Grasp preparation improves change-detection for congruent objects

Ed Symes
Mike Tucker
Rob Ellis
Lari Vainio
Giovanni Ottoboni

School of Psychology
University of Plymouth
Plymouth
United Kingdom

This work was supported by grants from the Economic and Social Research Council (RES-000-22-0799 and RES-000-23-1497). We would like to thank Phil Culverhouse for the generous use of his eye tracker, and Peter Gibbons for his help with piloting it. We would also like to thank Glyn Humphries, Scott Glover and two anonymous reviewers for their constructive comments and recommendations on an earlier draft.

Correspondence should be addressed to Ed Symes, School of Psychology, University of Plymouth, Drake Circus, Plymouth, Devon, PL4 8AA, United Kingdom

Tel: +44 (0)1752 233168
Fax: +44 (0)1752 233362
Email: esymes@plymouth.ac.uk
A series of experiments provide converging support for the hypothesis that action preparation biases selective attention to action-congruent object features. When visual transients are masked in so-called ‘change blindness’ scenes, viewers are blind to substantial changes between two otherwise identical pictures that flick back and forth. We report data in which participants planned a grasp prior to the onset of a change blindness scene in which one of twelve objects changed identity. Change-blindness was substantially reduced for grasp-congruent objects (e.g. planning a whole hand grasp reduced change blindness to a changing apple). A series of follow-up experiments ruled out an alternative explanation that this reduction had resulted from a labelling or strategising of responses, and provided converging support that the effect genuinely arose from grasp planning.

Key-words: Motor-visual priming; Visual attention; Object affordances; Change-blindness.
The central idea of O’Regan & Nöe’s (2001) sensorimotor account of vision is that vision is an exploratory activity that is mediated by our experience of how percepts and actions are lawfully coupled. Through our knowledge of these ‘sensorimotor contingencies’, we anticipate which information we currently require from the world. O’Regan (1992) argued that the visual world acts as an outside memory which we revisit as and when we need to. We are only aware of (and indeed, represent) those parts of the environment that we are currently attending to (see also O’Regan, Rensink & Clark, 1999; O’Regan & Nöe 2001). But what constitutes this ‘knowledge of sensorimotor contingencies’ exactly? What tangible processes, in other words, might help us to anticipate the information we require from the world?

The purpose of the current paper was to explore how the process of action planning might serve just such a function. Briefly, we report data demonstrating that preparing a certain hand grasp (a whole hand power grasp or a pinch precision grasp), biases selective attention to objects with congruent features. Before discussing this work, we consider the empirical precedence for the counter-intuitive notion that actions might affect how we process information from the visual world. We focus more on the theoretical implications of this in the General Discussion.

Evidence that action plans can prime the visual system to ‘anticipate’ the information we require from the world can be broadly separated in terms of short and long-term action-perception couplings. The activation of long-term action associations, for example, appeared to influence the visual perception of a patient with symptoms of unilateral neglect (Humphreys & Riddoch, 2001). Specifically, patient MP was more efficient at finding a target (e.g. a cup) from amongst distractor objects when his search was based on a description of the object’s action associations (e.g. “find the object you could drink from”), rather than the object’s name or salient visual
properties. Interestingly this was only the case when the object’s handle pointed towards MP. This study suggests, in the case of this individual patient at least, that when an object affordance is available (e.g. a handle pointing to the viewer), action associations or action-related ideas are capable of influencing attentional search mechanisms.

Learning studies represent another example of medium to long-term action-perception coupling. Although learning transfer has typically been studied from perception to action (e.g. observational learning), Hecht, Vogt and Prinz (2001) have recently reported cases of the reverse; action to perception transfer. Practice of circular arm movements (without visual feedback) for example, transferred to facilitate visual judgements of similar patterns, and this action-perception transfer even occurred when arm movements were not self-generated (and only kinaesthetic feedback of the movement was available).

Most of the evidence for action-perception couplings however, typically concerns shorter time-scales in which an actual (or planned) action impacts upon concurrent (or at least temporally close) visual processing. Furthermore, as Fagioli, Hommel and Schubotz (2007) have recently pointed out, these studies have tended to focus on feature-level couplings. Wohlschläger for example, has demonstrated motor-visual effects (using visual illusions and mental imagery) at the feature level of movement direction (e.g. clockwise or counter clockwise). Apparent motion displays that rotated in an ambiguous direction were perceived as rotating in the same direction as concurrent hand rotations (Wohlschläger, 2000), and planning a rotation of the hand in the opposite direction to a mental object rotation caused interference (Wohlschläger, 2001).
Craighero, Fadiga, Rizzolatti and Umiltà (1999) presented evidence of feature-level motor-visual priming in relation to object detection. In their Experiment 1, participants were instructed to prepare a grasping movement to an oriented bar (this grasping movement involved rotating the wrist clockwise or counterclockwise in order to align the hand appropriately to the bar for grasping). Participants were required to execute this grasping movement on the presentation of a visual bar (whose orientation was congruent or incongruent with the to-be-grasped bar). Results revealed faster responses when the planned grasping movement was congruent with the orientation of the visual bar. The authors concluded that planning a grasp had facilitated the visual processing of graspable objects whose intrinsic properties were congruent with the prepared grasp. Craighero, Bello, Fadiga and Rizzolatti (2002) obtained similar results when the same procedure of preparing a grasp to an oriented bar facilitated the visual processing of orientation-congruent hand pictures.

In Bekkering and Neggers (2002) investigation of selective visual attention, participants searched amongst an array of distractor objects for a predefined target of a particular orientation and colour, with the intention of either grasping it between thumb and forefinger, or pointing to it. Fewer saccades were made to distractors of the wrong orientation in the grasping rather than pointing condition (note that orientation is an object feature that is relevant to grasping, but not pointing), and equal saccades were made to distractors of the wrong colour in both conditions. Thus an intention to grasp apparently biased overt selective attention at the feature level of orientation (see also Hannus, Cornelissen, Lindemann & Bekkering, 2005 for extended investigations of this bias). Fischer and Hoellen (2004) have recently shown that such action-induced overt attentional biases are preceded by a similar covert bias.
Recent data from Fagioli et al. (2007) suggests that action-perception priming can also take place at a more general *dimension* level. In one experiment, participants prepared either a grasping action or a reaching action. The grasping action involved grasping between forefinger and thumb and lifting up a cube, whereas the reaching action involved reaching to and touching a dot (the two objects were located within arm’s length on a board in front of the participant). The participant then performed a visual discrimination task in which they looked for a deviant circle in an otherwise predictable sequence of seven circles. On detecting a deviant circle, the participant carried out their planned action. The results revealed that when a grasping action had been planned, size deviating targets were detected faster than location deviating targets (note that the dimension of size is highly relevant to grasping). When a reaching action had been planned however, location deviating targets were detected faster than size deviating targets (note that the dimension of location is highly relevant to reaching). The authors argued that preparing an action had primed the perception of stimuli with an action-relevant feature dimension.

In summary then, there exists a small yet diverse range of evidence suggesting that actions and action planning can prime the processing of feature and dimension overlapping perceptual events on both long and short time-scales.\(^1\) Taken together, there appears to be enough evidence to generalise that an intention or readiness to perform a certain action can constrain the kind of information that we access from the

\[^1\text{While the examples discussed above have concerned facilitatory effects of action on perception, it should be mentioned that there also exists a body of work that robustly demonstrates that under certain conditions action planning can impair the perception of a subsequent (and separate) feature overlapping perceptual event (e.g. Müsseler & Hommel, 1997 or see Hommel, 2004 for an overview).}\]
world. In particular, in planning an action, our perceptual systems appear to become more sensitive to those objects that afford our planned action.

The Experiments

The current paper used the change blindness paradigm as a tool to test the hypothesis that action planning biases the selective processing of congruent object features. In a typical change blindness task, a substantial change between two otherwise identical pictures that flick back and forth can go unnoticed for several seconds when a visual disruption of some sort coincides with the change (Simons & Levin, 1997; O’Regan et al., 1999). Changes only become noticed when attention is allocated to the change location before and after the change (Mitroff, Simons & Franconeri, 2002). Although attention is necessary, it does not guarantee awareness—changes can even go unnoticed if subjects are visually tracking a moving object at the moment of its change (Treisch, Ballard, Hayhoe, Sullivan, 2003). Change-blindness is a much researched and interesting phenomenon that offers insights into the nature of attention, awareness and other visual processes (see Simons & Rensink, 2005 for a recent review). Because faster detection of a change implies that attention to the change occurred earlier (Simons & Rensink, 2005), this paradigm provides an interesting tool for examining biases of selective attention. Within the context of action planning therefore, we reasoned that if planning an action biases attention to congruent features in the world, this should be reflected within the change blindness paradigm by faster detection of changes to these features.

In a series of experiments, participants were instructed to hold (and squeeze on change-detection) one of two response devices, whose shape required a whole hand power grasp or a pinch precision grasp. With the grasp prepared, participants then
searched an array of twelve objects for a single object whose identity was changing. This object’s size (large or small) was either congruent or incongruent with the prepared grasp. This experimental work is divided into three sections.

In Experimental Section 1 (“Establishing an effect of grasps”) two experiments are reported that set the scene for an effect of grasp planning on selective attention. In Experimental Section 2 (“Tests of Labelling”), three experiments tested whether the effect of grasps could have arisen from the labelling of responses. In Experimental Section 3 (“Tests of Planning”), a further three experiments tested whether the effect of grasps truly reflected planning. On all counts, the evidence firmly pointed to a genuine bias of selective attention brought about by grasp planning. We discuss possible mechanisms for this bias in the General Discussion.

