

The effects of task and saliency on latencies for colour and motion processing

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In human visual perception, there is evidence that different visual attributes, such as colour, form and motion, have different neural-processing latencies. Specifically, recent studies have suggested that colour changes are processed faster than motion changes. We propose that the processing latencies should not be considered as fixed quantities for different attributes, but instead depend upon attribute salience and the observer's task.

We asked observers to respond to high- and low-salience colour and motion changes in three different tasks. The tasks varied from having a strong motor component to having a strong perceptual component. Increasing salience led to shorter processing times in all three tasks. We also found an interaction between task and attribute: motion was processed more quickly in reaction-time tasks, whereas colour was processed more quickly in more perceptual tasks.

Our results caution against making direct comparisons between latencies for processing different visual attributes without equating salience or considering task effects. More-salient attributes are processed faster than less-salient ones, and attributes that are critical for the task are also processed more quickly.

Keywords: awareness; visual latency; visual pathways; colour; motion

1. INTRODUCTION

There has been much recent interest in looking at the time taken to process various visual-stimulus attributes, such as colour, form and motion. It is commonly accepted that different visual attributes are processed relatively independently in separate parts of the brain (Zeki 1978; Livingstone & Hubel 1988). These different attributes may have different processing latencies. Nevertheless, we are rarely aware of such asynchronies. How can these observations be reconciled?

Does the brain compensate for differences in processing time, such that a unified percept is recovered that mirrors the synchrony of real-world events? Research by Moutoussis & Zeki (1997) suggested that colour reaches our awareness faster than motion. When objects are repeatedly and rapidly changing colour (between red and green) and switching motion direction with the same frequency, then colour changes must occur *ca.* 80 ms after motion changes for them to be perceived as synchronous. In the framework of 'micro-consciousnesses' of Zeki & Bartels (1998), each specialized area of the brain leads independently to an awareness of a particular attribute. Differences in processing latencies for these different areas are not compensated for, and a faster processing of colour leads straightforwardly to a lead in awareness of colour over motion. Arnold *et al.* (2001) provided evidence for similar differential latencies, using colour-contingent after-effects. The explanation that colour is simply processed faster than motion has been disputed by Nishida & Johnston (2002). They argue that differential latencies arise because, at high temporal frequencies, the visual system is unable to compare a first-order change (colour) with a second-order position change (motion) and resorts to

matching first-order colour changes to first-order position changes (direction). They have provided evidence that at low alternation rates these asynchronies disappear.

We propose that the absolute processing times for various attributes should not be considered as fixed, but may be modulated by a number of factors. For example, the relative salience of the attributes being considered may vary in the above studies. There is a range of evidence that demonstrates that increasing stimulus strength leads to a reduction in processing time. A reduction in processing latency has been demonstrated with increasing stimulus luminance in simple reaction times (RTs) (Roufs 1963, 1974; Williams & Lit 1983), with a motion-depth phenomenon called the Pulfrich effect (Pulfrich 1922; Brauner & Lit 1976; Williams & Lit 1983) and using various temporal-order judgements (TOJs) (Roufs 1963, 1974; Williams & Lit 1983). Similar effects are found when observers respond to a change in stimulus velocity: increasing the size of the velocity change decreases RTs (Dzhafarov *et al.* 1993; Mateeff *et al.* 1995; Hohnsbein & Mateeff 1998). For this reason, in the current study, we investigate the effect of modulating the salience of colour and motion changes.

We are also interested in how the type of task being performed might affect the processing of different visual attributes. The finding by Moutoussis & Zeki (1997) that motion is apparently processed more slowly than colour seems peculiar for two reasons. Physiologically, there is overwhelming evidence that motion is processed by the faster magnocellular channel (e.g. Livingstone & Hubel 1988). Ecologically, it is crucial that the motions and locations of objects are processed very quickly for the motor system. For example, large uncompensated lags in processing motion would lead to difficulties in catching a ball or crossing a street of traffic.

The issue of the functional uses of motion information is linked to the idea that there are two relatively

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independent streams of visual processing, commonly referred to as the ‘what’ and ‘where’ streams (Ungerleider & Mishkin 1982; Livingstone & Hubel 1988). This debate was recently rekindled by Milner & Goodale (1995), who proposed that the two streams were better described as serving different purposes: perception and action. These two systems would presumably have different priorities in terms of type of visual information, and physiological evidence supports this dichotomy (Livingstone & Hubel 1988), although the segregation between the two pathways is not complete (Schiller & Logothetis 1990; Merigan & Maunsell 1993; Gegenfurtner & Hawken 1996). In particular, a processing stream for guiding action should process motion more efficiently, with higher temporal resolution and be less concerned with colour. By contrast, a system for detailed perception may be more specialized to recover colour and resolve high spatial frequencies (SFs). A symptom of such a split system would be that different tasks (i.e. perceptual versus action tasks) would exhibit more efficient, or faster, processing for particular attributes. We suggest that a simple RT task might be mediated by the dorsal stream, whereas perceptual judgements are more likely to be mediated by the ventral stream.

