subtle bias of visuospatial attention favouring left space that is commonly termed 'pseudoneglect'. This bias is attenuated, or shifted rightwards, with decreasing alertness over time, consistent with theoretical models proposing that pseudoneglect is a result of the right hemisphere's dominance in regulating attention. Although this 'time-on-task effect' for spatial bias is observed when averaging across whole samples of healthy participants, Benwell, C. S. Y., Thut, G., Learmonth, G., & Harvey, M. (2013b). Spatial attention: differential shifts in pseudoneglect direction with time-on-task and initial bias support the idea of observer subtypes. *Neuropsychologia*, 51(13), 2747–2756 recently presented evidence that the direction and magnitude of bias exhibited by the participant early in the task (left biased, no bias, or right biased) were stable traits that predicted the direction of the subsequent time-on-task shift in spatial bias. That is, the spatial bias of participants who were initially left biased shifted in a rightward direction with time, whereas that of participants who were initially right biased shifted in a leftward direction. If valid, the data of Benwell et al. are potentially important and may demand a re-evaluation of current models of the neural networks governing spatial attention. Here we use two novel spatial attention tasks in an attempt to confirm the results of Benwell et al. We show that rather than being indicative of true participant subtypes, these data patterns are likely driven, at least in part, by 'regression towards the mean' arising from the analysis method employed. Although evidence supports the contention that trait-like individual differences in spatial bias exist within the healthy population, no clear evidence is yet available for participant/observer subtypes in the direction of time-on-task shift in spatial biases.

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1. Introduction

Extensive research using a range of tasks has established that healthy subjects tend to exhibit a subtle bias of visual attention favouring left space, termed 'pseudoneglect' (Bowers and Heilman, 1980; Jewell and McCourt, 2000; Loftus and Nicholls, 2012; Mesulam, 1981; Thiebaut de Schotten et al., 2011; Voyer et al., 2012). However, this leftward bias is attenuated, or shifted

rightwards, with decreasing alertness/increasing fatigue over time (Benwell et al., 2013a; Dodds et al., 2008; Dodds et al., 2009; Dufour et al., 2007; Manly et al., 2005; Newman et al., 2013). These findings are consistent with theoretical accounts which posit that decreased activation of the right-hemisphere lateralised 'alertness' network may drive attention rightward (Corbetta and Shulman, 2011; Posner and Petersen, 1990).

In line with this, loud tones and time pressure designed to increase alertness temporarily reduce leftward inattention in patients suffering from 'spatial neglect', a common outcome of right hemisphere damage that is characterised by deficits in attending to contralesional space (George et al., 2008; Robertson et al., 1998). Furthermore, spatial neglect is temporarily ameliorated by

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psychostimulants but exacerbated by sedatives (Fleet et al., 1987; Geminiani et al., 1998; Gorgoraptis et al., 2012; Grujic et al., 1998; Lazar et al., 2002; Malhotra et al., 2006; Mukand et al., 2001). In healthy populations spatial bias is modulated by sleep deprivation (Manly et al., 2005; Schmitz et al., 2011) and psychostimulants (Dodds et al., 2009) as well as time-on-task.

Corbetta and Shulman (2011) propose that the majority of healthy people have a *right-hemisphere lateralised ventral attention network* which underpins alertness but also modulates inter-hemispheric rivalry in the *bilateral dorsal orienting network*. Decreased activation within the right lateralised ventral network may cause a more global decrease in right hemisphere activation, giving the left dorsal orienting network a competitive activation advantage over the right dorsal network, thus driving attention rightwards.

However, Benwell et al. (2013b) recently reported differential time-on-task effects depending on the direction of healthy participants' initial spatial bias. Specifically, participants who showed an initial left bias (LB) during the first block showed a significant rightward shift over the course of subsequent experimental blocks. Conversely, participants who showed a right bias (RB) in the first task block showed a non-significant leftward shift over time. As noted by Benwell et al., these findings are not consistent with current views of the interaction between alertness/arousal and spatial orienting, which would predict a rightward shift in spatial bias as alertness wanes over time regardless of initial bias, so that those participants with an initial right bias should shift further rightwards with time-on-task. Benwell et al. concluded that their results suggest distinct participant (observer) subtypes that may be driven by categorically different anatomical and/or functional asymmetries. This is a potentially pivotal finding, as it throws doubt on the idea that right hemisphere lateralisation of the ventral attention network is a uniform feature of neurologically healthy participants.

Given the important implications that the results of Benwell et al. have for theoretical models of attention, independent confirmation of the findings is required. One possibility for instance, is that their result may be an artefact of 'regression towards the mean' – where a variable that is extreme on its initial measurement will tend to be closer to the mean on subsequent measurements (Barnett et al., 2005; Galton, 1886; Stigler, 1997). This may have unintentionally arisen due to the method of splitting participants based on their initial spatial bias (during the first block only) and then including the same data used to categorise participants in the subsequent analyses. Here we aim to empirically test the possibility that the effect reported by Benwell et al. is an artefact of regression to the mean rather than being indicative of true participant subtypes for the direction of time-related shifts in spatial bias. Two experiments employed different spatial attention paradigms in an attempt to confirm the apparent opposing bias shifts between participants who initially show left, versus right, bias. The current paradigms differ to the landmark tasks used by Benwell et al. (2013b) to gauge spatial bias. The current tasks are more similar to other fixation controlled brief presentation paradigms that have been used to document evidence for observer subtypes in visuospatial bias (Newman et al., 2012; Thiebaut de Schotten et al., 2011) and on which shifts in visuospatial bias with time-on-task and decreased alertness have been shown (Dodds et al., 2008; Matthias et al., 2009; Newman et al., 2013). If opposing directional shifts in visuospatial bias over time in the current paradigms are not due to regression towards the mean, then the effects should hold after (i) appropriate statistical adjustment for bias introduced by regression towards the mean, and (ii) when the initial trials used to categorise participants are not included in the subsequent time-on-task analysis.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Ninety-one healthy right-handed volunteers performed a paradigm that allows derivation of a spatial asymmetry (bias) index. Event-related potential (O'Connell et al., 2011), molecular genetics (Newman et al., 2012) and alpha power (Newman et al., 2013) data from a subset of these participants have been previously published. Four participants responded to fewer than 75% of peripheral targets, suggesting they were insufficiently engaged in the task. These participants were excluded from further analysis. Two were excluded due to a technical error relating to response acquisition. Three participants lacked full time-on-task data within each load condition, so could not be included. This left a final sample of 82 participants (49 female) aged 18–47 ($M=23$).

2.1.2. Spatial attention (RSVP) task

Full details of this visual attention task are described elsewhere (O'Connell et al., 2011). A schematic of a single trial is illustrated in Fig. 1. Briefly, participants viewed a centrally presented rapid serial visual presentation (RSVP) stream for the occurrence of a designated probe item, while simultaneously monitoring peripheral locations for the appearance of a target. Peripheral targets were presented randomly (but with equal probability) in either left or right target location (or not at all) at either 1200 ms or 2400 ms. In all conditions, participants indicated detection of the peripheral target via a speeded mouse click with their right hand.

