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1 **Individual differences in direction-selective motion adaptation revealed by change-**
2 **detection performance.**

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1 **Abstract**

2

3 The motion aftereffect (MAE) and motion adaptation in general are usually considered to be
4 universal phenomena. However, in a preliminary study using a bias-free measure of the MAE
5 we found some individuals who showed at best a weak effect of adaptation. These same
6 individuals also performed poorly in a “change detection” test of motion adaptation based on
7 visual search, leading to the conjecture that there is a bimodality in the population with
8 respect to motion adaptation. The present study tested this possibility by screening 102
9 participants on two versions of the change-detection task while also considering potential
10 confounding factors including eye movements, practice-based improvements, and deficits in
11 visual search ability. The 5 strongest and the 5 weakest change detectors were selected for
12 further testing of motion detection and contrast detection after adaptation. Data showed an
13 inverse association between change-detection ability and performance in the motion-
14 detection task. We extend previous findings by also showing *i*) the weakest change detectors
15 exhibit less direction selectivity in their contrast thresholds after adapting to drifting gratings
16 and *ii*) the ability to detect change in motion direction correlates with the ability to detect
17 change in spatial orientation. Group differences between the strongest and weakest change
18 detectors cannot be attributed to a lack of practice, nor can they be explained by poor fixation
19 ability. Our results suggest genuine individual differences in the degree to which adaptation is
20 specific to stimulus orientation and direction of motion.

21

22 **Keywords: Psychophysics; Motion Adaptation; Change Detection; Visual Search;**
23 **Individual Differences**

24

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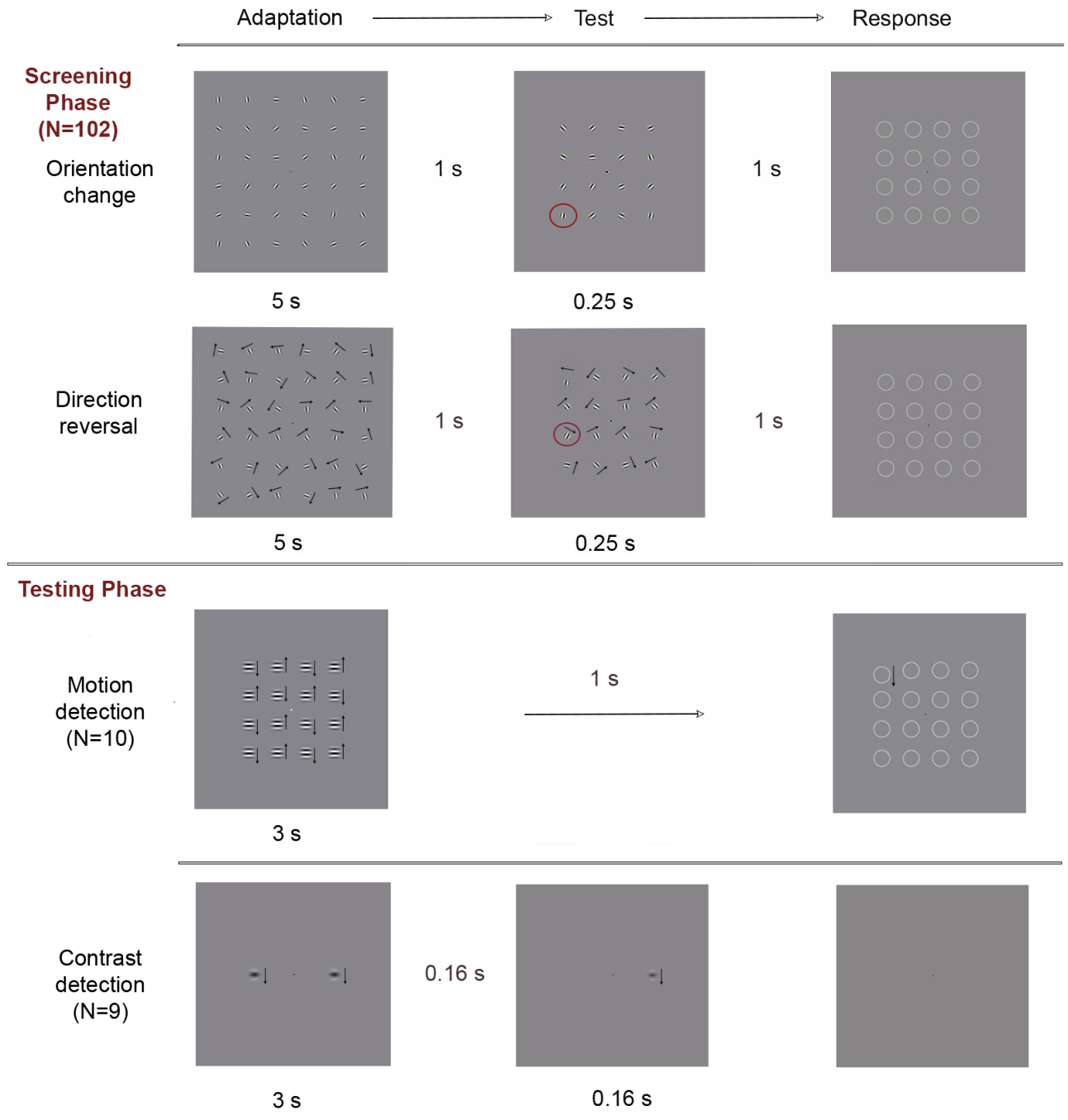
1 Introduction