We investigated the effects of manipulating three variables on the time taken by observers to detect a change in the visual attribute of an object. These three variables were:

- (i) attribute (colour or motion),
- (ii) salience (high or low),
- (iii) task (RTs, pointing or perceptual choice).

Before the main experiment, two preliminary experiments were performed to calibrate individually the stimuli presented to each observer. The first experiment ensured that all stimuli were subjectively isoluminant, and the second experiment was used to calibrate the stimuli for salience. After describing these two preliminary experiments, we report the results of the main experiment, where attribute, salience and task were all manipulated. To interpret these results, two simple models are presented to estimate the processing times in the different conditions. All experiments were completed by five observers: three were naive and the other two (WA and PM) were the authors.

2. MATERIAL AND METHODS

(a) *Preliminary experiment 1: determining apparent isoluminance*

To estimate the effect of colour on processing time, it is important to ascertain that the stimuli are not contaminated by luminance variations. Therefore, for each individual observer, we determined a range of colours that were subjectively isoluminant using a minimum-motion technique similar to that proposed by Anstis & Cavanagh (1983). This technique exploits the fact that motion at isoluminance is reduced (Ramachandran & Gregory 1978) or under some circumstances eliminated (Lu *et al.* 1999).

In every trial, the baseline colour red was fixed, with red, green and blue monitor saturations of 0.8, 0.1 and 0.1 (resulting in a colour of CIE coordinates $x = 0.493$, $y = 0.328$). A square

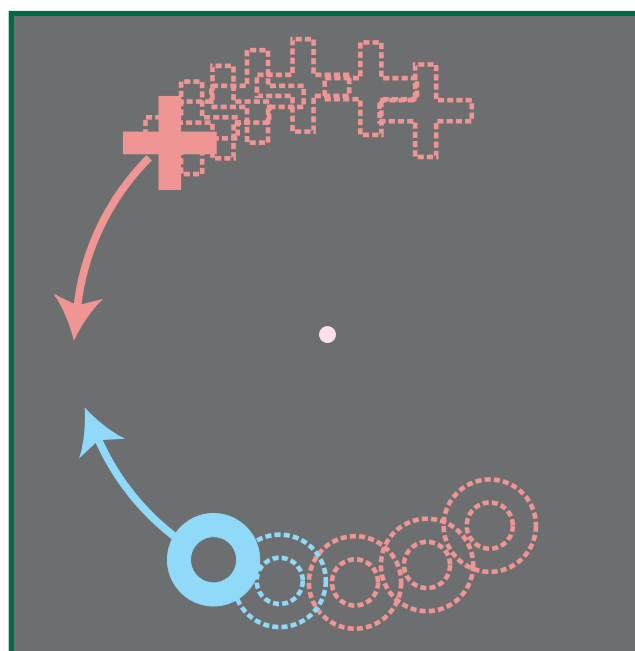


Figure 1. Schematic representation of the stimuli in preliminary experiment 2 and the main experiment.

wave of alternating stripes of this red and a comparison colour was shown in a motion cycle where the phase shifted vertically by one-quarter cycle every 13 ms. The stimulus subtended 6.4° at the viewing distance of 43 cm. The comparison colour had its red and blue saturations fixed, and within each trial the observers adjusted the saturation of the green component using key presses, until they had subjectively minimized the motion, effectively determining the isoluminant point. In each trial, one of eight different comparison colours was used, with red values from 56% to 77% saturation, and blue values from 34% to 13%. Each observer completed eight trials with each of the eight comparison colours. The direction of motion and start point of the green component were randomized between trials.

The result was a range of colours, all perceptually isoluminant, but more or less distant in colour space from the baseline red. A second-order polynomial was fitted to each observer's data to determine the amount of green required to make any combination of red and blue appear isoluminant with the baseline red colour.

(b) *Preliminary experiment 2: determining high and low salience*

Only limited conclusions can be drawn about the temporal properties of processing without considering salience (Walsh 2002). We therefore used both high- and low-saliency stimuli for the current experiment. As described in more detail below, our low-saliency condition was defined as the 99% detection level for a colour or motion change. The high-saliency level was the point at which RTs became almost asymptotic (Barbur *et al.* 1998).