Experimental Section 1: Establishing an effect of grasps

Experiment 1a: Neutral responses

This first experiment was designed as a control experiment in which an object-neutral response was planned (a spacebar press) prior to each trial, rather than the object-relevant grasps of later experiments. This control was run in order to establish from the outset whether there were any (non-action related) differences in the detection times of the small and large object stimuli used. Change-blindness scenes consisted of an array of twelve greyscale photographs of fruit and vegetables (half were small objects congruent with a precision grasp, and half were large objects congruent with a power grasp). One random object in the scene changed back and forth into another object of a similar size (e.g. an apple changed into an orange), and this change coincided temporally with a visually disrupting screen flicker that provided the necessary conditions for change blindness. Participants were told that the
identity of one of the twelve objects would change back and forth, and their basic task
was to press the spacebar as soon as they detected which object was changing (both
hands rested on the spacebar throughout viewing). By examining response times, we
were able to compare the time taken to detect changes in large and small objects.

Method

Participants. 21 volunteers between 52 and 18 years of age [mean ($M$) =
23.7 years] were paid for their participation in a single session that lasted
approximately ten minutes. Of these, 6 were males (5 right-handed, 1 left-handed) and
15 were females (right-handed). This female majority occurs in all experiments, and
reflects the participant pool available (consisting largely of female undergraduate
Psychology students). All participants self-reported normal or corrected-to-normal
vision and normal motor control, and all were naïve as to the purpose of the study.

Apparatus and stimuli. Experimental sessions took place in a dimly lit
room containing four identically equipped computer workstations that were arranged
in a quadrant and separated by large wooden screens that visually isolated each
workstation from its neighbours. Depending upon recruitment conditions, experiments
ran between one and four participants per session. Each workstation consisted of a
chair, and a table that was 80 cm in length ($l$) and width ($w$), and 72 cm in height ($h$).
Situated centrally at the back of the table was a RM Innovator desktop computer that
supported a 16-inch RM colour monitor (with a screen resolution of $1024 \times 768$
pixels and a refresh frequency of 85Hz). In front of the computer was a keyboard and
mouse. The viewing distance was approximately 50 cm, and the hand-to-screen
distance was approximately 30 cm.
Change-blindness was induced by cyclically presenting a screen ‘flicker’ (F) between an ‘original’ (O) and ‘modified’ (M) picture-pair in the order OFMFOFMF… This sequence cycled until a response was made, and a ‘change identification’ picture was shown to establish that the correct change had been detected. Thus the stimulus set consisted of a flicker stimulus (a blank grey screen), and 60 ‘original’, ‘modified’ and ‘change identification’ greyscale photographs (1024 × 768 pixels; 32.5 cm × 24.5 cm; visual angle (VA) ≈ 36.0° × 27.5°).

As shown in the example picture of Figure 1, each original picture consisted of a 4 × 3 array of six large objects (e.g. an apple) and six small objects (e.g. a strawberry). These had been selected at random from a pool of 24 items of fruit and vegetables, again, half of which were large and half of which were small. The size of each individual object photograph was manipulated such that all small objects were of a similar size (mean VA ≈ 2.3° × 1.6°), and all large objects were of a similar size (mean VA ≈ 4.9° × 4.1°). These objects and their measurements are listed in the Appendix.

The order of objects in the array resulted from a random shuffle of the 12 selected objects, and their positions on the screen varied within a loosely defined grid (thereby creating perceptually distinct-looking scenes). An appropriately sized object (thirty of each size were required) was selected at random from the twelve to be the changing object. An appropriately sized replacement object was selected at random from the pool (after object selection for the original picture, six large and six small objects remained in the pool). Thus in the modified picture, all objects remained the same as the original picture, except from a single changing object. This was removed and replaced by an object of a similar size (e.g. a strawberry was replaced with a cherry). Each original picture was also reproduced as a change identification picture,
whereby each object in the array had an identification ‘F-number’ (F1- F12) superimposed on it. These F-numbers corresponded to the twelve ‘F-keys’ on a keyboard.

![Image of an array of fruit and vegetables](image)

Figure 1. An example array of fruit and vegetables. In the modified version of this original picture (not shown here), the third object on the bottom row (an avocado pear) changed into an orange.

**Design and procedure.** There was one within subjects variable, with two levels: size of changing object (large or small). At the beginning of the experiment, participants were talked through some written instructions that explained the task. A short practice session of four trials was followed by one block of 60 experimental trials (2 conditions × 30 replications), with each of the 60 change blindness scenes being shown in a random order.

Each trial followed three broad phases: response preparation, change blindness and change identification. Preceding stimulus onset, some text appeared on the screen instructing participants to “Get Ready”. The participant rested the fingertips of both
hands on the spacebar of the keyboard (response preparation phase). The change blindness scene then appeared, and as it cycled the participant scrutinised the twelve objects for a change. Upon noticing the change, the participant immediately pressed the spacebar (change blindness phase). This response caused the change identification picture to appear, and the participant pressed an F-key on the keyboard corresponding to the F-number of the object they thought they has seen change (change identification phase). Otherwise, the trial timed-out after ten seconds. The sequence and timings for these three phases are illustrated in Figure 2.

Response times and errors were recorded to a data file for off-line analysis, and the possible source of error related to an F-key response that timed-out or did not correspond to the changing object’s F-number.

Figure 2. Schematic illustration of the sequence and timings of the displays in Experiment 1a
Results and Discussion

Errors and response times more than two $SD$s from each participant’s condition means were excluded from this analysis and the analyses of all the other experiments reported\(^2\). 1.8 % ($SD = 0.1$) of trials were removed as change identification errors (i.e. when an F-key identified the wrong object). No further analysis of errors was undertaken; the change identification error data revealed that on the vast majority of trials the correct object had been identified. A further 4.3% of the trials were removed as outliers, reducing the maximum detection time from 36995 ms to 22908 ms ($M = 4908$ ms; $SD = 3232$). The combined removal of errors and outliers left 93.9% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a paired samples T-Test. There was a significant effect of object size, $t(20) = 2.909$, $p = .009$, with changes to small objects (4591 ms) being detected on average 623 ms faster than changes to large objects (5214 ms).

This finding suggests that participants found it easier to detect changes in small objects. It is possible that these objects were more salient. Perhaps their small size made them easier to process as single units of attention (e.g. in a single saccade), or perhaps in order to successfully perform the task (which involved detecting changes of unknown size- sometimes large, sometimes small), participants needed to scale the spatial resolution of their attention to the smallest type of change. If so, then these objects would be most easily detected.

\(^2\) $SD$s for each participant were based on their pooled condition $SD$s. This outlier criterion typically removes about 4% of the data.
Experiment 1b: Grasp responses

The following experiment was designed to test our main hypothesis that planning a particular grasp would facilitate the detection of changes in congruently sized objects. Using grasp-simulating response devices, participants planned (in accordance with a text instruction that started each trial) either a whole-hand power grasp or a forefinger and thumb precision grasp prior to the onset of a change blindness scene. Change blindness scenes were those used in Experiment 1a. Participants were told that the identity of one of the twelve objects would change back and forth, and their basic task was to execute their planned grasp as soon as they detected which object was changing. By examining response times for each condition, we were able to assess whether the type of grasp planned had affected the time to detect changes in objects that were either congruent or incongruent with that grasp.

Method

Participants. Twenty-two volunteers between 18 and 53 years of age (mean, 23.8 years) were paid for their participation in a single session that lasted approximately twenty minutes. Of these, five were males (right-handed) and seventeen were females (right-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study.

Apparatus and stimuli. As Experiment 1a. In addition, the keyboard was moved closer to the screen (by 15 cm) to make room for the new response apparatus, which was affixed centrally (from left to right) and set in by 10.5 cm from the table’s leading edge. When holding this apparatus, the hand-to-screen distance was
approximately 30 cm. The apparatus was fixed to the table top in a vertical position and consisted of two physically connected devices- a cylindrical ‘power device’ \((l = 10 \, \text{cm}; \, \text{diameter} = 3 \, \text{cm})\), and a square ‘precision device’ \((l = 1.25 \, \text{cm}, \, w = 1.25 \, \text{cm}, \, h = 1.25 \, \text{cm})\). Similar response apparatus is described in more detail in Ellis and Tucker (2000). A power grasp was required to hold the power device and a precision grasp was required to hold the precision device (see Figure 3).

In order to avoid establishing any semantic associations between the devices and their size or required grasp, the power device was neutrally referred to by the experimenter as the “Black device” (it was coloured black) and the precision device as the “White device” (it was coloured white). Execution of a particular grasp depressed a micro switch embedded in that device, and this response was registered with millisecond accuracy by the computer (micro switches were connected via an input/output box to the parallel interface of the computer).

![Figure 3.](image.png) Response preparation and execution in Experiment 1b. On each trial the “Black device” was held in a power grasp, or the “White device” was held in a precision grasp. Execution of the planned grasp depressed an embedded micro switch.

*Design and procedure.* Four conditions arose from the orthogonal variation of two within subjects variables, each with two levels: planned grasp (power
or precision) and size of changing object (large or small). At the beginning of the experiment, participants were talked through some written instructions that explained the task. A short practice session of four trials was followed by 120 experimental trials. These consisted of two blocks of 60 trials (4 conditions × 15 replications), with each of the 60 change blindness scenes being shown in a random order within each block.

The trial procedure was similar to Experiment 1a (refer back to Figure 2); with three broad phases of response preparation (in this instance, of a grasp), change blindness and change identification. This time, the text instructions that preceded stimulus onset warned participants to prepare a response using either the “Black device” or the “White device”. The participant reached to the instructed device, and held it lightly in their dominant hand (using the device-appropriate hand shape). When the participant detected a change, s/he executed the grasp by squeezing the device. The participant then identified the change as before, by pressing the appropriate F-key.