2 Large individual differences in the duration of the MAE have previously been reported by
3 Granit (1928) and Sinha (1952), including the remarkable and neglected case noted by
4 Grindley (1930) of an observer who saw no movement aftereffect whatsoever. These reports
5 have been largely neglected, in part because the traditional duration measure of the MAE is
6 highly susceptible to criterion and other cognitive biases. It is hard to decide when a stimulus
7 has stopped moving, particularly when the observer knows that it is not really moving at all.
8 To address this issue, we have developed two bias-free methods for measuring motion
9 adaptation that are based on the ability of observers to detect a target that can be either
10 camouflaged by adaptation, or made visible only through adaption.

11 The first method is similar to the camouflage test for dichromacy described by Morgan,
12 Mollon and Adam (1992). For normal trichromats, visual search for an odd-man-out
13 differing in orientation from other elements in the texture is rendered more difficult by
14 randomly colouring the texture elements, but not for dichromats. Similarly, we have shown
15 that adapting to a texture of moving elements makes it harder to find a moving element
16 amongst a set of stationary elements (Figure 1, Row 3). Presumably, the apparent movement
17 of all the elements due to the MAE makes it harder to see the really moving element.

18 The second method is also a detection task, but in this case adaptation is required to detect the
19 target, rather than interfering with it. Studies of “change blindness” (O’Regan et al., 1996;
20 Rensink et al., 1997; Wright et al., 2000; Wright et al., 2002) have shown that the human
21 visual system is severely limited in its ability to detect even large changes in images between
22 scenes, such as the removal of an engine from an aircraft. Paradoxically, however, change in
23 a scene can be a powerful method for detection. For instance, before *in silico* methods,
24 astronomers detected the presence of planets, comets, and asteroids by presenting two images
25 in rapid succession, taken at the same sidereal time but on different dates. Due to its
26 movement, any object that had changed position against the background of the fixed stars
27 would pop out. The critical difference between these two lines of research is that change
28 blindness experiments deliberately introduce a blank interval or mask between two images
29 that is long enough to prevent low-level motion detection. It has thus been generally assumed
30 that motion detection is the only useful mechanism available to the visual system for
31 detecting uncued changes within complex images.

1 Nonetheless, detection of new and/or different objects can survive the introduction of an
2 interval that contains a stationary fixation point but is otherwise blank. This was
3 demonstrated using the direction-change (Morgan & Solomon, 2019) and orientation-change
4 (Morgan & Solomon, 2020, 2021) paradigms illustrated in the top two rows of Figure 1. In
5 both paradigms, the test array contains 1 Gabor pattern (the target) that differs from its
6 spatially corresponding adaptor. The other 15 (the distractors) do not. After 5 s adaptation to
7 a 6×6 array of Gabor patches with drifting (3.75 Hz) carriers, there is a blank interval
8 followed by a test in which the original 4×4 moving elements are re-presented, except that
9 one of them has changed in orientation (top row) or motion direction (second row). This is
10 followed by an array of placeholder circles. The observer's task is to use a mouse to click on
11 the "changed" position. In a variant of the task (not illustrated) all the elements except one in
12 the test array are changed, and the task is to click on the position of the "non-changed"
13 element. Whereas this non-change-detection task proved to be virtually impossible, for at
14 least some subjects, the change-detection task was relatively easy.



1

2 **Figure 1. Stimulus sequence for each task.** Arrows have been added to denote direction of
 3 drift. A maroon circle has been added to the target in the change-detection tasks (first two
 4 rows). For explanation see the text.

5

6 The relative facility with which changed targets can be detected, as compared to targets
 7 defined by a lack of change (i.e., when it is the distractors that change direction), suggests
 8 that detection is not based on adaptation-induced changes in the target's apparent contrast,

1 temporal delay, or velocity, since none of these qualities are associated with similarly strong
2 search asymmetries (Morgan & Solomon, 2020). Nor does change-detection depend on
3 deliberate memorization of the adapting stimuli, because change-detection is unaffected by
4 attentional load from an irrelevant central fixation task (Morgan & Solomon, 2021).
5 Consequently, there is a strong argument that change-detection reflects a fundamental
6 sensory process, based upon the automatic attraction of attention to a novel stimulus
7 appearing in the visual field after adaptation.

8
9 The facility for change-detection notwithstanding, Morgan and Solomon (2019) reported a
10 correlation across 10 participants between direction-change-detection and adaptation-induced
11 increases in the response time for detecting a lone moving target when the motion aftereffect
12 produced apparent motion in all test items. (This motion-detection task is depicted in Row 3
13 of Figure 1.) This correlation suggested that individual differences in the strength of motion
14 (and possibly other forms of) adaptation might systematically affect performance in a variety
15 of associated psychophysical tasks.