Two red objects, a cross and a circle, rotated around a central fixation point (figure 1). Both objects initially had the baseline red colour described in § 2a. Their diameters were 1.5° and they had the same area (1.25°). From random start positions, they moved around a circular path with a radius of 4° in opposite directions at 0.47 revolutions s^{-1} . After a random time, determined by a Poisson distribution with a mean of 4 s, one of the objects changed either colour or speed. The other object did not

change. On speed-change trials, the new speed was chosen from the range 0.51–0.73 revolutions s^{-1} . In colour trials, the second colour varied from trial to trial, but was chosen from a set of 10 isoluminant colours determined by the method outlined in § 2a. The observers' task was to fixate centrally and press a key as quickly as possible when they detected a change. Feedback was given for failure to respond (within 2 s) or responding when no change occurred. Each stimulus was repeated 16 times in four sessions. The observers had the opportunity to take a break every 20 trials.

In agreement with previous research (Dzhafarov *et al.* 1993; Hohnsbein & Mateeff 1998), the effect of increasing the size of the speed change was to decrease RTs. Similarly, as the difference between the two colours increased, RTs decreased. This is in broad agreement with research using isoluminant stimuli, which has shown a decrease in latencies using synchrony judgements (Bowen 1981) and simple RTs (Nissen & Pokorny 1977) as predicted by trichromatic discrimination. In our task, RTs were recorded and fitted with an exponential function with three degrees of freedom c_1 , c_2 and c_3 (Barbur *et al.* 1998): $RT = c_1 \exp(-x c_2) + c_3$, where x is the stimulus strength (speed or colour difference). From this fit, the high-saliency level was established as the point at which RTs came within 5% of the asymptote. Independently, a psychometric function (cumulative normal) was fitted to the detection rates and the low-saliency level was defined as the 99% threshold.

(c) Main experiment

The main aim of this experiment was to determine whether varying the task would affect the processing time for colour and motion. The stimuli were similar to those used to determine saliency in the second preliminary experiment (figure 1). At the start of each trial, a red cross and a red circle rotated in opposite directions around a central fixation point. However, only four changes were now possible: high- or low-saliency colour change, or high- or low-saliency motion change. Both objects changed once in every trial. The time lag between the two objects changing (inter-stimulus interval: ISI) varied from 0 to 200 ms (or 0–133 ms depending on the condition) in steps of 13.3 ms (the duration of one frame). Because the time to the first change and the time between the two changes varied randomly from trial to trial, the timing of these two events was entirely unpredictable. We thus avoid the potential complications in interpreting the kinds of stimuli used by Moutoussis & Zeki (1997) and Arnold *et al.* (2001) where attributes oscillate between two values in a repeated and regular manner. With these previous stimuli, the decay of colour and motion representations (Clifford *et al.* 2002) as well as possible predictive strategies must be considered.

The observers responded to the colour and motion changes in three different tasks. In the RT task, they simply responded as quickly as possible, with a key press, when something changed, irrespective of which object or which attribute changed. In the pointing task (*point*), the observers were asked to point to an object as soon as they saw it change. The position of their response was recorded via the touchscreen, and visual feedback was given; the object that they made contact with became larger, as though it had been squashed. The final task was a perceptual choice task (*choice*). In this task the observers were required to decide which object had changed first and then press the 'X' key for the cross or 'O' for the circle. Again, visual feedback was given, this time by illuminating the selected object.

The trials were organized into blocks by response type. Within each block, the observers saw one trial for every combination of

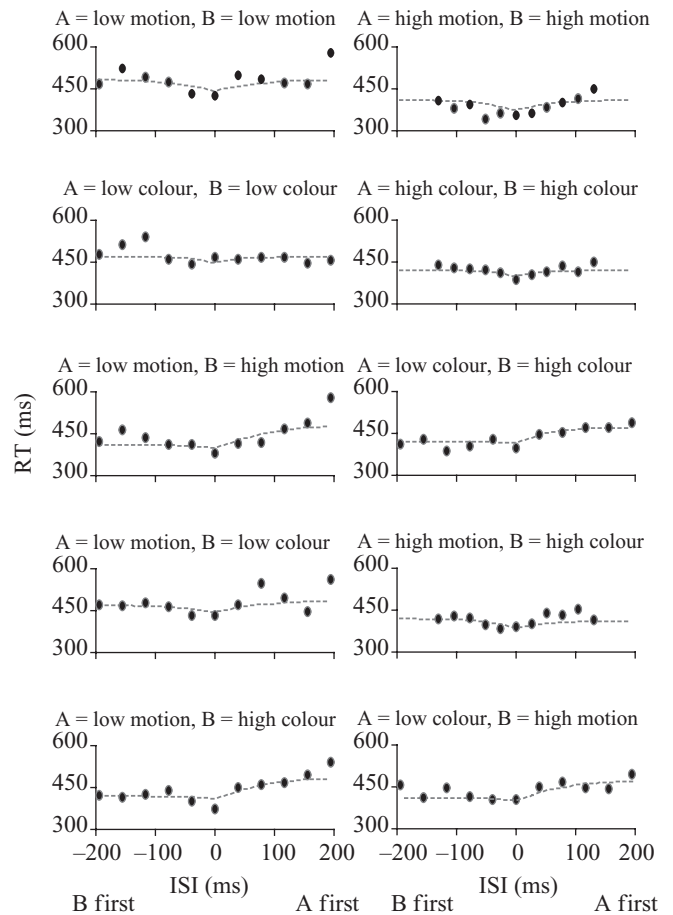


Figure 2. Results for one observer (PM) for the RT task. Each of the 10 possible combinations of the two changes is plotted on a separate graph. The horizontal axis gives the time of event B relative to event A. Filled circles give the observer's data, and the dashed lines show the model's fit.