Response times and errors were recorded to a data file for off-line analysis, and there were two possible sources of error: violations of the response instruction (participants used the wrong device), and change identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

**Results and Discussion**

1.5% (SD = 0.1) of trials were removed as errors (0.4% response errors, 1.1% change identification errors, 0% both errors on same trial). No further analysis of errors was undertaken; response and change identification error data revealed that on the vast majority of trials the text instructions had been adhered to and the correct
object had been identified. A further 4.6% of the trials were removed as outliers, reducing the maximum detection time from 45045 ms to 17878 ms ($M = 4684$ ms; $SD = 2709$). The combined removal of errors and outliers left 93.9% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of planned grasp (power or precision) and size of changing object (large or small).

A main effect of object size, $F(1,21) = 20.428$, $p < .001$, partial $\eta^2 = .493$, revealed faster mean change detection for small (4311 ms) rather than large (5079 ms) objects. The replication of this main effect suggests a robust advantage for detecting changes in small objects. Given that this same effect occurred in Experiment 1a (where no grasps were planned), we assume that it is a perceptual effect occurring independently of grasp-planning.

In addition, the theoretically crucial interaction between planned grasp and object size was observed, $F(1,21) = 13.845$, $p = .001$, partial $\eta^2 = .397$. In light of the independent main effect of object size reported above, we report this interaction by object size (and not by grasp type): Mean change detection was faster for large objects when a power grasp was planned (4902 ms) rather than a precision grasp (5256 ms); and was faster for small objects when a precision grasp was planned (4117 ms) rather than a power grasp (4506 ms). Thus planning to execute a grasp reduced change blindness to grasp-congruent objects by, on average, 372 ms.

Since change detection is dependent on attention being allocated to the location of the change both before and after the change, we would like to conclude that grasp planning had biased selective attention to grasp-congruent features. There are however, a number of alternative explanations for this interaction that the
remaining experiments put to the test. In particular, using various manipulations, each experiment set out to either replicate or remove the interaction. This interaction is presented for each experiment in a summary figure located in the General Discussion (Figure 7), and can be referred to with reference to specific experiments as required.

Experimental Section 2: Tests of labelling

The effect of grasps found in Experiment 1b may not have arisen from the actual premotor commands associated with a grasp plan. Instead the effect may have arisen from an alternative route that involved the labelling of responses. Specifically, it is possible that the effect arose from the mundane fact that participants were holding a response device in their hand whose physical properties shared some dimensional overlap with the physical properties of the changing object (e.g. Kornblum, 1994; Kornblum, Hasbroucq & Osman, 1990). In other words, participants may have (implicitly or explicitly) labelled the devices along the same dimension (size) that they did the objects. Such labels could be used strategically (e.g. “I am preparing a small response… I will look for a change in small objects”), or they might merely serve to implicitly prime size-congruent objects. Either way, they could produce the same pattern of results found in Experiment 1b.

In this section, we tested whether the effect of grasps found in Experiment 1b could have arisen from the strategic (Experiment 2a) or implicit (Experiments 2b and 2c) use of response labels.

Experiment 2a: Strategic saccades

If participants labelled their responses in terms of size (possibly from device-related visual or proprioceptive size cues- see Experiments 2b and 2c) then these
labels may have been used strategically to search for changes in certain objects. In preparing a power grasp (let us suppose it is labelled ‘large’) a participant might preferentially make saccades to objects congruent with the planned grasp (i.e. ‘large’ objects). This strategy would certainly produce the pattern of the results found in Experiment 1b; there would always be a detection-time advantage for preferentially searched objects (i.e. grasp congruent ones). However, it does seem unlikely that a participant would knowingly adopt such a strategy, since grasp type would only serve as a valid cue for finding the change on 50% of trials (grasp type and the size of changing object were orthogonally balanced). Also, the text instructions for preparing a grasp referred to the devices colour (e.g. “BLACK device” or “WHITE device”), a design consideration formulated precisely to deter participants from generating their own labels based on the devices size. Nevertheless, if this strategy was employed, then we might expect to find a clear pattern of eye fixations revealing a systematic search of grasp-congruent objects (e.g. on a power grasp trial, all fixations are made to large objects, and none to small objects).

A more moderate hypothesis relating to eye movements is that the grasp plan implicitly biased overt attention to select grasp congruent objects. This is consistent with our basic assertion that grasp planning biased selective attention to grasp-congruent features. It is also consistent with the general findings of Bekkering and Neggers (2002), as discussed in the Introduction. Perhaps the premotor command serves directly as a top-down biasing signal for eye movements, or perhaps it is implicitly labelled at a separate level of abstraction (other potential biasing mechanisms are proposed in the General Discussion). According to this moderate hypothesis, the expected pattern of fixations should merely reflect a bias and not a fixed strategy (e.g. on a power grasp trial, more fixations are made to large objects
than small objects). To test these hypotheses, Experiment 1b was replicated as closely as possible whilst monitoring eye movements.

**Method**

**Participants.** 18 volunteers between 19 and 49 years of age (mean, 22.2 years) were paid for their participation in a single session that lasted approximately 90 minutes. All were right-handed, and two were males. All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study. One other participant did not provide sufficiently accurate eye tracking data and was excluded (45.8% accuracy).

**Apparatus and stimuli.** A new stimulus set of 60 scenes (flipped horizontally to create 120) was created using the same pool of 24 items described in the Appendix. Each original picture again consisted of a $4 \times 3$ array of six large objects and six small objects. Each $1024 \times 768$ pixel scene was divided into a $4 \times 3$ grid (x-axis gridlines: 0, 256, 512, 768, 1024; y-axis gridlines: 0, 256, 512, 768) producing twelve discrete grid locations. An object was placed in the centre of each grid location.

The order of objects in the array was determined as follows: 1) twelve objects were selected at random from the pool (six large and six small); 2) an appropriately sized changing object was selected at random from these (thirty of each size were required: sixty when flipped); 3) a size-matched replacement object was selected at random from those remaining in the pool; 4) the changing object (and its replacement) were assigned to a particular grid position (the resulting stimulus set consisted of 5 changing objects $\times$ 2 sizes $\times$ 12 locations = 120 scenes); 5) the remaining eleven objects in the scene were randomly shuffled to determine their grid positions.
Because the experimental display and eye tracking computers were connected via their parallel interfaces, a power and precision response apparatus (of similar construction to before) was wired directly into a computer mouse and connected to the PS/2 connection port of the display computer. The power device (with precision device adjacent to it) was fixed centrally in an upright position to a wooden board \((l = 44 \text{ cm}, w = 25 \text{ cm}, h = 3.7 \text{ cm})\). This rested on the lap, hidden from view directly underneath the bench top.

The movements participants made with their left eye were tracked by a head-mounted eye tracking system (ASL- Applied Science Laboratories, Series 4000SU-SYS; Massachusetts, USA). The participant sat at a bench top \((h = 91.5 \text{ cm})\) in a dimly lit room, with their chin resting on a chin rest (22 cm above the bench top surface). The distance from the chin rest to the display monitor was 68 cm (new VA’s for mean object sizes were as follows- large objects: \(1.7^\circ \times 1.2^\circ\); small objects: \(3.6^\circ \times 3.0^\circ\)). Attached to the chin rest frame was a bite bar that the participant clenched between their teeth. Looking directly ahead at the monitor, the participant rested their left arm (ready for keyboard use) on the bench top, and their right hand (ready for device use) on the board located on their lap. The keyboard was set in 30 cm from the bench top edge, and fixed centrally (left-to-right) to the bench top at an angle of 45° from the perpendicular. This allowed the participant to locate and press an F-key (when identifying the change) without having to move their head.

With an accuracy of 0.5° of visual angle, signals from the eye tracker were acquired at a sample rate of 50Hz, and transformed into fixation points and eye-positions by the EYENAL software (ASL, Massachusetts, USA). At the start of the experiment, and at set intervals during it (every thirty trials), a particular protocol was adhered to that calibrated the eye tracker to the individual parameters of the
participant. In addition, for data synchronisation purposes, EYENAL received and saved timings from the display computer throughout.

**Design and procedure.** Apart from the following differences, the design was the same as Experiment 1b. Before the start, preparations included taking a dental imprint of the participant (for the bite bar), and setting up and calibrating the eye tracker. Participants spent a while reaching to the power and precision devices on their laps, such that after a while they could comfortably reach and locate either device without looking under the bench top. Practice trials lasted for a couple of minutes, and were performed without wearing the eye tracking headset. The 120 scenes displayed in the actual experiment were randomised, and then divided into four blocks of 30 trials, allowing for frequent rest periods. During these breaks, the participant removed the bite bar and headset. Experimental blocks resumed after re-calibration of the eye-tracker, and each block lasted approximately five minutes (during which time the participant was required to keep their head absolutely still).

At the start of each trial, the text instructions warning participants to prepare a response (i.e. “Black device” or “White device”), appeared in the top left corner of the screen for 1999 ms. Participants moved their right hand into position and held (without squeezing) the instructed device. A fixation point consisting of a small dot centred in four crosshairs (overall size = 4cm × 4cm; VA: 3.4° × 3.4°) then appeared centre screen for a further 1999 ms. Forcing a saccade from the top left (the text) to centre screen (the fixation point) ensured that the eye tracker recorded a fixation. An adjustment based on this central fixation, was made to all following fixations on that trial. Creating this one-to-one correspondence between the eye tracker and screen positions compensated for any drift in tracking on each trial (e.g. actual screen centre = 512 × 384 pixels; reference point = 510 × 404 pixels; x-axis adjustment = +2 pixels,
y-axis adjustment = -10 pixels). The disappearance of the fixation point was followed by the change blindness and change identification phases of previous experiments (return to Figure 2).