16
17 The present study describes a test of that suggestion. We screened a large sample of
18 participants on two change-detection tasks. The strongest and weakest change-detectors were
19 then subjected to two further psychophysical tests of adaptation to motion: motion detection
20 (as in Morgan & Solomon 2019), and contrast detection (as in Morgan et al., 2006, 2011).
21 Group-level differences between the performances of strong and weak change-detectors are
22 apparent in the data from these two tests.

23 24 **Method**

25 26 *Participants*

27 Participants included members of the public, university students, and staff recruited via the
28 Sona recruitment platform (sona-systems.com) and local advertisements. All attested to
29 normal or corrected-to-normal visual acuity with no known visual pathology including
30 sensitivity to flickering stimuli (e.g., epilepsy). Experiments took place between December
31 2021 and May 2023. The study was approved by the Proportionate Review Research Ethics
32 Committee, and written informed consent was provided by all participants. Payment for
33 participation was commensurate with the London Living Wage.

34

1 The study was divided into a two-task screening phase and a three-task testing phase. Of the
2 102 participants (mean age: 26.3 years, range: 18–60) who began the screening phase, 97
3 (mean age: 26.5 years) managed to complete both tasks, and 2 of these produced data that had
4 to be excluded from further analysis due to a calibration error in the eye-movement
5 recording. From the remaining 95 (24 male, 71 female), we recruited 5 of the strongest (mean
6 age: 25 years, range: 19–33) and 5 of the weakest change detectors (mean age 30 years,
7 range: 19–51) to participate in the testing phase. During the course of the study, 11 subjects
8 (identified in Figure 2) withdrew their participation.

9

10 *Apparatus*

11 Right eye gaze position was sampled at 1000 Hz using a table-mounted infrared camera
12 (Eyelink 1000, SR Research Ltd., Mississauga, Ontario, Canada) throughout the screening
13 phase and the motion-detection task in the testing phase. The camera was placed to the lower
14 right visual field, 0.7 m from the eye. Prior to each block of trials, gaze position was
15 calibrated with a fixation target positioned at the centre and 14.25 degrees up, down, left, and
16 right of the centre of a gamma-corrected 19" Dell M992 monitor in a darkened room. The
17 monitor's refresh rate was 60 Hz, and it was viewed from a chinrest at 0.8 m, so that one
18 pixel subtended 1.2 arcmin at the observer's eye. The Monitor's average luminance was kept
19 halfway between the maximum and minimum of 124.7 and 0.2 cd/m². Viewing was binocular
20 through natural pupils, with observers wearing their normal correcting lens for the viewing
21 distance if necessary. The experimental protocol was implemented using MATLAB (The
22 MathWorks Inc., Natick, Massachusetts, USA), the Psychtoolbox (Brainard, 1997; Kleiner &
23 Brainard, 2007; Pelli, 1997), and the Eyelink toolbox (Cornelissen, 2002).

24

25 Change-detection tasks

26 *Stimulus*

27 Each Gabor pattern was the product of a randomly oriented 3.12 cycle/° sinusoidal
28 modulation of luminance having a Michelson contrast of 0.5 and a circular Gaussian blob
29 with spatial spread $\sigma = 0.16^\circ$. Centre-to-centre distance of adjacent Gabor patterns was 2.9° .
30 In the orientation-change task, each sinusoid reversed phase at a rate of 3.75 Hz and the target
31 Gabor pattern was rotated 90° with respect to its spatially corresponding adaptor. In the
32 direction-change task, each sinusoid drifted in a random direction with a temporal frequency
33 of 3.75 Hz and the target Gabor pattern drifted in the direction opposite to its spatially
34 corresponding adaptor. In all other respects, the two tasks were identical.

1

2 *Procedure*

3 Initially, each participant completed 1 block of motion-change trials and 1 block of direction-
4 change trials. The order was randomized across participants. Change-detection performance
5 was determined from the final 20 trials of a 50-trial block. In each of these 20 trials, a 5-s
6 adapting array of 36 Gabor patterns was followed by a 1-s blank interval. A 0.25-s test array
7 of 16 Gabor patterns then appeared, which was followed by another 1-s blank interval, and
8 then the 16-circle response screen (see Figure 1). Participants were instructed to maintain
9 fixation upon a central point that remained visible throughout the experiment and were
10 required to identify the test array's odd-man-out by clicking inside its spatially corresponding
11 circle in the response screen. The actual target's position was indicated by the disappearance
12 of its spatially corresponding circle, immediately after the participant's click.

13

14 During the first 30 trials of each block, to attract attention toward the subtle, evanescent cues
15 to the correct response (Morgan & Solomon, 2020), we added a short (0, 0.017, 0.033, 0.067,
16 or 0.133 s), randomly selected delay between onset of the target (which always followed the
17 offset of the adapting array by exactly 1 s) and onset of the distractors. At the longer delays
18 this caused the delayed target to “pop out.” Subjectively, the delay was difficult to distinguish
19 from the “change” cue, so the procedure acted as a form of training for the subjects. Note that
20 the zero-delay condition allowed measurement of the performance with a novelty cue alone.