At the end of each trial participants were asked whether the designated central probe item was present and responded 'yes/no' via a non-speeded left or right mouse click, respectively. The effect of the central probe has already been explored in these data and reported elsewhere (Newman et al., 2012, 2013) and is not of interest here as data were collapsed across central probe condition in the analysis below.

Nonetheless a brief description of the central task is warranted. The designated central probe item changed across three conditions (no report, low-load, and high-

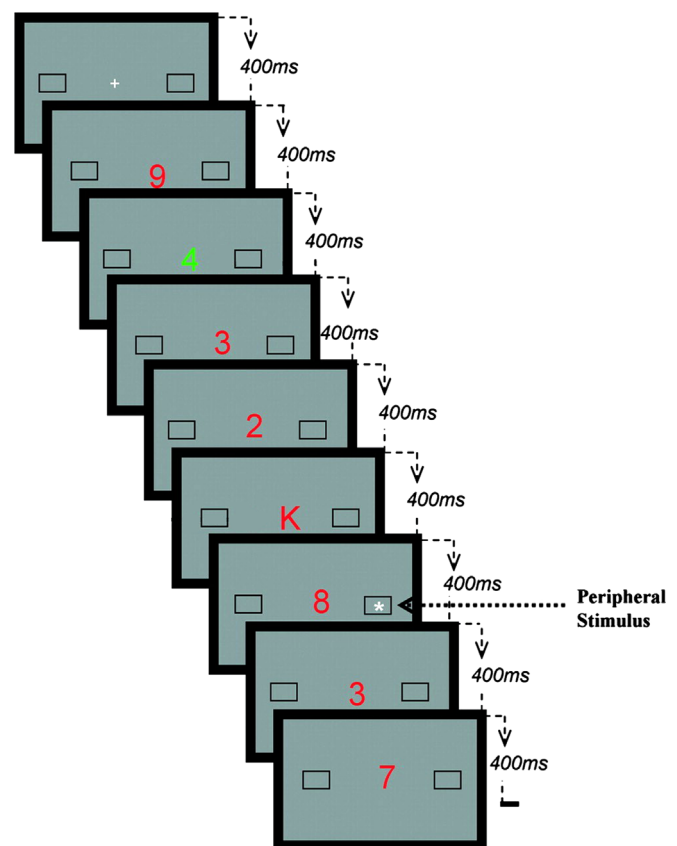


Fig. 1. A single trial from the RSVP attention task. Participants were fixated on the central stream searching for a designated probe item, while simultaneously monitoring the periphery for a brief stimulus that could appear to the right or left or not at all (catch trials). Participants indicated detection of the peripheral target with a speeded mouse click. At the end of each trial participants were asked whether the central stream probe item was present and responded yes/no with a non-speeded left or right mouse click, respectively.

load) which were completed in separate blocks. The only aspect that differed between these three conditions was the instructions regarding the central probe item. At the beginning of the no report condition, participants were instructed to simply fixate on the central RSVP stream and monitor for and respond to peripheral targets. In the low-load condition, participants were instructed that the probe item was any green character within the central stream. In the high-load condition, the probe item was any red letter within the central stream of characters. The central probe item appeared unpredictably in 50% of the trials and its order of appearance within the RSVP stream was randomised. The onset of the central probe never coincided with the peripheral target.

2.1.3. Procedure

Participants were seated, supported by a chin rest, at 50 cm viewing distance. Although continuous EEG was recorded, only behavioural data were reported herein. Participants were instructed to maintain central fixation and avoid blinking or moving during each trial, but were encouraged to blink and move in the short breaks between each trial, if desired. When participants had mastered a practice session, they were left alone in a darkened room to begin the task (described above). Participants performed the three load conditions over one session. Each load condition comprised 300 trials with participants receiving short rest periods after every 100 trials and a longer rest period at the end of each condition for which the lights were turned back to normal luminance. Before beginning a new load condition, participants read on-screen instructions and the experimenter explained the task verbally then ensured the participants' comprehension of the new task. The extended rest intervals between conditions for task instructions meant that it was not appropriate to analyse time-on-task across the whole testing session, and the data were thus collapsed across load conditions in line with [Dodds et al. \(2008\)](#) and [Newman et al. \(2013\)](#). The duration of each load condition (approximately 48 min) ensured sufficient data for time-on-task analyses within each separate condition.

2.1.4. Analysis

In line with [Newman et al. \(2013\)](#) time-on-task was measured by collapsing the data across load, dividing the duration of the task into n number of time bins of equal sizes, and testing for trends across those bins. A measure of reaction time (RT) bias is derived from peripheral RT (ms) using the following formula:

$$\text{RT bias index} = \frac{(\text{left target RT}) - (\text{right target RT})}{(\text{mean left and right target RT})}$$

This index gives positive values when reaction-times are faster for right relative to the left targets (rightward spatial bias) and negative values when the opposite is true (leftward bias).

Consistent with [Benwell et al. \(2013b\)](#) participants were split into groups according to their initial bias direction (left or right) during the first time-bin to test for differential direction of subsequent bias shift. Given that our paradigm required more than one trial to derive a measure of RT bias, we did not use 95% confidence intervals (CIs) from zero bias during the first time-bin to split participants into groups, as was done by [Benwell et al.](#) Rather we split participants according to whether their RT bias index during the first time-bin was positive or negative. Thus, we did not include a 'no initial bias group' in our analysis. Time-bin \times initial bias group ANOVAs were then conducted on the RT bias index and polynomial

contrasts within each initial bias group were used to follow up significant time-bin \times initial bias group interactions. Polynomial contrasts are preferred over linear regression for assessing the shift in spatial bias over time because linear regression by definition will fit data to a linear model while polynomial contrasts test for a linear trend but also take into account the possibility that the data may be explained by a higher order model (e.g. quadratic, cubic, fourth order, etc.).

Three methods were used to gauge whether 'regression to the mean' could be driving the differential shift over time for the different spatial bias groups. First, we split the time-course of the task (300 trials) into 3 equal 100 trial time-bins and initial spatial bias is defined as spatial bias during the first of three time-bins. After testing for any differential shift in the direction of spatial bias change over time, conditional upon initial spatial bias, we split the sample into groups based on bias during the second time-bin, and then based on bias during the third time-bin. This analysis allowed us to gauge whether 'regression to the mean' could be driving the differential shift over time for the different spatial bias groups. Second, we reasoned that if regression towards the mean does not account for the opposing directions of bias shifts in the two groups, then this effect should hold when the initial trials used to split participants are not included in subsequent time-on-task analysis. To test this, we split the time-course of the task (300 trials) into 6 time-bins (each bin comprising 50 trials, equating to approximately 7 min per time bin) and categorised participants according to their initial spatial bias direction (left or right) during the first of these time-bins. This number of time-bins was chosen to ensure enough trials per bin for a reliable measure of spatial bias within each time-bin, while still permitting adequate temporal resolution to see the dynamics of time-on-task shifts in spatial bias. For transparency we repeated all analyses splitting the 300 trials instead into five (i.e. 60 trials per bin), four (i.e. 75 trials per bin) and three (i.e. 100 trials per bin) time bins, and the key conclusions reported below hold in each case (see supplementary material). We next performed a time-on-task analysis on the remaining 5 time bins, excluding the data from the first time bin that was used to categorise participants. Third, we tested for regression towards the mean by (i) assessing whether initial spatial bias and subsequent change in spatial bias were significantly correlated, then (ii) applying an adjustment to the initial spatial bias scores to control for regression towards the mean and performing a time-on-task analysis including this adjusted initial RT bias data.