Object Fixation Criteria: The minimum fixation duration that EYENAL recorded as a fixation point was set at 100 ms. The number of fixations made to each object type (small and large) on each trial was calculated by matching the eye positions of each fixation with the grid positions of the object stimuli presented on that trial. Specifically, if a fixation fell within five pixels of both the x and y coordinates of a particular grid position, then it was counted as a fixation of that grid position’s current object.

Because this experiment was interested in how grasp planning affected the search strategy of large and small objects, we selected only those fixations that genuinely reflected searching. Thus at the end of each trial we counted the initial fixation to the changing object, but we excluded any repeat fixations to it. It was often the case for example, that participants would repeatedly fixate the changing object (presumably checking that it really was changing).

Eye Tracking Errors: We assumed that the last object to be fixated on any trial would, perhaps necessarily, be the changing object. Indeed, this assumption was corroborated by the fact that the last fixated object was the changing object on 100% of trials for some participants. All trials in which the last fixation made did not correspond to the object that the participant identified to be the changing object (i.e. with an F-key response), were therefore treated as eye tracking errors, and excluded from the analyses.

Response Errors: There were two possible sources of response error: violations of the response instruction (participants used the wrong device), and change
identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

Results and Discussion

Response Time ANOVA: 1.5% (SD = 0.1) of trials were removed as errors (0.9% response errors, 0.6% change identification errors, 0% both errors on same trial). As previously, no further analysis of response errors was undertaken. A further 3.9% of trials were removed as outliers, reducing the maximum detection-time from 44042 ms to 14676 ms (M = 3971 ms; SD = 2139). The combined removal of errors and outliers left 94.6% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of planned grasp (power or precision) and size of changing object (large or small).

A main effect of object size, $F(1,17) = 4.957, p = .040$, partial $\eta^2 = .226$, again revealed faster mean change detection for small (3870 ms) rather than large (4069 ms) objects. An interaction between planned grasp and object size was also replicated, $F(1,17) = 4.746, p = .044$, partial $\eta^2 = .218$ (see Figure 4a below). Mean change detection was faster for large objects when a power grasp was planned (3908 ms) rather than a precision grasp (4372 ms); and was faster for small objects when a precision grasp was planned (3765 ms) rather than a power grasp (3832 ms). Thus planning to execute a grasp reduced change blindness to grasp-congruent objects by, on average, 266 ms.

Response Time ANCOVA: In this analysis, a covariate was added to the analysis that corresponded to the proportion of fixations made to grip-congruent objects in each condition for each participant. Computing the condition means of this
covariate required some additional filtering of trials. Those 5.4% of trials that were removed from the response time data (i.e. errors and outliers) were also removed from the fixation data. In addition, 8.8% ($SD = 9.5$) of trials were identified as eye tracking errors. 0.6% of these trials had already been removed as response time errors or outliers. Thus a further 8.2% of trials were removed, leaving 86.4% of the raw data as usable fixation trials.

The interaction between planned grasp and object size reported above for the ANOVA, remained statistically significant after removing the influence of the covariate, $F(1,17) = 4.728, p = .045$, partial $\eta^2 = .228$. Evidently, the effect of grasp planning was not reliant on eye movements, strategic or otherwise. The adjusted means for this interaction revealed a much cleaner effect than before (see Figure 4b below). As can be seen in comparing the two graphs of Figure 4, removing the influence of fixations more clearly revealed a facilitatory influence of both grasp types on the speed of detecting changes to congruent objects.

Figure 4. The legend applies to both graphs. Each graph shows mean response times as a function of the response device used (power or precision) and the size of the changing object (large or small). In graph b. these response times have been adjusted following the partialling out of the covariate.

Fixation ANOVA: In examining object fixations in their own right, we calculated the number of fixations made to large and small objects on each of the 86.4% usable fixation trials. Condition means were computed for each participant and
subjected to a repeated measures ANOVA with the within subjects factors of planned grasp (power or precision) and size of changing object (large or small).

A main effect of planned grasp, $F(1,17) = 7.821, p = .012$, partial $\eta^2 = .315$, revealed that on average more objects were fixated following the preparation of a precision grasp (3.8 objects), rather than a power grasp (3.5 objects). It is tempting to speculate— in the true spirit of embodied cognition— that preparing a precision grasp encouraged a more precise search of the visual scene (by fixating more individual objects)!

A main effect of object size, $F(1,17) = 8.315, p = .010$, partial $\eta^2 = .328$, revealed that on average more small objects were fixated (3.9 objects) than large objects (3.4 objects). This finding may help to explain the main effect of object size found previously in response times (e.g. Experiment 1a). A tendency to look at more small objects (perhaps, as we argued before, because they were easier to process as single units of attention), would promote the earlier detection of changes in small objects.

An interaction between planned grasp and object size was also observed, $F(1,17) = 4.555, p = .048$, partial $\eta^2 = .211$. Only small objects appeared to reflect a grasp-congruent increase in the average number of fixations: more small objects were fixated following the preparation of a congruent precision grasp (precision = 4.1; power = 3.7); whereas fewer large objects were fixated following the preparation of a congruent power grasp (precision = 3.5; power = 3.3). This interaction suggests that grasp planning did modulate eye movements to some extent. One possibility is that grasp planning only biased saccades to grasp-congruent objects that were already perceptually salient (in this instance, small objects). Whatever the underlying explanation, the overall pattern of this interaction reflects an asymmetrical bias that is
not inconsistent with the notion of a fixed strategy. This is especially apparent when
one considers the difference between the mean number of objects fixated that were
grasp-congruent (3.7) and grasp-incongruent (3.6). [This difference corresponds to
one-tenth of an object (or fixation). A fixed strategy should surely have produced a
much more dramatic difference than this.]

Nevertheless, we do not mean to play down the possible implications of this
interaction, for it certainly establishes a link between eye-movements and grasp
planning, which is of undoubted interest. Indeed, as we discuss in the General
Discussion, there exists a fundamental coupling between shifts of spatial attention and
eye-movements (e.g. Rizzolatti, Riggio, Dascola & Umiltà, 1987). If grasp planning
modulates selective attention as we suggest, then some involvement of eye
movements would be expected too. Indeed, a possible basis of the grasp-induced
attentional bias (as evidenced in manual response times) may initially reside in
modulation of the covert visual processing of grasp-relevant features, which then goes
on to influence overt eye movements (such that there is a bias for foveating grasp-
relevant object types). We do not feel however that these biased foveations account,
in and of themselves, for the response time effect, because as we saw in the response
time ANCOVA, the effect remained (and even appeared more robust) once fixations
were partialled out as a covariate.

Experiment 2b: Visual labels

Although Experiment 2a suggests that response labels were not used
strategically to direct eye movements to grasp-congruent objects, it remains a
possibility they were used implicitly (and covertly). This scenario would provide an
alternative account of the previous findings of faster change detection for grasp-
congruent objects. It is therefore important to establish whether there is any evidence that labels are generated from the responses and their devices. Such labelling could conceivably arise from the visual size information available in the ‘large’ and ‘small’ response devices (either currently available or remembered).

In this experiment we removed the natural source of affordance between objects and actions (i.e. an affordance for grasping) by horizontally fixing the response devices to the table (see Figure 5). Rather than grasping, both devices now required the planning and execution of an object-neutral finger press. Michaels (1988, 1993) argued that our everyday actions are governed by their nonabstract meaningful relations with the visual world. Finger press responses (unlike precision and power grasps) do not appear to have meaningful relations with small and large objects. Thus all that remained in terms of sources of compatibility between action planning and changing objects was the dimensional overlap of size between the devices used and the objects. This size information was available visually for labelling, since participants visually selected and located the instructed device before resting their index finger on it (and the device was in peripheral view throughout the trial). It should be noted that any sources of labelling were purely visual, since the proprioceptive feedback received from resting the tip of the index finger on either device was identical in terms of size related information.

Given that dimensional overlap of size existed between the response devices used and the objects in the scene, we predicted some form of labelling and consequently a size-related priming effect. Nevertheless, given that there were no other sources of compatibility (between action planning and objects), and given that the natural affordance between action and object was removed, we anticipated that if
planning a finger press was going to speed up change detection for size-congruent objects, it would only be minimal when compared to our previous results.

Method

Participants. 22 volunteers between 18 and 26 years of age (mean, 20.4 years) were paid for their participation in a single session that lasted approximately twenty minutes. Of these, four were males (right-handed), and eighteen were females (sixteen right-handed, two left-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study.

Apparatus and stimuli. The stimuli were those used previously (e.g. Experiment 1a), and the experimental setting and response apparatus were as Experiment 1b- apart from the following exceptions. As Figure 5 shows, the response devices were fixed horizontally to the table, and the small (precision) device was fixed in position above the large (power) device.

Design and procedure. The basic design was similar to Experiment 1b-four within subject conditions varied equally across 120 trials [planned device press: large (power) or small (precision); and size of changing object: large or small]. The
change blindness and change identification phases were identical to previous experiments, although the following aspects of the procedure were different.

When text instructions indicated which device (“Black” or “White”) to use at the start of each trial, the participant rested the index finger of their dominant hand on the instructed device and prepared to execute the press by maintaining a state of readiness to press down throughout the trial. Upon noticing a change in the change blindness sequence, the participant depressed the device.

Response times and errors were recorded to a data file for off-line analysis, and there were two possible sources of error violations of the response instruction (participants used the wrong device), and change identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

**Results and Discussion**

1.2% ($SD = 0.1$) of trials were removed as errors (0.4% response errors, 0.8% change identification errors, 0% both errors on same trial). As previously, no further analysis of errors was undertaken. A further 4.1% of the trials were removed as outliers, reducing the maximum detection time from 44826 ms to 26164 ms ($M = 4809$ ms; $SD = 2753$). The combined removal of errors and outliers left 94.7 % of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of planned device press [large (power) or small (precision)] and size of changing object (large or small).