21

22 Although different adapting arrays were used in different 50-trial blocks, the same adapting
23 array was used for every trial within each block. Participants 61–102 all used the same
24 adapting arrays.

25

26 Motion-detection tasks

27 *Stimulus*

28 Each Gabor pattern was the product of a horizontally oriented 3.99-cycle/° sinusoidal
29 modulation of luminance having a Michelson contrast of 0.6 and a circular blob with a ($\sigma =$
30 0.20°) Gaussian profile truncated at $\pm 2\sigma$. Centre-to-centre distance of adjacent Gabor patterns
31 was 1.8°. Note this stimulus geometry differs slightly from that used in the change-detection
32 tasks. It replicates the stimulus geometry used by Morgan and Solomon (2019). In the
33 baseline condition, sinusoids were static. In the experimental condition, each sinusoid drifted

1 up or down randomly with a temporal frequency of 7.5 Hz, until response. In all other
2 respects, the two conditions were identical.

3

4 *Procedure*

5 On each trial, a 3-s adapting array of 36 Gabor patterns was followed by a 1-s blank interval,
6 which was followed by the 16-circle response screen (see Figure 1). Encouraged to maintain
7 fixation upon a central point that remained visible throughout the experiment, participants
8 were required to click within the response screen's one circle that was actually moving. (This
9 target circle was moving up or down with a speed of 8.2 arcmin/s.) Note that a strong motion
10 aftereffect would induce apparent motion in all the circles. Participants were encouraged to
11 respond quickly and accurately as possible. The actual target circle was indicated by its
12 disappearance, immediately after the participant's click.

13

14 Each participant completed at least 3 blocks of 64 trials in each of the two conditions. Half
15 the trials in the experimental condition featured a target moving in the direction opposite to
16 its spatially corresponding adaptor. The other half featured a target moving in the same
17 direction as its spatially corresponding adaptor. The same adapting array was used for every
18 trial within each block. All participants used the same adapting arrays.

19

20 Contrast-detection task

21 *Stimulus*

22 Each Gabor pattern was the product of a horizontally oriented 0.78-cycle/° sinusoidal
23 modulation of luminance and a circular Gaussian blob with spatial spread $\sigma = 0.32^\circ$. Gabor
24 patterns were placed on the horizontal meridian, 4.4° left and/or right of the fixation point.
25 All sinusoids drifted up or down with a temporal frequency of 15 Hz. During adaptation, the
26 Michelson contrast of each sinusoid was 0.9. This stimulus nearly matches the stimulus used
27 by Morgan et al. (2006), who documented direction-specific threshold elevations. The only
28 differences are the temporal frequency (20% larger here, due to the monitor's higher refresh
29 rate) and the viewing distance (65% smaller here, to match that of the change-detection and
30 motion-detection tasks).

31

32 *Procedure*

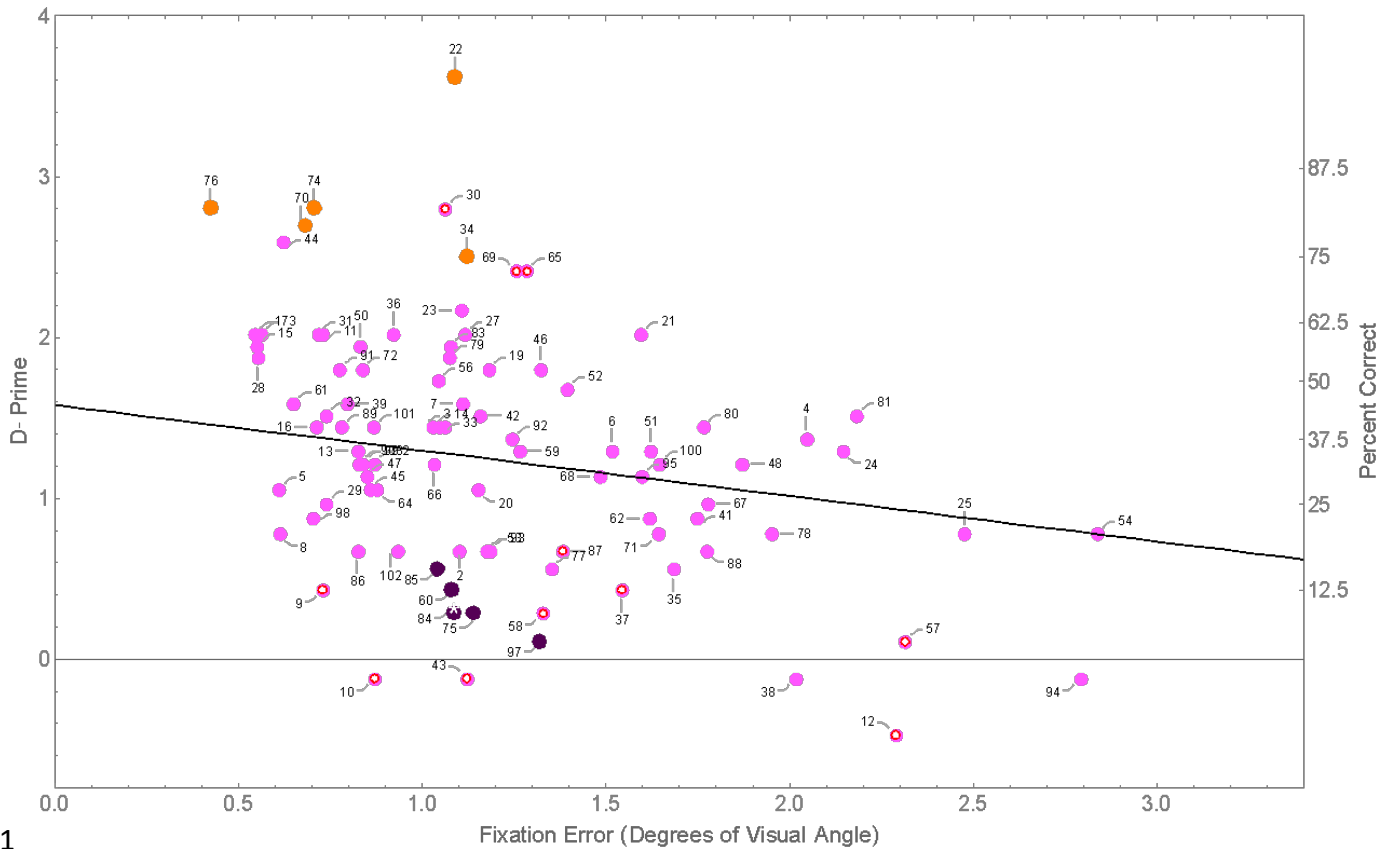
33 Each trial began with an adaptation period, during which two identical Gabor patterns drifted
34 vertically on either side of fixation (see Figure 1). The adaptation period lasted 30 s on the