2.2. Results

The ANOVA revealed a significant interaction between time-bin (3 bins) and initial bias group [$F(2,160)=4.5, p=.013$]. In line with the results of [Benwell et al. \(2013b\)](#), polynomial contrasts within each initial bias group revealed a significant linear shift in RT bias with time-on-task in a rightward direction over time for the initial left bias (LB) group [linear $F(1,54)=10.6, p=.002$; quadratic $F=1.2, p=.278$] and a non-significant leftward shift in RT bias in the initial right biased (RB) group [linear $F(1,26)=.4, p=.549$; quadratic $F=2.7, p=.115$] (see [Fig. 2A](#)). After confirming the general pattern of the results of [Benwell et al.](#), we next split the sample into groups first based on bias during the 2nd time-bin, and then during 3rd time-bin, and re-ran the time-on-task analysis. [Fig. 2A–C](#) shows the effect of regression to the mean on differential spatial bias shifts when participants are grouped according to a specific time interval and this interval is then included in the subsequent time-on-task analysis. For each graph in [Fig. 2](#), the most extreme bias measurement is

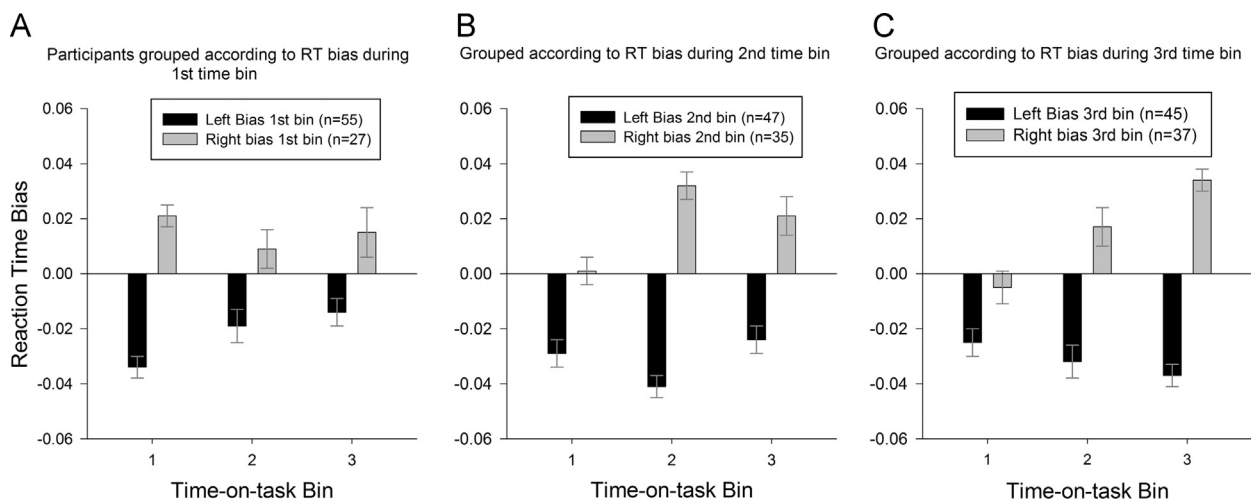


Fig. 2. Participant grouping method and regression to the mean may cause opposing directional shifts in spatial bias over time. (A) Apparent shift in RT bias towards zero over time when participants are grouped according to bias in the 1st time-bin. (B) Bias in the 1st and 3rd time bins appears closer to zero when participants are grouped according to the middle time-bin. (C) Apparent shift in RT bias away from zero over time when participants are grouped according to bias during the 3rd time bin. Error bars represent standard error.

found in the time-bin used to group the sample while bias within the other time bins regress towards the mean. This effect holds true when using more time-bins (tested using 3, 6 and 12 time-bins); however 3 time-bins are reported here to allow depiction using only 3 plots (Fig. 2). Fig. 2A shows an apparent shift in RT bias towards zero over time when participants are grouped according to bias in the 1st time-bin. When participants are grouped according to the middle time-bin (Fig. 2B) bias in the 1st and 3rd time bins appears closer to zero than the middle bin, and when participants are grouped according to bias during the 3rd time bin (Fig. 2C) there is an apparent shift in RT bias away from zero over time.

We next split the full series of trials instead into 6 smaller time-bins, then grouped participants based on their bias during the first of these 6 bins and ran a time-on-task analysis including the data used to group participants, as above. Again the results of this analysis were consistent with those of Benwell et al. (2013b). The ANOVA revealed a significant time-bin (6 bins) by initial bias group interaction [$F(5,400)=7.87, p<.001$] and polynomial contrasts showed a significant linear rightward shift in the direction of RT bias in the initial LB group [linear $F(1,54)=9.43, p=.003$; quadratic $F=12.3, p=.001$; cubic $F=.68, p=.412$; fourth order $F=3.0, p=.088$; and fifth order $F=.42, p=.518$] and a non-linear leftward shift in RT bias in the initial RB group [linear $F(1,26)=.15, p=.698$; quadratic $F=13.5, p=.001$; cubic $F=7.7, p=.010$; fourth order $F=10.3, p=.003$; and fifth order $F=3.0, p=.094$] (see Fig. 3A). We next excluded data from the first time bin which was used to group participants and ran a time-on-task analysis on only the remaining 5 time bins (see time-bins 2–6 in Fig. 3A). The ANOVA revealed a significant time-bin (5 bins) by initial bias group interaction [$F(4,320)=2.61, p=.036$]. However, polynomial contrasts showed that excluding the first time-bin abolished the rightward shift in RT bias in the initial LB group [linear $F(1,54)=.02, p=.892$; quadratic $F=.20, p=.659$; cubic $F=1.2, p=.276$; and fourth order $F=.00, p=.944$] and resulted in a significant linear shift in the rightward direction in the initial RB group [linear $F(1,26)=10.08, p=.004$; quadratic $F=.05, p=.821$; cubic $F=.15, p=.699$; and fourth order $F=6.4, p=.018$]. Thus when discounting the initial time-bin (i.e. analysing only bins 2–6 in Fig. 3A) the effect is opposite to the overall effect in Fig. 3A and to that reported by Benwell et al. (2013b). It appears therefore that these data patterns may reflect regression to the mean rather than meaningful participant subtypes. Other methods to confirm the existence of regression towards the mean are explored below.

2.2.1. Confirmation of the regression towards the mean effect

Regression towards the mean can also be tested by assessing whether initial values and subsequent change are significantly correlated (Barnett et al., 2005; Rocconi and Ethington, 2009). We calculated the change in RT bias between the initial time-on-task bin and the final time-on-task bin for each participant and regressed this against initial RT bias. This revealed a significant correlation, $r=.535, p>.001$, confirming that a regression towards the mean effect exists here. A similar result was reported by Benwell et al. (2013b) (Fig. 6), however in that case it was interpreted as supporting the hypothesis of observer subtypes for directional shifts in spatial bias, rather than an indication of regression towards the mean.