There were no statistically significant results, and the theoretically crucial interaction between planned device press and object size was not statistically significant, $F(1,21) = 1.939, p = .178$, partial $\eta^2 = .085$. However, there did appear to
be a small (non significant) trend of compatibility between device and changing object (see Figure 7b, Expt. 2b). The difference of this finding and that of Experiment 1b was partially supported by cross-experimental analyses in which data was pooled from the two experiments and Experiment was added as a between subjects factor. An interaction between Experiment, planned grasp/planned device press and object size failed to reach statistical significance for the ‘±2 SD’ cut-off data, \( F(1,42) = 1.494, p = .228 \), partial \( \eta^2 = .034 \). However, this interaction was found to be statistically significant when longer change detections were removed from the raw data (trials with detections under ten seconds, \( F(1,42) = 4.822, p = .034 \), partial \( \eta^2 = .103 \); trials with detections under five seconds, \( F(1,42) = 8.973, p = .005 \), partial \( \eta^2 = .176 \)). This suggested that for shorter detection times at least, Experiment as a factor had in fact modulated the interaction between planned grasp/planned device press and object size.

These results were as predicted; no strong interaction was found since there were no longer any nonabstract meaningful relations (i.e. natural affordances) between action planning and object. Presumably planning a finger press did not provide a sufficiently meaningful basis upon which to bias selective attention towards particular objects. As mentioned earlier however, visual cues of response device size provided a more abstract source of dimensional overlap with objects in the scene. Any generation of response labels however, was not sufficient to (significantly) prime participants for changes in size-congruent objects. Nevertheless, there was some indication in the pattern of response times that a weaker priming effect had occurred (cf. a 176 ms nonsignificant effect of Experiment 2b as compared to the 372 ms significant effect of Experiment 1b).
Overall, we conclude from this experiment that there is not sufficient evidence to suggest that the dimensional overlap of size labels (as generated from visual cues of response device size) was solely responsible for the interaction in Experiment 1b. Our initial assertion that grasp preparation had biased selective attention to grasp-congruent objects remains the most compelling account of that data.

Experiment 2c: Proprioceptive Labels

As previously discussed, it is still possible that size labels of the responses produced the interaction between grasp type and object size in Experiment 1b, only in this instance, such codes were derived not from visual information, but from proprioceptive information received simply from holding a particular device throughout the trial (regardless, that is, of any plan to execute the grasp).

Experiment 3 tested this possibility by firstly removing grasp planning altogether (the planned response was now a foot press), and by secondly removing all visual access to the response devices (thus preventing a direct visual route to size labelling responses). Participants followed the start-of-trial text instruction (e.g. “Black device”), by reaching out and squeezing the visually concealed device (e.g. power). The participant then left their hand in place, gently holding the device throughout the trial (i.e. a continuous source of proprioceptive feedback). Upon noticing the changing object the participant executed a foot press (which had no dimensional overlap with either type of changing object). Importantly, proprioceptive feedback from the power or precision device was available throughout the trial (as it was in Experiment 1b), although this time there was absolutely no planning of a grasp (in fact the grasp had already been executed prior to stimulus onset).
We predicted a null effect in this experiment, since without an actual plan to execute a grasp there is no obvious reason why mere proprioceptive feedback should create any basis for biasing selective attention. No obvious reason that is, other than the possibility already discussed that proprioceptive feedback could evoke a size label of the response that might prime size-congruent objects. We considered this to be unlikely however, since it is not even clear that proprioceptive feedback from power or precision grasps would be labelled in a binary fashion (as if they were somehow two properties of the same action). The labelling of actions in a binary fashion seems most likely to arise when identical actions vary along some dimension (e.g. left and right hand keypresses are identical actions with different spatial properties).

Method

Participants. 21 volunteers between 18 and 40 years of age (mean, 22.8 years) were paid for their participation in a single session that lasted approximately twenty minutes. Of these, five were males (right-handed), and sixteen were females (fourteen right-handed, two left-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study.

Apparatus and stimuli. The stimuli were those used previously (e.g. Experiment 1a), although the experimental setting and response apparatus were somewhat different. Experimental sessions took place in the same room as Experiment 1b, and again, depending upon recruitment conditions, used between one and four participants. However, participants now sat on raised chairs at four different computer workstations that were situated along a workbench. The workbench was divided into four by wooden partitions that visually isolated each workstation from its
neighbours. Situated centrally near the back of each workstation ($l = 85\text{ cm}$, $w = 88\text{ cm}$, $h = 92\text{ cm}$) was a 16-inch RM colour monitor (with a screen resolution of $1024 \times 768$ pixels and a refresh frequency of $85\text{ Hz}$). Next to the monitor, up-ended onto its side, was an RM Innovator desktop computer. Directly in front of the monitor was a keyboard and mouse. The viewing distance was approximately $50\text{ cm}$. The use of these workstations allowed room for the participants to rest a purpose-built response-board apparatus on their laps, hidden from view directly underneath the bench top.

The apparatus consisted of a wooden board ($l = 28\text{ cm}$, $w = 45\text{ cm}$, $h = 1\text{ cm}$) with various attached components (see Figure 6). At the end of the board nearest to the participant’s torso (i.e. when resting on their lap) was a centrally fixed home button (not used in this experiment) consisting of a perspex-covered wooden wedge with inset micro switch ($l = 12\text{ cm}$, $w = 7\text{ cm}$, max $h = 1.7\text{ cm}$). Behind this was a block of wood ($l = 12.5\text{ cm}$, $w = 4.5\text{ cm}$, $h = 3.5\text{ cm}$) that served to raise the power/precision response devices above and behind the home button. The precision device was fixed in position to the top of the power device. These two considerations (the block raiser, and the fixed precision device), allowed a smooth and comfortable reaching trajectory from home button to either response device. Finally, there was a foot press button which shared the same dimensions as the home button, and was placed on the floor. Participants were instructed to take off the footwear from their dominant foot, and rest their toes lightly on the foot press button. Given the sensitivity of the embedded micro switch, participants were asked to make gentle foot responses by clicking the button with their toes rather than with their whole foot. All micro switches were connected via an input/output box to the parallel interface of the computer.
Figure 6. The response-board apparatus variously used in Experiments 2c, 3a and 3c consisted of a wooden board (a.) upon which were fixed a home button (b.) and a wooden block (c.) that served to raise and support the power device. The precision device was fixed in position on top of the power device (d.). In addition, there was a foot press button (e.). Not all of the components were necessarily used in each experiment (details are given in the text).

Design and procedure. The basic design was similar to Experiment 1b- four within subject conditions varied equally across 120 trials (already-executed grasp: power or precision and size of changing object: large or small). The change blindness and change identification phases were identical to previous experiments, although the following aspects of the procedure were different. Prior to any practice or experimental trials, participants were familiarised with the response apparatus and foot press switch. They spent a while reaching to the power and precision devices on their laps, such that after a while they could comfortably reach and locate either device without looking under the bench top. When text instructions indicated which device (“Black” or “White”) to hold at the start of each trial, the participant reached to the instructed power or precision device and squeezed
it. This activated the change blindness sequence, and participants released their squeeze and left their hand in place, holding the device throughout the trial. Upon noticing a change in the change blindness sequence, the participant depressed the foot press button with their dominant foot.

Response times and errors were recorded to a data file for off-line analysis, and there were two possible sources of error- violations of the response instruction (participants used the wrong device), and change identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

**Results and Discussion**

1.9% \( (SD = 0.1) \) of trials were removed as errors (0.6% response errors, 1.5% change identification errors, 0.2% both errors on same trial). As previously, no further analysis of errors was undertaken. A further 4.2% of the trials were removed as outliers, reducing the maximum detection time from 39424 ms to 19194 ms \( (M = 5126 \text{ ms}; SD = 2828) \). The combined removal of errors and outliers left 94.0 % of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of already-executed grasp (power or precision) and size of changing object (large or small).

There were no statistically significant results, and the theoretically crucial interaction between already-executed grasp and object size was not observed, \( F(1,20) = .088, p = .769 \), partial \( \eta^2 = .004 \). The difference of findings between this experiment and Experiment 1b was supported in a cross-experimental analysis in which data was pooled and Experiment was added as a between subjects factor. An interaction between Experiment, planned grasp/already-executed grasp and object size suggested
that Experiment as a factor had modulated the two-way interaction, $F(1,41) = 4.732$, $p = .035$, partial $\eta^2 = .103$.

Given the absence of any grasp planning (indeed, the grasp had already been executed prior to stimulus onset), proprioceptive feedback alone (as derived from holding a particular response device throughout the trial) did not appear to provide a sufficiently meaningful basis upon which to bias selective attention towards particular objects. This null effect suggests that response labels were not generated through proprioceptive feedback; a finding that is understandable when one considers that the size of power and precision grasps may not be easily labelled in binary terms. As was the case with the other two experiments in this section, we once again conclude that the most compelling account of the data in Experiment 1b does not relate to a labelling of responses, but instead to a bias of selective attention caused by grasp planning itself.

Experimental Section 3: Tests of planning

Although the effect of grasps in Experiment 1b (and 2a) does not appear to be an outcome of response labelling, can we really be sure that it is the outcome of grasp planning? In this section we attempt to place the burden of proof on planning.