1 initial trial and every 10th trial thereafter, and 3 s on all other trials. Adaptation was followed
2 by a 0.16 s blank screen, after which a single Gabor pattern was presented for 0.16 s, either to
3 the left or right of fixation. The observer was required to indicate the position of this target
4 with a keypress.

5
6 On half the trials, the target drifted in the same direction as the adapting Gabor patterns; on
7 the other half it drifted in the opposite direction. Target contrast in each of these two
8 conditions was randomly selected from a 2-dB interval surrounding QUEST's (Watson &
9 Pelli, 1983) maximum *a posteriori* estimate for the 81%-correct threshold.

11 **Results**

12 There was a significant correlation in performance between the two change-detection tasks
13 (Spearman's $\rho = 0.31$, $p = 0.002$). Combined performances on the two change-detection
14 tasks were converted to d-prime (d') values (Green and Swets, 1966; Hacker & Ratcliff,
15 1979). There was no significant difference between males and females (Welch's $t = -1.03$, p
16 $= 0.31$). Fixation error was defined as the mean Euclidean distance from the fixation point to
17 the participant's centre of gaze. Figure 2 shows that there was a significant negative
18 association between d' and average fixation error across both tasks (Spearman's $\rho = -0.40$, p
19 < 0.0001), which survived (with Spearman's $\rho = -0.35$, $p < 0.001$ and Pearson's $r = -0.34$, p
20 < 0.002) removal of the 7 data points with Cook's distances higher than three times the mean
21 of all Cook's distances removed. Participants with fixation errors greater than 2 degrees of
22 visual angle were considered unsuitable for further testing. A total of 14 participants with $d' <$
23 0.43 were retested to allow for previously observed improvements in change-detection after
24 practice (Morgan & Solomon, 2019). Symbols in Figure 2 illustrate trial blocks with the
25 smallest fixation errors. Although these trial blocks usually contained the participant's best
26 change-detection performances, P77 is a notable exception. Calibration artifacts due to this
27 participant's corrective eyewear prevented measurements of fixation error in high-scoring
28 blocks. Consequently, P77 was not considered amongst the weakest change detectors, whose
29 data points fall furthest below the regression line shown in Figure 2, excluding distances
30 below the horizontal line at $d' = 0$. The strongest change detectors were those participants
31 whose data points lie furthest above the regression line shown in Figure 2.



1
 2 **Figure 2.** Change-detection requires stable fixation. Each point on the graph represents one
 3 participant. Combined performances on the two change-detection tasks were converted to d-
 4 prime (d') values and used to identify the 5 strongest (orange) and 5 weakest (dark purple)
 5 ‘change detectors’. Black line shows a least-squares fit to the data. Subjects who withdrew
 6 from the study are indicated with open circles. The asterisk denotes zero-weighting of the
 7 vertical component of fixation error for P84, due to blink artifacts resulting from cylindrical
 8 correction for astigmatism.