2.2.2. Statistical adjustment for regression towards the mean

Once the existence of regression towards the mean is established, a statistical adjustment can be made to the initial scores to reduce the influence of regression

to the mean (Roberts, 1980). This adjustment is $\chi' = \chi + (1 - r_{yy})(\mu - \chi)$, where χ' =adjusted baseline score, χ =initial score, r_{yy} =test–retest reliability and μ =mean initial scores of total sample (see Finke et al. (2010) and Rocconi and Ethington (2009) for recent examples of Roberts' (1980) adjustment). We established the test–retest reliability of initial spatial bias (see Fig. 4) and ran a time-on-task analysis on the six time-bins, substituting the adjusted initial RT bias data into the 1st time-bin (see Fig. 3B). The ANOVA using the adjusted initial bias scores revealed a significant main effect of time-bin (6 bins) [$F(5,400)=2.92, p=.013$]. Polynomial contrasts showed that this was best explained by an overall rightward shift in spatial bias over time [linear $F(1,80)=10.43, p=.002$; quadratic $F=.11, p=.745$; cubic $F=.89, p=.349$; fourth order $F=.63, p=.634$; and fifth order $F=2.97, p=.089$] (see Fig. 3B). This main effect was modified by a time-bin by initial bias group interaction [$F(5,400)=2.66, p=.022$]. Polynomial contrasts showed a non-significant rightward shift in the initial LB group [linear $F(1,54)=3.06, p=.086$; quadratic $F=3.53, p=.066$; cubic $F=.004, p=.953$; fourth order $F=1.74, p=.193$; and fifth order $F=.25, p=.617$] and a significant linear shift – also rightward – in RT bias in the initial RB group [linear $F(1,26)=7.06, p=.013$; quadratic $F=2.769, p=.108$; cubic $F=1.61, p=.215$; fourth order $F=5.30, p=.030$; and fifth order $F=3.99, p=.056$] (see Fig. 3B). When controlling for bias introduced by regression towards the mean (Fig. 3B) the effect is opposite to the effect in Fig. 3A and that reported by Benwell et al. (2013b). It appears therefore that these data patterns reflect regression to the mean rather than meaningful participant subtypes.

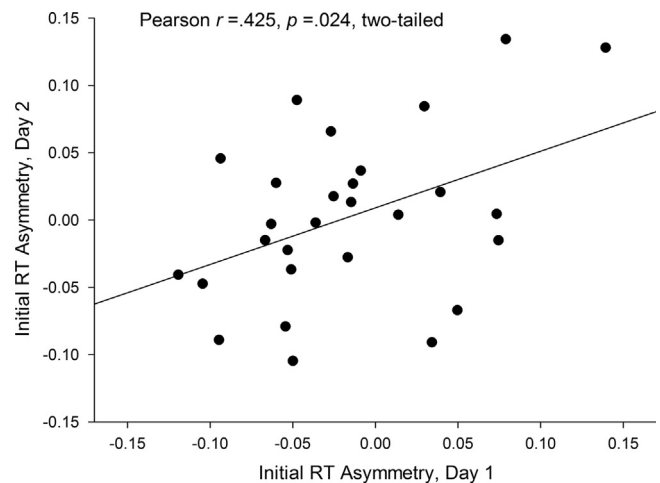


Fig. 4. Test–retest reliability of initial spatial bias on the RSVP task. Relationship between initial spatial bias scores across separate testing sessions (at least 6 days apart) on the RSVP task. The significant Pearson's correlation between initial bias scores confirms that initial bias is a relatively stable trait.

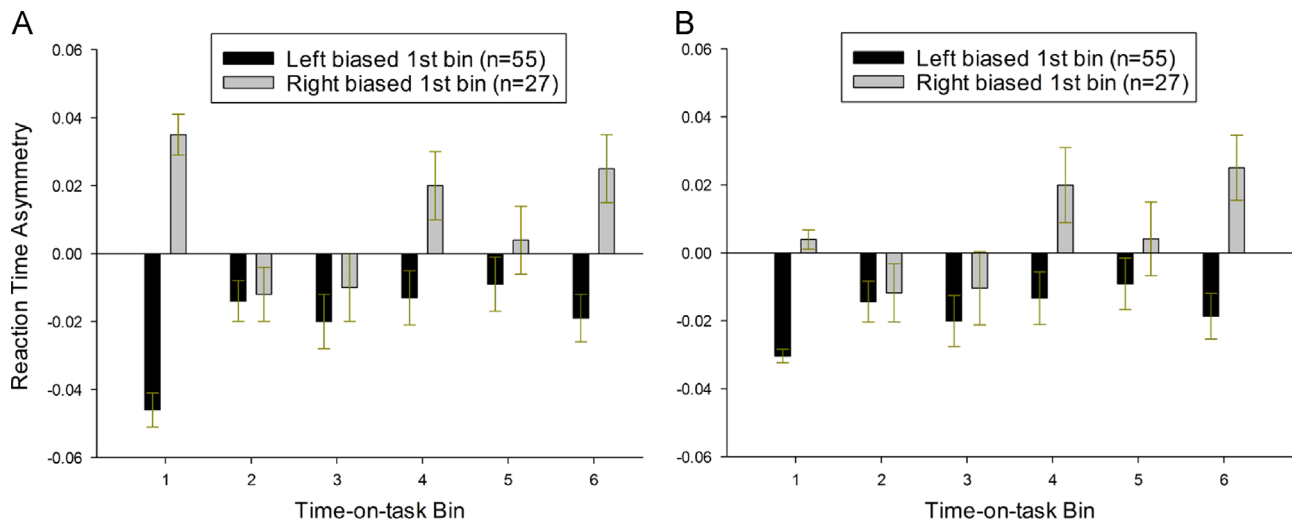


Fig. 3. An apparent differential direction of spatial bias shift over time is abolished when bias introduced by regression towards the mean is controlled for statistically. (A) Apparent shift in RT bias towards zero over time when participants are grouped according to bias in the 1st time-bin. (B) When scores from the 1st time-bin are adjusted to control for regression towards the mean, the apparent differential shift in direction of spatial bias over time is abolished and the RT asymmetry of both groups tends to shift rightwards (less negative/more positive) over time. Error bars represent standard error.

2.2.3. Test–retest reliability of initial spatial bias on the RSVP task

In order to assess the test–retest reliability of our initial bias measure, 28 healthy right handed participants (18 female) aged 21–28 ($M=23.5$) were recruited to complete the paradigm on two separate days (separated by at least 6 days). The paradigm and procedure were identical to those reported above, with the constraint that participants completed only 100 trials of each load condition, instead of the full 300 trials in each load condition. Each participant's initial bias measurements on each of the two days were taken from the first 50 trials of each load condition (equivalent to the first of 6 time-bins in Fig. 3A above). Pearson's correlation revealed that the initial bias measures across the two test sessions were significantly correlated, [Pearson $r = .425$, $p = .024$; Spearman $\rho = .365$, $p = .056$], see Fig. 4 below.

3. Experiment 2

Here we report data from a new cohort of participants on a different spatial attention paradigm to show the generality of the participant grouping and regression to the mean effect across spatial attention paradigms.