Experiment 3a: Reach-to-grasp responses

In this experiment, response times related to the release of a home key prior to reaching to and grasping a device. Responses times therefore more clearly coincided with the planning phase of a grasp (i.e. the window of time before a grasp hand shape had even been formed on its way to grasping a device). Participants followed the start-of-trial text instruction (e.g. “Black device”), and mentally planned to reach out and grasp the visually concealed device (e.g. power). The participant then pressed and
held down a home button to start the change blindness sequence, and upon noticing a change in the scene, carried out their planned reach-to-grasp of the instructed device. Note that at the time of grasp planning, and throughout the change blindness display, the participant had no access to visual size cues from the instructed response device (it was visually concealed), and no access to proprioceptive size cues from the instructed device (the hand held down a home button). We nevertheless predicted that even without these visual and proprioceptive cues relating to the response devices (i.e. without salient cues for size-labelling the response), simply planning a grasp would be sufficient to produce an interaction similar to Experiment 1b between planned grasp and object size.

**Method**

**Participants.** 17 volunteers between 18 and 36 years of age (mean, 23.1 years) were paid for their participation in a single session that lasted approximately twenty minutes. Of these, two were males (one right-handed, one left-handed), and fifteen were females (one left-handed, fourteen right-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study. Two other participants exceeded an error criterion of 20% overall and were excluded.

**Apparatus and stimuli.** All aspects of the experimental setting and response-board apparatus described in Experiment 2c applied, although the foot press button was not used. The stimuli were those used previously (e.g. Experiment 1a).

**Design and procedure.** The basic design was similar to Experiment 1b- four within subject conditions varied equally across 120 trials (planned grasp: power or
precision and size of changing object: large or small). The change blindness and change identification phases were identical to previous experiments, although the following aspects of the procedure were different. Prior to any practice or experimental trials, participants were familiarised with the response-board apparatus. From a starting position where all four fingers of the dominant hand pressed down the home button, participants spent a minute or so reaching from the home button to one or other of the power or precision devices on their lap and grasping it (without looking under the bench top). Once participants were able to comfortably and accurately reach and locate either device at speed, they were given a short practice session of less than five minutes.

The experimenter explained to the participants that when the text instructions appeared they were to mentally prepare to reach and grasp the instructed device. Text instructions indicated which (grasp) response device was to be used for the current trial (“Black” or “White”), and having mentally prepared a reach-to-grasp participants activated the change blindness sequence by depressing and holding down the home button. Upon noticing a change in the change blindness sequence, the participant released the home button (which recorded response times) and reached towards and grasped the instructed device.

Response times and errors were recorded to a data file for off-line analysis, and there were two possible sources of error- violations of the response instruction (participants used the wrong device), and change identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

Results and Discussion
5.7% ($SD = 0.2$) of trials were removed as errors (3.0% response errors, 3.1% change identification errors, 0.3% both errors on same trial). No further analysis of errors was undertaken; although error rates were higher than previous experiments (reflecting the increased difficulty of the task). A further 3.9% of the trials were removed as outliers, reducing the maximum detection time from 39972 ms to 28130 ms ($M = 4929$ ms; $SD = 2930$). The combined removal of errors and outliers left 90.3% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of planned grasp (power or precision) and size of changing object (large or small).

The expected interaction between planned grasp and object size was observed, $F(1,16) = 11.900, p = .003$, partial $\eta^2 = .427$. Mean change detection was faster for large objects when a power grasp was planned (4979 ms) rather than a precision grasp (5283 ms); and was faster for small objects when a precision grasp was planned (4559 ms) rather than a power grasp (4945 ms). Thus planning to form and execute a grasp reduced change blindness to grasp-congruent changing objects by, on average, 345 ms. This is good support for our proposal that actual grasp planning produced the detection advantage for grasp-congruent changing objects (e.g. in Experiment 1b). Because response times were recorded when the home button was released (and not when a device was squeezed), the planning phase of the grasp was clearly isolated from other considerations such as visual and proprioceptive cues of response (device) size.

Experiment 3b: Forced-choice responses
Despite the findings of Experiment 3a, it is possible that the behavioural effect of interest has been fundamentally misinterpreted. The actual effect of Experiment 1b may have occurred at response time, therefore having nothing to do with grasp planning. For example, participants may detect a change in the scene, and the selected object subsequently primes an object-congruent motor plan. Hence the effect may be visuomotor, rather than motor-visual.

Behavioural evidence of visuomotor priming by visual objects has been demonstrated numerous times (e.g. Craighero, Fadiga, Rizzolatti & Umiltà, 1998; Craighero, Fadiga, Umiltà & Rizzolatti, 1996; Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001, 2004). In an experiment that is particularly relevant to this current discussion (Experiment 1 of Tucker & Ellis, 2001), participants held in their dominant hand a power and precision device of similar dimensions to those reported here. The precision device was grasped between forefinger and thumb, and the power device was grasped between the palm and remaining fingers. Participants made speeded forced-choice responses to real precision and power grasp congruent objects (responses were rule-dependent on whether the object was manufactured or natural). When participants viewed power grasp congruent objects (e.g. a potato) they made slightly faster and more accurate power rather than precision grasps, and vice versa when viewing precision grasp congruent objects (e.g. a grape).

Although we cannot directly compare this experiment (where stimulus identification necessarily preceded grasp planning) with the current experiments (where grasp planning necessarily preceded stimulus identification), it is nevertheless interesting to note that Tucker and Ellis’ (2001) nine millisecond visuomotor priming effect was of a completely different order to the proposed motor-visual priming effect found here (e.g. Experiment 1b: 372 ms). Indeed, the various replications of the
visuomotor priming effect described have all produced effects between 10-30 ms (Ellis & Tucker, 2000; Tucker & Ellis, 2001, 2004).

In considering the disparate nature of the tasks (one clearly visuomotor and one clearly motor-visual) and the disparate nature of the effect sizes (with the current effect being approximately forty times larger than Tucker and Ellis’ (2001) visuomotor priming effect), our strong intuition is that each task reflects a different phenomenon (namely visuomotor and motor-visual priming). Nevertheless, Experiment 3b tested this assumption by presenting the change blindness task as a straightforward visuomotor task. Half of the objects in the change blindness scene were tinted a reddish colour, thereby creating two object categories (grey and red). Participants grasped (in their dominant hand) the precision device between forefinger and thumb and the power device between the palm and remaining fingers, and made a speeded forced-choice response as soon as they detected the change (the responses were rule-dependent on whether the object was red or grey). Given that the task was now a visuomotor task, we predicted a small visuomotor priming effect in line with previous findings (of the order of about 10-30 ms). If, however, we are wrong and the effect of grasps (reported in Experiments 1b, 2a and 3a) simply reflected visuomotor priming, then we should expect to find exactly the same effect as before (namely one of approximately 350 ms); and we should then assume that this large effect size was (for whatever reason) a by-product of the change blindness task.

---

3 Although this prediction was theoretically sound, in practice there was the risk that such a small effect would be masked by the additional variability in response times associated with the more difficult task of change-detection. Tucker and Ellis (2001) for example, used a much easier task in which a single object was viewed, and participants made a speeded response to its object category (natural or manufactured).
**Method**

*Participants.* 18 volunteers between 18 and 27 years of age (mean, 20.1 years) were paid for their participation in a single session that lasted approximately fifteen minutes. Of these, four were males (right-handed), and fourteen were females (right-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study. One other participant exceeded an error criterion of 20% overall and was excluded.

*Apparatus and stimuli.* The experimental setting and response apparatus were the same as Experiment 1b, except that the response devices were not fixed to the table, but instead were held lightly in the participant’s dominant hand (cf. Ellis & Tucker, 2000). The precision device was grasped between forefinger and thumb, and the power device was grasped between the palm and remaining fingers.

The stimuli from previous experiments (e.g. Experiment 1a) were re-used in a modified form. In each scene, three large and three small objects were selected pseudo randomly from the scene and tinted red. Thus in each scene, six objects were red, and six remained greyscale. Object selection was not completely random, since special care was taken to ensure that in half of the scenes (scenes 1-30) the changing object was red, and in the other half it was grey (scenes 31-60). The sixty scenes were shown twice in a random order (120 trials).

*Design and procedure.* The basic design was the same as Experiment 1b- four within subject conditions varied equally across 120 trials (size of changing object: large or small and grasp response: power or precision). The change blindness and change identification phases were identical to previous experiments, although the following aspects of the procedure were different.
The task was a speeded forced-choice reaction time task whereby participants were given a response rule instructing them to squeeze the “White” device if the changing object was grey or the “Black” device if it was red. On each trial the change blindness sequence started after one second, and upon noticing which object was changing, participants had to accurately apply the response rule by squeezing the appropriate device as quickly possible.

Response times and errors were recorded to a data file for off-line analysis, and there were two possible sources of error: response errors (violations of the response rule), and change identification errors (an F-key response that timed-out or did not correspond to the changing object’s F-number).

Results and Discussion

2.6% ($SD = 0.2$) of trials were removed as errors (2.1% response errors, 0.6% change identification errors, 0.1% both errors on same trial). The change identification data revealed that on the majority of trials the correct changing object had been detected. Since the response errors had arisen from a forced-choice task, they were of interest and were analysed further below. An additional 4.2% of the trials were removed as outliers, reducing the maximum detection time from 32115 ms to 15071 ms ($M = 4738$ ms; $SD = 2478$). The combined removal of errors and outliers left 93.2% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures ANOVA with the within subjects factors of size of changing object (large or small) and grasp response (power or precision).

The theoretically crucial interaction between object size and grasp was not observed, $F(1,17) = 0.009$, $p = .924$, partial $\eta^2 = .001$. The difference of findings
between this experiment and Experiment 1b was supported in a cross-experimental analysis in which data was pooled and Experiment was added as a between subjects factor. An interaction between Experiment, planned grasp/grasp response and object size suggested that Experiment as a factor had modulated the two-way interaction, $F(1,38) = 6.010, p = .019$, partial $\eta^2 = .137$.