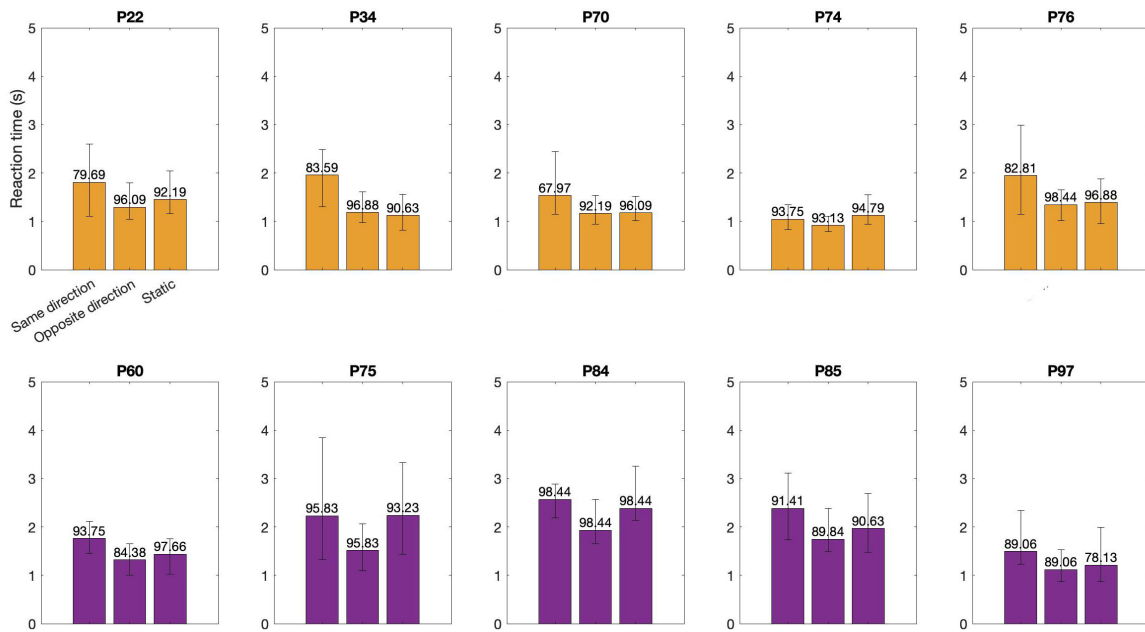
9
 10 Although there was a large, significant difference ($t = 12.33, p < 0.01$) between the d-prime
 11 values for the 5 strongest change detectors and those for the 5 weakest, there was no
 12 significant difference ($t = 1.5, p = 0.18$) between the fixation errors of the 5 strongest change
 13 detectors and those of the 5 weakest.

14
 15 Testing Phase

16 *Motion detection*

17 The five strongest and five weakest change detectors identified in the screening phase
 18 completed the motion detection task. Their results are shown in Figure 3. Incorrect responses
 19 were excluded from reaction-time statistics.

1



2

3 **Figure 3. Results from the motion detection experiment.** Observers identified a slowly
4 moving target circle among 15 stationary distractors, as quickly and accurately as possible,
5 after viewing a moving or static 4×4 array of Gabor patterns (see Figure 1). Median reaction
6 times are shown on the vertical axes and percentages correct for each condition are displayed
7 on top of the corresponding bar. The error bars contain 50% of the data (i.e., the interquartile
8 range). Data from strong change detectors are shown in orange and weak change detectors
9 are shown in purple.

10

11 Morgan and Solomon (2019) found a correlation between change-detection accuracy and the
12 effect of motion adaptation in the motion detection task, using the RT-difference score,
13 $\frac{(R_1 - R_2)}{(R_1 + R_2)}$, where R_1 is the median RT in the “same” condition and R_2 is the median RT in the
14 control (no moving adaptor) condition. However, the RT-difference score does not take
15 account of accuracy. Because we recorded both accuracy and reaction times on each trial, two
16 measures known to trade off against each other and/or reflect different limitations (e.g.,
17 Heitz, 2014), we used the Balanced Integration Score (BIS; Liesefeld & Janczyk, 2019) as a
18 single ‘efficiency’ measure, which places equal weight on both reaction times and accuracies.
19 The BIS is the difference between standardised accuracies and mean correct reaction times:

20

21

22

$$BIS_{i,j} = z_{i,j}(accuracy) - z_{i,j}(RT)$$

1 for the i th participant's j th condition, where the z-scores are computed as:

2

3

$$z_{i,j}(m) = \frac{m_{i,j} - \bar{m}}{s_m}$$

4 That is, the z-score of measure m (in condition j of participant i) is the difference between

5 participant i 's performance on that measure in condition j and the mean of that measure

6 across all participants and conditions, standardised by the standard deviation of the

7 observations across all participants and conditions. A BIS of zero means that the efficiency in

8 that condition is 'average' relative to the other conditions in the study. A positive value

9 indicates better than average performance and a negative value indicates worse than average

10 performance. The higher the efficiency, the better the performance in that condition. We

11 calculated the correlation between change-detection accuracy and the effect of motion