3.1. Methods

3.1.1. Participants

Fifty-three healthy right handed volunteers performed a paradigm that allowed derivation of a spatial bias index. Two participants' data were lost due to a technical error in response acquisition, leaving $N=51$ (24 female) participants aged 20–26 ($M=22$).

3.1.2. Random dot motion (RDM) task

Participants completed a bilateral version of the random dot motion (RDM) task (Britten et al., 1992; Newsome et al., 1989) in which they fixated centrally and monitored peripheral patches of randomly moving dots (one patch in each hemi-field) for targets defined by instances of coherent motion in the downward direction (see Fig. 5B). The task was divided into discrete trials but in line with Kelly and O'Connell (2013), the dots moved incoherently upon initial presentation and coherent motion (the 'target') was then introduced after a random delay via a seamless step transition from incoherent to coherent motion. Stimuli were presented using a 51-cm CRT display (85 Hz; 1024×768 resolution).

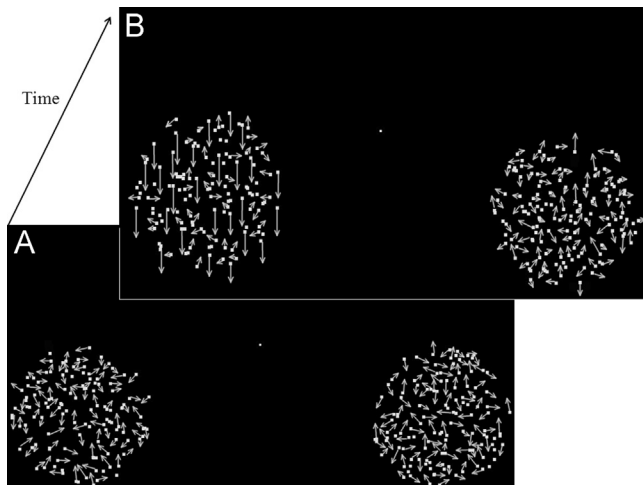


Fig. 5. Random dot motion (RDM) task. Participants fixated on the central dot and monitored the peripheral patches of randomly moving dots (A) for instances of coherent downward motion (B). Participants responded to downward motion targets via a speeded button press. Downward motion targets only occurred once per trial in either the left or right hemi-field (with equal probability), except for 'catch trials' in which no coherent motion appeared. Pre-target random motion lasted either 1.82, 2.22 or 2.62 s, chosen randomly on a trial-by-trial basis.

Motion coherence level was consistent during the experimental block and was determined for each participant via a four-down, one-up staircase beginning at 80% coherence and ending after 15 reversals. Steps down (decreased coherence/increased difficulty) were 11% and steps up were 13%—setting the up/down step ratio at .84, as advised by García-Pérez (1998) to converge on the individualised coherence level at which the participant could achieve approximately 85% accuracy. Each participant's individualised coherence level was calculated by taking the mean coherence at their final 14 reversals. The average of the individualised coherence levels was 22% ($SD=8.3$) and average accuracy during the experimental block was 84% ($SD=8.8$).

During both the staircase and experimental blocks the central fixation point was a white 5×5 -pixel square, and response to targets was given via a speeded simultaneous button press with the left and right hand, executed as soon as participants were sure they had perceived coherent downward motion in either the left or right hemi-field dot patch. A pre-target interval displaying random motion lasted either 1.82, 2.22 or 2.62 s, chosen randomly on a trial-by-trial basis. Coherent motion was always in the downward direction and only ever occurred once per trial in either the left or right hemi-field (with equal probability). Catch trials in which no coherent motion appeared were also included and participants were instructed to make no response on these trials. Catch trials occurred at random intervals with 25% frequency during the staircase block and 10% frequency during the experimental block. Any blink or fixation break (defined as a deviation >4 degrees from fixation point) during a trial was recorded by an Eyelink1000 eye tracker and the trial was immediately discontinued and restarted after a brief message reminding participants to "keep your eye on the spot". Thus all participants completed one experimental block containing 330 trials with no breaks from fixation or blinks, and 300 of these trials contained coherent downward motion targets.

All stimuli were white and presented against a black background. The circular dot patches were of 8 degrees diameter with the centre of each patch situated 4 degrees below and 10 degrees to the left or right of central fixation point (see Fig. 5). During random motion, an average of 118 white dots (each dot 6×6 pixels) were placed at random and independent positions within each of the left and right hemi-field circular patches at a rate of 21.25 frames/s. During coherent downward motion, a proportion of the dots (i.e. the coherence level) was randomly selected on each frame to be displaced by a fixed distance of .282 degrees in the downward direction on the following frame, resulting in a motion speed of 6 degrees/s.

3.1.3. Procedure

The task was carried out in a dimly lit sound-attenuated room with participants seated, supported by a chin rest, at 57 cm viewing distance. Again, although continuous EEG was recorded, only behavioural data are reported herein. Participants were instructed to maintain central fixation and to avoid blinking or moving during each trial, but were encouraged to blink and move in the short breaks between each trial, if desired. When participants had mastered a practice session, they were left alone in a darkened room to begin the staircase block (described above) which lasted approximately 15 min. After the staircase, each participant performed the experimental block (lasting approximately 35 min) at the specific coherence level determined during that participant's staircase block. Before beginning the task, participants read on-screen instructions and the experimenter explained the task verbally to ensure adequate comprehension. Participants were left alone in the recording room to complete each block.

3.1.4. Analysis

As in Experiment 1, an RT (ms) bias index that gives positive values for rightward spatial bias and negative values for leftward bias can be derived from this paradigm. Time-on-task was operationalized by dividing the trials into five time-bins (i.e. 66 trials per time-bin, equating to approximately 7 min per time-bin). This number of time-bins was chosen to ensure enough trials per bin for reliable measures of spatial bias within each time-bin, while still permitting adequate temporal resolution to see the dynamics of time-on-task shifts in spatial bias. For transparency we repeated the analysis splitting the total 330 trials into six (i.e. 55 trials per bin), four (i.e. 82 trials per bin) and three (i.e. 110 trials per bin) time-bins, and the key conclusions reported below hold in each case (see [Supplementary material](#)). Participant grouping for initial bias was based on leftward or rightward bias indices during the first time-bin, as in Experiment 1. The first time bin was included in the subsequent time-bin \times initial bias group ANOVA. We then excluded the data from the first time bin which was used to form the initial bias groups and ran the time-bin \times initial bias group analysis on the remaining four time bins. Finally, we tested for regression towards the mean by assessing whether initial spatial bias (during the first of five time-bins) and subsequent change in spatial bias were significantly correlated. We then applied an adjustment to the initial spatial bias scores to control for regression towards the mean and performed a time-on-task analysis including this adjusted initial RT bias data.