An analysis of the response error data however, (which was also subjected to a repeated measures ANOVA with the within subjects factors of size of changing object and grasp response), revealed significant main effects of object size [more response errors were made detecting changes in large objects (2.8%) rather than small objects (1.4%), $F(1,17) = 5.347, p = .034$, partial $\eta^2 = .239$]; and grasp response [more response errors were made making precision grasp (2.9%) rather than power grasp responses (1.3%), $F(1,17) = 6.750, p = .019$, partial $\eta^2 = .284$]. Interestingly, these two factors interacted as follows, $F(1,17) = 14.199, p = .002$, partial $\eta^2 = .455$: fewer response errors were made for large changing objects when a power grasp response was made (0.7%) rather than a precision grasp response (4.9%); and fewer response errors were made for small changing objects when a precision grasp response was made (0.9%) rather than a power grasp response (1.9%). Importantly, this pattern of response errors demonstrates that the modified task had successfully set up the conditions for visuomotor priming, since a standard stimulus-response compatibility effect was observed.

The fact that there was no indication of even a small visuomotor priming effect in response times may reflect the noise inherent in the detection task (e.g. return to footnote 3). Regardless, the results failed to provide evidence that a 350 ms effect could be reproduced by invoking visuomotor processes. It is likely then, that the
previous experiments (e.g. Experiment 1b) reflect the effects of action-to-vision rather than vision-to-action.

Experiment 3c: Foot responses

This final experiment shared the same aim as Experiment 3b- namely to distinguish between potential visuomotor or motor-visual processes. The logic behind this experiment was borrowed from Experiment 4 of Craighero et al. (1999), who faced a similar challenge in differentiating their motor-visual effect from a visuomotor one. The logic is as follows: if grasp planning biases attention to grasp-congruent objects (i.e. a motor-visual effect), then this grasp plan should facilitate change detection regardless of what action is actually carried out (e.g. if the planned grasp is withheld and a foot response is made instead). However, if it is the visual object that primes a congruent action plan (i.e. a visuomotor effect), then no facilitation of change detection should arise with a foot response (since it has no source of compatibility with the changing object).

As with Experiment 3b, change blindness scenes with half red and half grey objects were used; and as with Experiments 2c and 3a, the response-board apparatus and foot press button were used. Participants followed the start-of-trial text instruction (e.g. “Black device”), and planned to reach out (from the home button) and grasp the instructed device (e.g. power). On two thirds of trials the changing object was grey and participants executed their planned reach-to-grasp. On one third of trials the changing object was red and participants withheld their planned reach-to-grasp and made a foot press response. In keeping with our motor-visual priming hypothesis, we predicted that analysis of foot press responses should nevertheless reveal an
interaction between planned grasp and object size (with improved change detection for grasp-congruent objects).

Method

Participants. 16 volunteers between 18 and 38 years of age (mean, 24.1 years) were paid for their participation in a single session that lasted approximately forty-five minutes. Of these, four were males (right-handed), and twelve were females (ten right-handed, two left-handed). All participants self-reported normal or corrected-to-normal vision and normal motor control, and all were naïve as to the purpose of the study. One other participant exceeded an error criterion of 20% overall and was excluded.

Apparatus and stimuli. All aspects of the experimental setting and response-board apparatus (return to Figure 6) described in Experiment 2c were used: participants sat at the workbench with the response-board apparatus on their lap, and the toes of their dominant foot rested on the foot press button. The stimuli consisted of 180 different change blindness scenes (and their modified and change identification variants) that were produced from the sixty scenes used in Experiment 3b. A horizontal flip of red changing object scenes 1-30 produced scenes 61-90. A horizontal flip of grey changing object scenes 31-60 produced scenes 91-120, which in turn produced scenes 121-150 (vertical flip), which in turn produced scenes 151-180 (horizontal flip). Thus in 120 scenes (\(\frac{2}{3} \times 180\)) the changing object was grey (60 large and 60 small), and in 60 scenes (\(\frac{1}{3} \times 180\)) the changing object was red (30 large and 30 small).

Design and procedure. Eight conditions arose from the orthogonal variation of three within subjects variables, each with two levels: response type (hand
or foot); planned grasp (power or precision) and size of changing object (large or small). At the beginning of the experiment, participants were talked through some written instructions that explained the task. A substantial practice session lasting about fifteen minutes was followed by 180 experimental trials. These consisted of two blocks of 90 randomised trials (hand responses: 4 conditions × 15 replications; foot responses: 4 conditions × 5 replications).

The change blindness and change identification phases were identical to previous experiments, although the following aspects of the procedure were different. Prior to any practice or experimental trials participants were familiarised with the response-board apparatus and foot press button. Once participants were able to comfortably and accurately reach from the home button and locate either the power or precision device at speed, they were given a practice session. To ease the cognitive complexity of the task, the experiment (and practice session) was split into two halves. The text instructions for each half always indicated that the same (grasp) response device was to be used for the current trial (e.g. “Black”), and this instruction changed in the second half (e.g. “White”). For eight participants the sequence was “Black” (power device) for the first half (90 trials) followed by “White” (precision device) for the second. This order was reversed for the remaining eight participants.

The experimenter explained to the participants that when the text instructions appeared they were to mentally prepare to reach and grasp the instructed device. Text instructions indicated which (grasp) response device was to be used for the current trial (“Black” or “White”), and participants then activated the change blindness sequence by depressing and holding down the home button with their dominant hand. There was however, an added dimension to the task that restricted participants from automatically executing their planned reach-to-grasp on detecting a change. Instead
participants were required to identify the colour of the changing object as quickly as possible. If the changing object was grey (which it was on ⅔ of trials), participants carried out their planned reach-to-grasp by releasing the home button (which recorded response times) and reaching towards and squeezing the instructed device. If the changing object was red however (which it was on ⅓ of trials), participants withheld their planned reach-to-grasp and whilst keeping the home button depressed, pressed down the foot press button with their dominant foot (which recorded response times).

Response times and errors were recorded to a data file for off-line analysis, and there were three possible sources of error: release errors: the home button was mistakenly released or not released; response errors: an incorrect response was made (power or precision grasp, or foot press); change identification errors: an F-key response that timed-out or did not correspond to the changing object’s F-number.

Results and Discussion

6.9% (SD = 0.3) of trials were removed as errors (4.7% release errors, 3.5% response errors, 2.9% change identification errors, 3.4% multiple errors on same trial). Although the error rates were the highest of all the experiments (reflecting the increased difficulty of the task), release, response and change identification error data nevertheless revealed that on the majority of trials the instructions had been adhered to and the correct object had been identified. A further 4.1% of the trials were removed as outliers, reducing the maximum detection time from 36043 ms to 21267 ms (M = 4785 ms; SD = 2695). The combined removal of errors and outliers left 89.0% of the raw data as correct responses, and the condition means of this remaining data were computed for each participant and subjected to a repeated measures
ANOVA with the within subjects factors of response type (hand or foot), planned grasp (power or precision) and size of changing object (small or large).

There was one statistically significant finding-an interaction between all three factors, $F(1,15) = 6.405, p = .023$, partial $\eta^2 = .299$, which suggested that the response type had influenced the nature of the interaction between planned grasp and object size. This was explored further by performing two separate repeated measures ANOVAS (one under each response type), with the within subjects factors of planned grasp and size of changing object.

For the foot response analysis, there was a statistically significant interaction between planned grasp and object size, $F(1,15) = 4.631, p = .048$, partial $\eta^2 = .236$. Mean change detection was faster for large objects when a power grasp was planned (4985 ms) rather than a precision grasp (5356 ms); and was faster for small objects when a precision grasp was planned (4532 ms) rather than a power grasp (4974 ms). Thus planning a ‘to-be-executed’ grasp reduced change blindness to grasp-congruent changing objects by, on average, 406.5 ms- despite the fact that this planned grasp was not carried out and in its place a foot press response was made. In agreement with Experiment 3b therefore, this result provides another line of evidence that the crucial finding of this paper (the interaction between planned grasp and object size first observed in Experiment 1b) was a true motor-visual effect reflecting grasp planning, and not a visuomotor one.

For the hand response analysis however, there were no statistically significant findings, and in particular, the expected interaction between planned grasp and object size was not observed, $F(1,15) = 1.280, p = .276$, partial $\eta^2 = .079$. Although it does not detract from the finding in foot responses, the absence of an effect here is surprising, and there is no obvious explanation. A purely speculative account is that
on identifying the objects’ colour, participants re-planned the instructed reach-to-grasp. This re-planning stage might have dissipated any facilitatory effect associated with the initial reach-to-grasp plan. In contrast, on foot response trials there would be no need to re-plan since the initial grasp plan could simply be abandoned in favour of a foot response (with the facilitatory influence of the initial reach-to-grasp plan remaining intact).

**General Discussion**

“Typically, a person who searches for a specific object in the environment also has a specific intention of what he or she wants to do with that object... Therefore, an efficient visual search system should detect action-relevant information in an enhanced way.” Bekkering and Neggers (2002, p.370).

An efficient visual search system, as can be generalised from the assorted priming studies reviewed in the Introduction, appears able to constrain the kind of information that we access from the world, based on an intention or readiness to perform an action. In the current study, participants searched for a changing object in a visual scene, and they had a specific intention of what action to perform when they found the object (although this action was not performed on the object itself). We hypothesized that these conditions should be sufficient to reveal enhanced visual processing. Specifically, we predicted that planning to execute a certain grasp would improve the detection of changes in congruent objects.