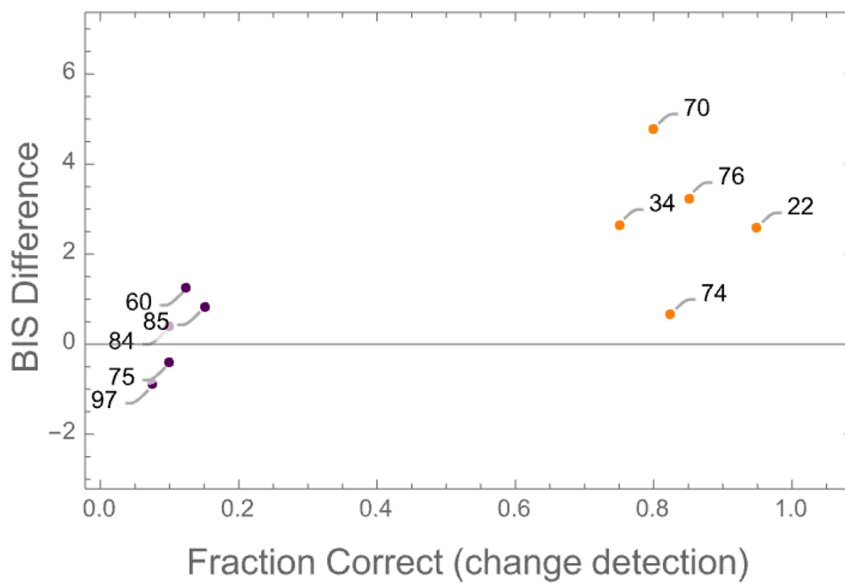
12 adaptation in the motion detection task, using the BIS-difference, $\frac{(BIS_1 - BIS_2)}{(BIS_1 + BIS_2)}$, where BIS_1 is

13 calculated for the "same" condition and BIS_2 is for the control (no moving adaptor)

14 condition. This correlation was significant ($r = 0.71$, $p = 0.018$).

15

16



17

18 **Figure 4.** BIS-differences for 10 observers in the motion detection experiment (ordinate)

19 plotted against fraction correct for the change-detection experiment for the same subjects.

20 Data from the two change-detection tasks have been combined in all subjects.

21

1 Results for our 10 selected observers are shown in Figure 4. A positive BIS-difference
2 indicates that adaptation in the target-same condition led to longer RTs and/or reduced
3 accuracies, compared to the control condition with no moving adaptor. Results showed a tight
4 cluster (bottom left corner) of weak change detectors with near-zero BIS-difference,
5 suggesting a smaller direction-specific effect of motion adaptation. Four of the five strong
6 change detectors showed larger BIS-difference, but participant 74 did not. This participant
7 had exceptionally fast RTs (see Figure 3) and low error rates. We speculate that they may
8 have found some alternative strategy to motion detection in order to identify the moving
9 target. One possibility is that they noticed a change in the target's position. Despite the
10 overlap between weak and strong change-detectors, the two groups produced significantly
11 different BIS-differences: $t = 3.27$, $p = 0.01$.

12

13 Response times typically include a motor component that is independent of the decision
14 process. This motor component (or “non-decision time”) is likely to be a small fraction of the
15 response times recorded in the motion-detection task. Nonetheless, we performed two
16 additional analyses to see whether group differences in non-decision time could have
17 contributed to the group difference in BIS differences. First, we re-analysed the data after
18 adding 1 s to each of the strongest change-detector's response times. Then we re-analysed the
19 data after adding 1 s to each of the weakest change-detector's response times. In both cases,
20 the correlation between change-detection accuracy and BIS difference disappeared. However,
21 in both cases, the significant difference between BIS differences remained ($t = 3.25$, $p = 0.01$
22 and $t = 3.13$, $p = 0.01$, respectively). Consequently, we can be confident that the strongest
23 change detectors really did find the motion-detection task more difficult than the weakest
24 change detectors.

25

26 In our final, contrast-detection experiment, gratings drifting in the direction opposite to their
27 spatially coincident adaptors were compared with gratings drifting in the same direction as
28 adapting stimuli. We used the Akaike Information Criterion (Burnham & Anderson, 2003) to
29 compare a model in which detection thresholds for the two gratings were identical with a
30 model in which detection threshold for the latter grating was higher.¹ Whereas each of the

¹ In this case, $\Delta AIC = 2L - 2$, where L is the natural logarithm of the ratio between maximum joint likelihoods: l_1/l_0 , where $l_1 = \max_{\alpha_0, \Delta\alpha, \lambda} \prod_i P(C_i|\alpha_0, \Delta\alpha, \lambda)$, $l_0 = \max_{\alpha_0, \lambda} \prod_i P(C_i|\alpha_0, 0, \lambda)$, and probability correct on each trial i is modelled, by convention (e.g., May & Solomon 2015), as a Weibull function of stimulus contrast x_i : $P(C_i|\alpha_0, \Delta\alpha, \lambda) = (1 - \lambda) - (0.5 - \lambda) \exp(-[x_i/(\alpha_0 + \Delta\alpha)]^4)$.

1 strongest change detectors produced data consistent with a direction selective elevation of
 2 contrast threshold ($\Delta AIC > 10$), 3 (P75, P84, P85) of the weakest change detectors showed
 3 strong evidence for no direction-selective elevation ($\Delta AIC < 2$, Fig 5).

4



5

6 **Figure 5.** Mean direction selective threshold elevation in good and weak change detectors.