3.2. Results

As in Experiment 1, when the data used to split participants into initial bias groups was included in the subsequent time-on-task analysis the results were in line with those of [Benwell et al. \(2013b\)](#). A time-bin (5 bins) by initial bias group interaction [$F(4,196)=5.03$, $p=.001$] was driven by a statistically significant linear rightward shift in RT bias over time in the initial LB group [linear $F(1,20)=16.95$, $p=.001$; quadratic $F=.133$, $p=.719$; cubic $F=.96$, $p=.345$; fourth order $F=.02$, $p=.889$] and a non-linear leftward shift in RT bias in the initial RB group [linear $F(1,29)=.66$, $p=.422$; quadratic $F=8.53$, $p=.007$; cubic $F=6.28$, $p=.018$; and fourth order $F=2.04$, $p=.164$] (see [Fig. 6A](#)). When the data from the first of five time bins was discarded after having been used for participant sorting, and the analysis carried out on the remaining four time bins (bins 2–5 in [Fig. 6A](#)), the rightward linear shift in RT

bias in the initial LB group was still present [linear $F(1,20)=4.66$, $p=.043$; quadratic $F=.12$, $p=.665$; and cubic $F=.193$, $p=.665$] and a non-significant shift – also in the rightward direction – was present in the initial RB group [linear $F(1,29)=3.69$, $p=.065$; quadratic $F=.01$, $p=.952$; and cubic $F=.29$, $p=.595$]. Thus the differential direction of spatial bias shift was abolished when the time-bin 1 data used to group participants was discarded (i.e. see bins 2–5 in [Fig. 6A](#)).

3.2.1. Confirmation of the regression towards the mean effect

As in Experiment 1, here we assessed whether initial bias values and subsequent changes were significantly correlated, providing a further test for regression towards the mean ([Barnett et al., 2005](#); [Rocconi and Ethington, 2009](#)). We calculated the change in RT asymmetry between the initial time-on-task bin and the fifth/final time-on-task bin for each participant and regressed this against initial RT bias. This revealed a significant correlation, $r=.494$, $p>.001$, confirming that a regression towards the mean effect exists. We note again that although a similar result was reported by [Benwell et al. \(2013b\)](#) ([Fig. 6](#)), our conclusions are antithetical. Namely, the existence of the significant correlation indicates regression to the mean.

3.2.2. Statistical adjustment for regression towards the mean

After confirming the existence of regression towards the mean, we established the test–retest reliability of the initial bias measure (see [Fig. 7](#)) and performed the same adjustment to initial bias scores (see [Experiment 1](#)) to reduce the influence of regression to the mean ([Roberts, 1980](#)). The ANOVA using the adjusted initial bias scores revealed a non-significant main effect of time-on-task (5 bins) [$F(4,196)=2.20$, $p=.071$], and no significant time-bin by initial bias group interaction [$F(4,196)=.34$, $p=.851$]. Thus when controlling for bias introduced by regression towards the mean ([Fig. 6B](#)) the differential shift in spatial bias reported in [Fig. 6A](#) is abolished.

3.2.3. Test–retest reliability of initial spatial bias on RDM task

Twenty-seven healthy right handed participants (17 female) aged 21–28 ($M=23.6$) completed the paradigm on two separate days in order to assess the test–retest reliability of our initial bias measure. The procedure was identical to that reported above, except participants completed 110 trials of the RDM task, instead

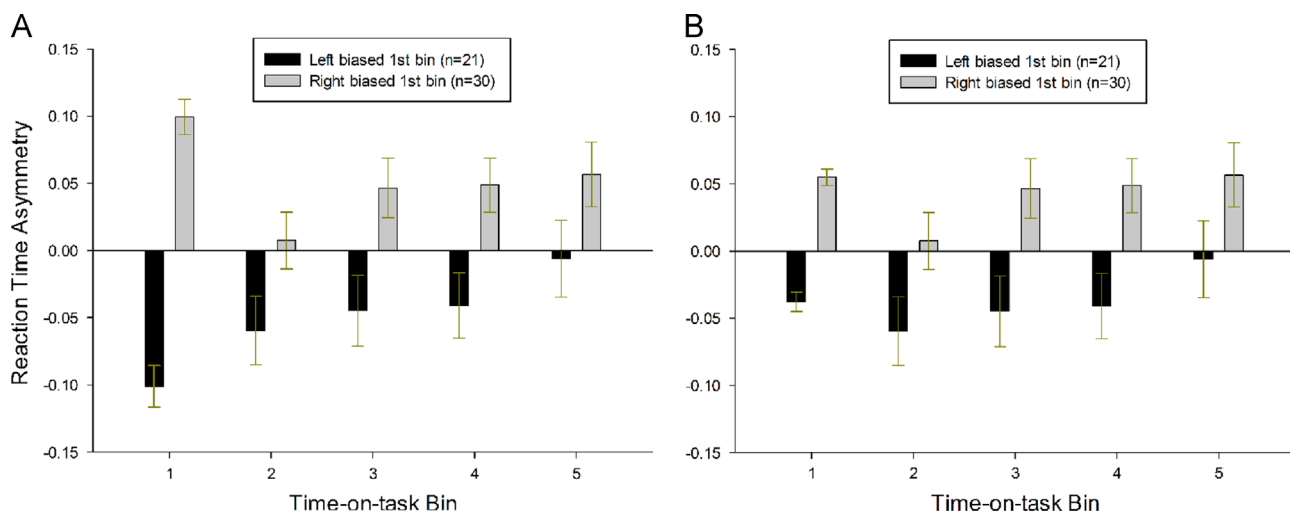


Fig. 6. An apparent differential direction of spatial bias shift over time is abolished after controlling for bias introduced by regression towards the mean. (A) Participants are grouped according to bias in the 1st time-bin and this grouping data is included in the time-on-task analysis, producing an apparent differential direction of spatial bias shift over time between the two groups. (B) When scores from the 1st time-bin are adjusted to control for regression towards the mean, the apparent differential shift in direction of spatial bias is abolished. Error bars represent standard error.

of the full 330 trials. Each participant's initial bias measurements were taken from the first 66 trials (equivalent to the first of the 5 time-bins in Fig. 6A above) on each of the two days and analysed with a Pearson's correlation. This revealed that the initial bias measure was significantly correlated across the two sessions, [Pearson $r = .464$, $p = .015$; Spearman $\rho = .405$, $p = .036$], see Fig. 7 below.

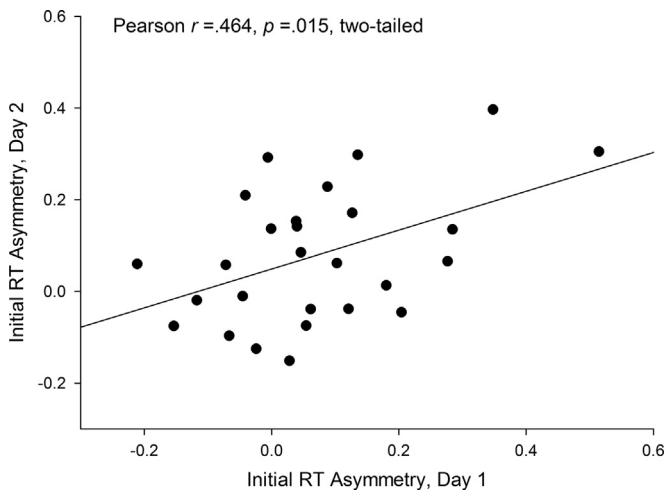


Fig. 7. Test–retest reliability of initial spatial bias on the RDM task. Relationship between initial spatial bias scores across separate testing sessions (at least 6 days apart) on the random dot motion (RDM) task. The significant Pearson's correlation between initial bias scores confirms that the initial bias is relatively stable over time.