**Summary of Experiments**

Experimental Section 1 (“Establishing an effect of grasps”) produced two major findings. Firstly, Experiment 1a (“Neutral responses”) observed a bias for detecting changes in small objects. Because spacebar presses were prepared as a
response to the change blindness scenes in this experiment, this main effect reflected a purely perceptual bias that was independent of grasp planning (in fact Experiment 2a attributed this effect to eye movements). As Figure 7a below reveals, although this difference did not always reach statistical significance, changes to small objects were consistently detected fastest in all experiments.

The interaction between planned grasp and object size observed in Experiment 1b (“Grasp responses”) provided clear support for our hypothesis that grasp planning would bias selective attention to grasp-congruent object features (see Figure 7c, Expt. 1b). Thus planning a grasp (that was later executed using a power or precision response device) reduced the time taken to detect changes in grasp-congruent objects. The true nature of this interaction (and later ones like it) was somewhat obscured by the unrelated main effect of object size discussed above.

Experimental Section 2 (“Tests of Labelling”) tested the possibility that this interaction had arisen from the labelling of responses, and/or their devices, in terms of size (size was a dimension that overlapped between stimuli and responses). No support for this alternative account was found in any of the three experiments. Firstly, Experiment 2a (“Strategic saccades”) reproduced an effect of grasps [see Figure 7c, Expt. 2a(i)], which was shown to arise independently of eye-movements [see Figure 7c, Expt. 2a(ii)]. It could not therefore have arisen from the strategic use of labels that

---

4 This point is important when interpreting the interaction. When visually examining the appropriate graph (see Figure 7c, Expt. 1b) by grasp type rather than by object size, the influence of this main effect makes it appear that only precision grasp planning facilitated detection of changes in congruent objects. This is misleading however, given the influence of the main effect. Experiment 2a illustrates this point well, by demonstrating the interaction with and without the main effect [c.f. Figure 7c, Expt. 2a (i) and Expt. 2a (ii)].
directed overt attention to congruent objects. Secondly, Experiment 2b (“Visual labels”) produced a null effect- see Figure 7b, Expt. 2b- when grasping was replaced with a finger press of the same physical response devices (even though responses could potentially be labelled in terms of visual size cues). Thirdly, Experiment 2c (“Proprioceptive labels”) produced a null effect- see Figure 7b, Expt. 2c- when grasp planning was replaced with simply holding a response device and making a foot press response (even though responses could potentially be labelled in terms of proprioceptive size cues).

Experimental Section 3 (“Tests of Planning”) placed the burden of proof on actual grasp planning. The three experiments in this section all provided evidence supporting the argument that planning was the crucial factor affecting change detection. Thus in Experiment 3a (“Reach-to-grasp responses”), responses were recorded by the release of a home button as the hand reached towards a device for grasping. This setup ensured that the planning phase of the grasp was isolated from the actual grasping. Nevertheless, the crucial interaction between grasp type and object size was still observed (see Figure 7c, Expt. 3a). In Experiment 3b (“Forced-Choice Responses”), a forced-choice change blindness task created the necessary conditions for a visuomotor priming effect, yet none was found in response times (see Figure 7b, Expt. 3b). If the previous grasp-related effects had been visuomotor in nature, then a similar effect should have been observed here. Experiment 3c (“Foot responses”), provided further evidence for this argument, by revealing an interaction between planned grasp and object size on trials where the grasp squeeze was actually withheld and a foot press response was made instead [see Figure 7c, Expt. 3c(i)]. This effect must have been produced by grasp planning, since the actual grasp was never made. Anomalously however, on trials where the grasp squeeze was executed as
planned, there was no such interaction [see Figure 7b, Expt. 3c(ii)]. Despite this anomaly, the three experiments in this section all point to a genuine case of grasp planning affecting vision.

In conclusion, the combined findings of Experimental Sections 2 and 3 provided overwhelming support for our preferred interpretation of Experiment 1b: grasp planning biased selective attention to grasp-congruent objects in the scene, thereby imposing a detection time advantage for them. The only inconsistent finding throughout, as mentioned in the previous paragraph, was the unexpected null effect in one condition of Experiment 3c.
Figure 7. The legend applies to all three graphs. The upper graph (a.) shows the mean response times for each experiment as a function of the size of the changing object (large or small). Statistical significance values are reported at the top of this graph. The central and lower graphs (b. & c.) show the mean response times for each experiment as a function of the response device used (power or precision) and the size of the changing object (large or small). With a significance criterion of $p < .05$, the central graph (b.) depicts statistically non-significant results and the lower graph (c.) depicts statistically significant results.
Theoretical Implications

This data joins the small but growing number of motor-visual priming studies (see Introduction) that report a facilitatory influence of action on perception. Some authors have interpreted these kinds of effects in terms of the premotor theory of attention (e.g. Craighero et al. 1999; Pavese & Buxbaum, 2002; Eimer, Forster, Van Velsen & Prabhu, 2005). According to this theory (Rizzolatti et al. 1987), premotor planning of eye movements generates shifts of attention to the spatial location of the intended eye movement (Sheliga, Riggio & Rizzolatti, 1994). More generally, goal-directed actions (to a region of space) and spatial attention are claimed to share common control structures in the brain. Most evidence for this has involved eye movements. Brain imaging comparisons of covert spatial attention and eye movement preparation for example, have revealed overlapping circuitry that is active in both tasks, such as the frontal and supplementary eye fields and several parietal and temporal regions (e.g. Corbetta et al. 1998). More recent evidence supporting the theory includes manual movements. For example Eimer, Forster, Van Velsen and Prabhu (2005) have reported evidence of similar lateralised event-related brain potentials being elicited during covert manual response preparation and covert shifts of spatial attention.

In considering their grasp-related motor-visual effect (see Introduction), Craighero, Fadiga, Rizzolatti, and Umiltà (1999) proposed an extension of the premotor theory, arguing that it could be generalised to the orienting of attention to any objects that can be acted on (and not just spatial locations). The findings from the present study provide support for this generalisation. Firstly, the power and precision grasps were not directed to a region in space, and secondly, they did not possess an obvious spatial dimension. So the grasp-induced bias of selective attention must have
referred to grasp-congruent features of the objects (i.e. their size) and not their location. Perhaps this is why the bias was shown to occur independently of eye movements in Experiment 2a. The eye movement data reflects how frequently discrete locations were fixated (albeit locations containing an object), but it does not tell us about the underlying nature of feature processing (which is not location-bound).

We can only speculate about the precise mechanisms underlying the selective bias of our effect. We know that attention was required to produce awareness of the change, and that somehow grasp planning affected the time this took. Experiment 2a clearly ruled out an overt strategic bias of attention (the effect in response times held independently of the fixation data); although there was some evidence that grasp planning had (asymmetrically) modulated eye movements. None of this rules out a bias of covert selective attention of course.

One possibility, which we favour, is that our effect reflects a more general enhancement of visual processing that manifests itself as a bias of selective attention. Bekkering & Neggers (2002) hypothesised that a general enhancement of visual processing for relevant features may be the underlying mechanism that produces action-induced biases of selective attention. Specifically, they suggested that action intentions may tune feature-relevant neural channels, thereby representing them at a higher resolution and ultimately biasing competition in attentional selection (e.g. Desimone, 1998). In some respects, this tuning hypothesis echoes the sentiments of the Ecological approach to perception and action. Michaels and Stins (1997) for example, argued that the perceiver-actor is ‘attuned’ to perceptual information that constrains an upcoming action, such that action ‘sets up’ attention to particular information.
Moore and Armstrong (2003) have recently provided direct evidence that action planning may indeed be a candidate mechanism for selectively enhancing visual processing. They demonstrated via electrical stimulation of sites within monkey frontal eye fields (those sites implicated in planning eye-movements), that premotor commands initiate a bias in the strength of visual signals in corresponding sites of extrastriate visual cortex. We suggest that this kind of selective enhancement may not only be initiated by oculomotor plans, but may also be initiated by manual action plans such as grasping.

References


**Appendix**

For each new scene, twelve objects (and an additional replacement object) were randomly selected from the following pool of twenty four objects:

<table>
<thead>
<tr>
<th>Object no.</th>
<th>Small object identity</th>
<th>Axis (cm)</th>
<th>Object no.</th>
<th>Large object identity</th>
<th>Axis (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Primary</td>
<td></td>
<td></td>
<td>Primary</td>
</tr>
<tr>
<td>1</td>
<td>Ginger root</td>
<td>1.7</td>
<td>13</td>
<td>Apple</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Apricot</td>
<td>1.9</td>
<td>14</td>
<td>Avocado pear</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>Baby potato</td>
<td>1.8</td>
<td>15</td>
<td>Lemon</td>
<td>4.6</td>
</tr>
<tr>
<td>4</td>
<td>Chestnut</td>
<td>1.7</td>
<td>16</td>
<td>Mango</td>
<td>4.5</td>
</tr>
<tr>
<td>5</td>
<td>Button mushroom</td>
<td>1.6</td>
<td>17</td>
<td>Peach</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Broccoli floret</td>
<td>1.9</td>
<td>18</td>
<td>Onion</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Baby tomato</td>
<td>1.6</td>
<td>19</td>
<td>Orange</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Chilli pepper</td>
<td>2.6</td>
<td>20</td>
<td>Pear</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Garlic clove</td>
<td>2.5</td>
<td>21</td>
<td>Tomato</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Radish</td>
<td>2</td>
<td>22</td>
<td>Potato</td>
<td>4.5</td>
</tr>
<tr>
<td>11</td>
<td>Shallot</td>
<td>2.5</td>
<td>23</td>
<td>Pepper</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Strawberry</td>
<td>1.6</td>
<td>24</td>
<td>Squash</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>2.0</td>
<td></td>
<td>mean</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>0.4</td>
<td></td>
<td>sd</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Axis (cm)**