7

8 **Discussion**

9 Morgan and Solomon (2019) showed that weak change detectors were faster than other
 10 observers in the search for a moving placeholder after adaptation, an advantage consistent
 11 with reduced direction-specific adaptation, rather than a deficit in visual search (which would
 12 result in longer than typical reaction times in all conditions). The current study extends this
 13 finding by considering not only differences in reaction time, but also accuracy, between
 14 strong and weak change detectors. The advantage of the BIS metric is that it can detect a
 15 trade-off between the two measurements masquerading as a group difference in reaction time.
 16 We found no evidence of this. Furthermore, the correlation between change-detection
 17 accuracy and the effect of adaptation in the motion-detection task contradicts an account
 18 based purely on impaired visual search. Nevertheless, as a cautionary measure, we used a
 19 contrast detection task without visual search reliance. This task revealed no overlap in

1 direction-specific threshold-elevation between the two groups. The pattern of results
2 presented here is therefore unlikely to be the result of impaired visual search.

3 In contrast to the previous small-scale study (Morgan & Solomon, 2019), the present study
4 used a large and heterogenous sample of the population to investigate whether there is any
5 evidence for bimodality in the distribution of change-detection abilities. There is not. The
6 data in Figure 2 are consistent with a unimodal distribution, in which both strong and weak
7 change detectors fall along a main sequence relating change-detection ability to eye-fixation
8 accuracy.

9 Adaptation in the change-detection task is retinotopic (Morgan & Solomon, 2019). The
10 antecedent to this study found that one out of three putatively weak adapters was more
11 variable at fixating during adaptation than the rest of the participants in the study. In the
12 present study, we carried out a thorough examination of eye-movement effects on change
13 detection. Participants with poor change-detection performance were retested on at least two
14 separate occasions to allow for improvements in fixation and/or change detection, and
15 change-detection scores corresponding to their lowest fixation error were considered when
16 selecting the strongest and weakest change detectors. For the latter group, participants whose
17 scores fell furthest from the regression line were selected, i.e. whose scores were least
18 accounted for by fixation error. Although the significant inverse relationship between d-prime
19 and average fixation error across both tasks highlights the importance of fixation stability for
20 change-detection, we did not find a significant difference between the fixation errors of
21 strong and weak change detectors (after eliminating P84's blink artifacts). While fixation
22 must be closely monitored during the adaptation and test phases of the change-detection task,
23 the poor performance of weak adapters revealed here cannot be explained by aberrant eye
24 movements.

25
26 Any attempt to identify the physiological mechanism responsible for the relatively poor
27 performance of our weakest change detectors would be purely speculative at this stage.
28 However, there is evidence implicating neurons of the magnocellular pathway in rapid
29 adaption to motion. Daumail et al. (2023) examined how the responses of LGN neurons
30 change across successive (repeated) grating cycles. They found that neurons from all cell
31 classes (parvocellular, magnocellular, and koniocellular) showed significant adaptation.
32 However, only magnocellular neurons showed adaptation when responses were averaged to a

1 population response. Kohn & Movshon (2003) demonstrated neuronal adaption to motion
2 (gain control) in primate cortical area MT and concluded that it was inherited from neurones
3 earlier in the pathway. Our data are consistent with the possibility that our weakest change
4 detectors have reduced functioning in the magnocellular pathway, as has been suggested in a
5 different context for some kinds of amblyopes (e.g., Davis et al., 2006), dyslexics (e.g., Stein,
6 2001), and children with autism spectrum conditions (e.g., Greenaway, et al., 2013). This
7 would also explain why they are less subject to motion camouflage induced by the MAE and
8 less susceptible to direction-specific loss of contrast sensitivity after adaptation. In future
9 studies we plan to investigate this possibility by screening for amblyopia, and by including
10 tests that would not be expected to be affected by a magnocellular deficit, such as adaptation
11 to colour.

12

13 Conclusion

14 To summarise, in accordance with previous findings, the results of this study show an inverse
15 association – in a new set of participants – between change-detection ability and adaptation-
16 induced performance reduction in the motion-detection task. We extend the previous finding
17 by showing a correlation between change-detection ability when change is defined by a
18 direction reversal and change-detection ability when it is spatial orientation that changes.
19 These change-detection abilities were found to be positively associated with adaptation-
20 induced direction-selective elevation of contrast detection threshold, a result that raises the
21 possibility of underlying individual differences in divisive gain control. Furthermore, we
22 provide evidence against explanations based on practice, fixation ability, and/or visual search.
23 Instead, there seem to be large individual differences in direction-selective motion adaptation
24 among our participants. In addition to insights into the nature of these differences, this work
25 is of importance to the vision science community as it demonstrates the effectiveness of
26 operationalizing the aftereffect as change localization, which can easily be used to measure
27 other forms of adaptation in an unbiased manner. Here, we provide evidence for its
28 usefulness as a performance-based assessment of both motion and orientation-selective
29 adaptation.

30

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1 Review Research Ethics Committee. No aspects of the study were preregistered. Materials:
2 Study materials are not publicly available. Data: All primary data and analysis scripts are
3 publicly available (<http://www.staff.city.ac.uk/~solomon/ChangeDet.zip>).

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