4. Discussion

The observation by Benwell et al. (2013b) that time-on-task has opposite effects on spatial bias in individuals who are initially classified as left-, compared to right-, biased is a potentially pivotal finding that would demand a re-evaluation of current models of the neural networks governing spatial attention. In both Experiments 1 and 2, we used novel spatial attentions tasks to provide confirmation of Benwell et al.'s differential time-on task effects, whereby participants with an initial LB showed a significant rightward shift in spatial bias over the course of the experimental session, whereas participants with an initial RB showed a non-significant leftward shift (Figs. 2A, 3A and 6A). Subsequent analysis however showed that the apparent differential shifts with time-on-task might be driven by regression to the mean due to the participant grouping and analysis method employed (Fig. 2B and C). The differential direction of time-on-task shift does not hold when regression towards the mean is controlled by excluding the initial data used to split participants from subsequent analysis. Nor does it hold when the influence of regression towards the mean is statistically controlled by adjusting the initial spatial bias scores (Roberts, 1980). Therefore, time-on-task may not truly have an opposite effect on the direction of spatial bias drift in participants with an initial LB versus participants with an initial RB.

A number of methodological differences between the current study and those of Benwell et al. (2013b) must be acknowledged. First, the current study used two different paradigms to measure spatial bias. The paradigms differ to the landmark task used by Benwell et al. (2013b) to gauge visuospatial bias. The current tasks are more similar to the fixation-controlled, lateral stimuli paradigms that have been used to document participant factors (i.e. genetics and anatomy) underpinning individual differences in visuospatial bias (Newman et al., 2012; Thiebaut de Schotten

et al., 2011) and on which shifts in visuospatial bias with time-on-task and decreased alertness have been observed (Dodds et al., 2008; Matthias et al., 2009; Newman et al., 2013). Since the pattern of data presented in Benwell et al. was confirmed using both of our paradigms, we argue that this shows the generalisability of the results across spatial attention paradigms and validates our subsequent demonstration that those results may be driven by regression to the mean. Second, Benwell et al. used 95% CIs from zero bias during the first time-bin to categorise participants into initial bias groups, while the current study categorised participants according to whether their RT bias index was positive or negative during the first time-bin and thus did not include a 'no initial bias group'. The use of 95% CIs to categorise participants creates more extreme left and right initial bias groups which may be prone to regression towards the mean. However, since the use of 95% CIs to categorise participants provides more confident categorisation into initial bias groups, it could be argued that this should attenuate the effect of regression towards the mean. Even if this argument is accepted, some portion of Benwell et al.'s subjects will still be categorised into the initial LB/RB group based on random variation, unless the test–retest correlation coefficient for initial block bias is 1.0. Via a number of correlation analyses, Benwell et al. demonstrate that the test–retest correlation coefficient for initial bias is approximately .77, and therefore there would still be a tendency for the mean bias of each group to have a relative shift toward zero after the first block due to the principle of regression to the mean (Barnett et al., 2005; Galton, 1886; Stigler, 1997). Third, Benwell et al. included only the first versus final time-bin in the time-on-task \times initial bias group ANOVAs and conducted separate linear regression analyses across all time-bins to assess whether the time-on-task related change in spatial bias fitted a linear model. The current study instead included all time-bins in the time-on-task \times group ANOVA and used polynomial contrasts to assess whether a linear model is the best fit for the time-on-task related change in spatial bias. Linear regression by definition will fit data to a linear model, while reporting all polynomial contrasts takes into account the possibility that the data may be also explained by a higher order model (e.g. quadratic, cubic, 4th order, etc.).

The significant test–retest reliability of initial spatial bias reported here and by Benwell et al. provides further evidence that the direction/magnitude of baseline spatial bias is relatively stable (Tomer, 2008). However these data cannot establish the existence of differential categories for the direction of spatial bias shift over time because the test–retest sessions only included initial trials rather than the full task. Nonetheless, stable trait-like differences in spatial attention bias likely exist across the healthy population and have been linked to such participant factors as underlying genetics, receptor binding and neuroanatomy (Bellgrove et al., 2007; Newman et al., 2012; Thiebaut de Schotten et al., 2011; Tomer, 2008). Many studies have now replicated the overall rightward shift in spatial bias with decreasing alertness over time (Benwell et al., 2013a; Dodds et al., 2008, 2009; Dufour et al., 2007; Manly et al., 2005; Newman et al., 2013). Moreover, Newman et al. (2013) showed that pre-target α power became more prominent over the right, relative to left, hemisphere as the reaction time task progressed over 48-min and that this change was correlated with a significant rightward shift in spatial bias. These data are broadly consistent with the notion that fatigue of the right-hemisphere lateralised ventral 'alertness' network asymmetrically affects recruitment of the conjoined dorsal orienting network thus driving attention rightward. Although one could conceive that a range of individual participant factors (genetic, pharmacological, and neuroanatomical) could modulate activity within the attention networks and thus the time-on-task modulation of spatial bias, we contend that such evidence is currently lacking. Although promising, our experiments suggest that the findings of Benwell et al. (2013b) are likely driven, at least in part, by regression towards the mean and therefore may not be

indicative of true participant/observer subtypes. A re-analysis of Benwell et al.'s data, adjusting the initial scores to control for regression to the mean, or discarding the initial trials used to categorise participants from subsequent time-on-task analyses, may give clearer evidence regarding the existence of true participant/observer subtypes in the direction of spatial bias shift over time.

Acknowledgements

This research was supported by funding from the Australian Research Council under the Future Fellowship scheme to MAB [FT130101488].

Appendix A. Supplement material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.neuropsychologia.2014.09.017>.

References

- Barnett, A.G., van der Pols, J.C., Dobson, A.J., 2005. Regression to the mean: what it is and how to deal with it. *International Journal of Epidemiology* 34 (1), 215–220.
- Bellgrove, M.A., Chambers, C.D., Johnson, K.A., Daibhis, A., Daly, M., Hawi, Z., Lambert, D., et al., 2007. Dopaminergic genotype biases spatial attention in healthy children. *Molecular Psychiatry* 12 (8), 786–792.
- Benwell, C.S.Y., Harvey, M., Gardner, S., Thut, G., 2013a. Stimulus- and state-dependence of systematic bias in spatial attention: additive effects of stimulus-size and time-on-task. *Cortex* 49 (3), 827–836.
- Benwell, C.S.Y., Thut, G., Learmonth, G., Harvey, M., 2013b. Spatial attention: differential shifts in pseudoneglect direction with time-on-task and initial bias support the idea of observer subtypes. *Neuropsychologia* 51 (13), 2747–2756.
- Bowers, D., Heilman, K.M., 1980. Pseudoneglect: effects of hemispace on a tactile line bisection task. *Neuropsychologia* 18 (4–5), 491–498.
- Britten, K.H., Shadlen, M.N., Newsome, W.T., Movshon, J.A., 1992. The analysis of visual motion: a comparison of neuronal and psychophysical performance. *Journal of Neuroscience* 12 (12), 4745–4765.
- Corbetta, M., Shulman, G.L., 2011. Spatial neglect and attention networks. *Annual Review of Neuroscience* 34 (24), 569–599.
- Dodds, C.M., van Belle, J., Peers, P.V., Dove, A., Cusack, R., Duncan, J., Manly, T., 2008. The effects of time-on-task and concurrent cognitive load on normal visuospatial bias. *Neuropsychology* 22 (4), 545–552.
- Dodds, C.M., Müller, U., Manly, T., 2009. Effects of psychostimulants on alertness and spatial bias in healthy participants. *Journal of Cognitive Neuroscience* 21 (3), 529–537.
- Dufour, A., Touzalin, P., Candas, V., 2007. Time-on-task effect in pseudoneglect. *Experimental Brain Research* 176 (3), 532–537.
- Finke, K., Dodds, C.M., Bublak, P., Regenthal, R., Baumann, F., Manly, T., Müller, U., 2010. Effects of modafinil and methylphenidate on visual attention capacity: a TVA-based study. *Psychopharmacology* 210 (3), 317–329. <http://dx.doi.org/10.1007/s00213-010-1823-x>.
- Fleet, W.S., Valenstein, E., Watson, R.T., Heilman, K.M., 1987. Dopamine agonist therapy for neglect in humans. *Neurology* 37 (11), 1765–1770.
- Galton, F., 1886. Regression towards mediocrity in hereditary stature. *Journal of the Anthropological Institute* 15, 246–263.
- García-Pérez, M.A., 1998. Forced-choice staircases with fixed step sizes: asymptotic and small-sample properties. *Vision Research* 38 (12), 1861–1881.
- Geminiani, G., Bottini, G., Sterzi, R., 1998. Dopaminergic stimulation in unilateral neglect. *Journal of Neurology Neurosurgery and Psychiatry* 65 (3), 344–347.
- George, M.S., Mercer, J.S., Walker, R., Manly, T., 2008. A demonstration of endogenous modulation of unilateral spatial neglect: the impact of apparent time-pressure on spatial bias. *Journal of the International Neuropsychological Society* 14 (1), 33–41.
- Gorgoraptis, N., Mah, Y.H., MacHner, B., Singh-Curry, V., Malhotra, P., Hadji-Michael, M., Cohen, D., et al., 2012. The effects of the dopamine agonist rotigotine on hemispatial neglect following stroke. *Brain* 135 (8), 2478–2491.
- Grujic, Z., Mapstone, M., Gitelman, D.R., Johnson, N., Weintraub, S., Hays, A., Kwasnica, C., et al., 1998. Dopamine agonists reorient visual exploration away from the neglected hemispace. *Neurology* 51 (5), 1395–1398.
- Jewell, G., McCourt, M.E., 2000. Pseudoneglect: a review and meta-analysis of performance factors in line bisection tasks. *Neuropsychologia* 38 (1), 93–110.
- Kelly, S.P., O'Connell, R.G., 2013. Internal and external influences on the rate of sensory evidence accumulation in the human brain. *Journal of Neuroscience* 33 (50), 19434–19441.
- Lazar, R.M., Fitzsimmons, B.F., Marshall, R.S., Berman, M.F., Bustillo, M.A., Young, W. L., Mohr, J.P., et al., 2002. Reemergence of stroke deficits with midazolam challenge. *Stroke* 33 (1), 283–285.
- Loftus, A.M., Nicholls, M.E.R., 2012. Testing the activation-orientation account of spatial attentional asymmetries using transcranial direct current stimulation. *Neuropsychologia* 50 (11), 2573–2576.
- Malhotra, P.A., Parton, A.D., Greenwood, R., Husain, M., 2006. Noradrenergic modulation of space exploration in visual neglect. *Annals of Neurology* 59 (1), 186–190.
- Manly, T., Dobler, V.B., Dodds, C.M., George, M.A., 2005. Rightward shift in spatial awareness with declining alertness. *Neuropsychologia* 43 (12), 1721–1728.
- Matthias, E., Bublak, P., Costa, A., Müller, H.J., Schneider, W.X., Finke, K., 2009. Attentional and sensory effects of lowered levels of intrinsic alertness. *Neuropsychologia* 47 (14), 3255–3264. <http://dx.doi.org/10.1016/j.neuropsychologia.2009.08.004>.
- Mesulam, M.M., 1981. A cortical network for directed attention and unilateral neglect. *Annals of Neurology* 10 (4), 309–325.
- Mukand, J.A., Guilmette, T.J., Allen, D.G., Brown, L.K., Brown, S.L., Tober, K.L., VanDyck, W.R., 2001. Dopaminergic therapy with carbidopa L-dopa for left neglect after stroke: a case series. *Archives of Physical Medicine and Rehabilitation* 82 (9), 1279–1282.
- Newman, D.P., O'Connell, R.G., Bellgrove, M.A., 2013. Linking time-on-task, spatial bias and hemispheric activation asymmetry: a neural correlate of rightward attention drift. *Neuropsychologia* 51 (7), 1215–1223.
- Newman, D.P., O'Connell, R.G., Nathan, P.J., Bellgrove, M.A., 2012. Dopamine transporter genotype predicts attentional asymmetry in healthy adults. *Neuropsychologia* 50 (12), 2823–2829.
- Newsome, W.T., Britten, K.H., Movshon, J.A., 1989. Neuronal correlates of a perceptual decision. *Nature* 341 (6237), 52–54.
- O'Connell, R.G., Schneider, D., Hester, R., Mattingley, J.B., Bellgrove, M.A., 2011. Attentional load asymmetrically affects early electrophysiological indices of visual orienting. *Cerebral Cortex* 21 (5), 1056–1065.
- Posner, M.I., Petersen, S.E., 1990. The attention system of the human brain. *Annual Review of Neuroscience* 13, 25–42.
- Roberts, A.O.H., 1980. Regression toward the mean and the regression-effect bias. In: Echternacht, G. (Ed.), *New directions for testing and measurement*, Vol. 8. Jossey-Bass, San Francisco, pp. 59–82.
- Robertson, I.H., Mattingley, J.B., Rorden, C., Driver, J., 1998. Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature* 395 (6698), 169–172.
- Rocconi, L.M., Ethington, C.A., 2009. Assessing longitudinal change: adjustment for regression to the mean effects. *Research in Higher Education* 50 (4), 368–376. <http://dx.doi.org/10.1007/s11162-009-9119-x>.
- Schmitz, R., Deliens, G., Mary, A., Urbain, C., Peigneux, P., 2011. Selective modulations of attentional asymmetries after sleep deprivation. *Neuropsychologia* 49 (12), 3351–3360.
- Stigler, S.M., 1997. Regression towards the mean, historically considered. *Statistical Methods in Medical Research* 6, 103–114.
- Thiebaut de Schotten, M., Dell'Acqua, F., Forkel, S.J., Simmons, A., Vergani, F., Murphy, D.G.M., Catani, M., 2011. A lateralized brain network for visuospatial attention. *Nature Neuroscience* 14 (10), 1245–1246.
- Tomer, R., 2008. Attentional bias as trait: correlations with novelty seeking. *Neuropsychologia* 46 (7), 2064–2070.
- Voyer, D., Voyer, S.D., Tramoto, L., 2012. Free-viewing laterality tasks: a multilevel meta-analysis. *Neuropsychology* 26 (5), 551–567.