saliency and attribute for the two objects (10 combinations) at each of 11 time lags, totalling 110 trials. Each observer completed eight of these blocks for each of the three response conditions, intermixed over a period of a week or more.

3. RESULTS

Figure 2 shows the mean data for all conditions for the RT task for one observer (PM), with the model's fit (described in § 3b). The horizontal axis shows the time of the second change relative to the first. For example, in the bottom right plot, '–200' means that a high-saliency motion change preceded a low-saliency colour change by 200 ms. All observers had similar patterns of data, which were similarly well fitted by the model. At large ISIs, the RT asymptotically approaches the mean of the underlying RT distribution for the individual attribute that changed first. The dip in RTs at small ISIs corresponds to the increased probability of early detection when the two changes occur simultaneously.

With a similar layout, figure 3 shows the results for the *point* task for the same observer (PM), with the model's fit (also described in § 3c). In this case, the proportion of trials in which object A was 'squashed' is plotted on the vertical axis. Here, 'object A' is the circle or cross that

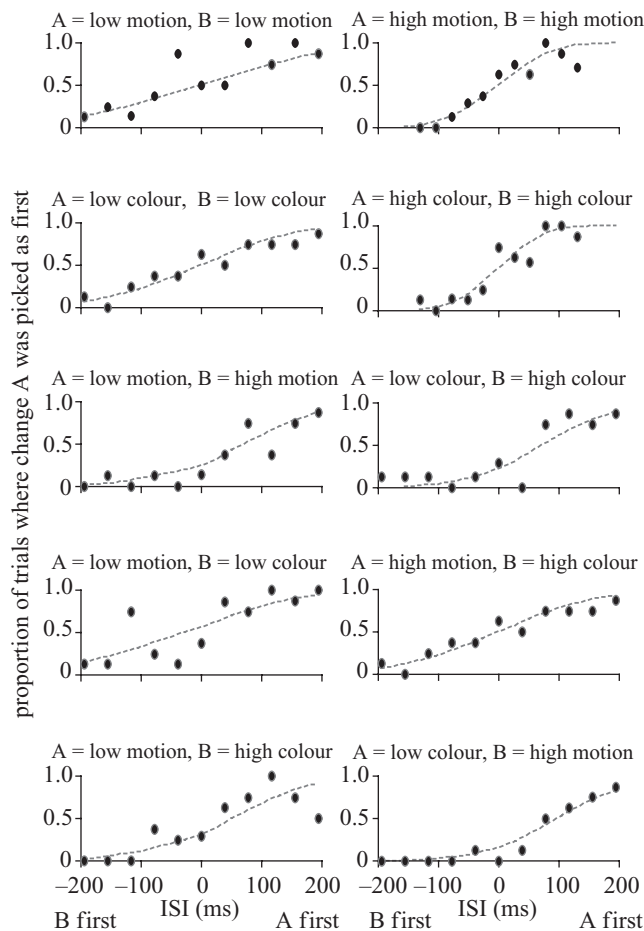


Figure 3. Results for one observer (PM) for the *point* task. Each plot shows a different stimulus combination. The proportion of trials in which the observer pointed to object A is given on the ordinate, and the stimulus ISI is given on the abscissa.

changed in the attribute listed first. Data for the *choice* task followed a similar pattern to the *point* data.

(a) Models

We devised simple models to allow a comparison between the different conditions. These can be conceptualized as ‘race’ models (e.g. Raab 1962; Miller & Ulrich 2003) where each event (a colour or motion change) produces a separate pulse of activation. Each activation signal is processed independently and in parallel. In the *RT* task, a participant will respond as soon as any signal is processed and a motor response is generated. In the other two tasks, the participant will perform a TOJ based on which signal arrives first at some ‘decision centre’. These models allow us to compare the latencies, or processing times, for each signal under our different task conditions and for the two stimulus saliencies.

(b) Model for reaction times

Objects A and B undergo attribute changes at times t_A and t_B , respectively. The ISI is given by $ISI = t_B - t_A$. Let us assume that the response delay to a change in attribute of object A is represented by the random variable R_A . Likewise, the change in object B has an associated

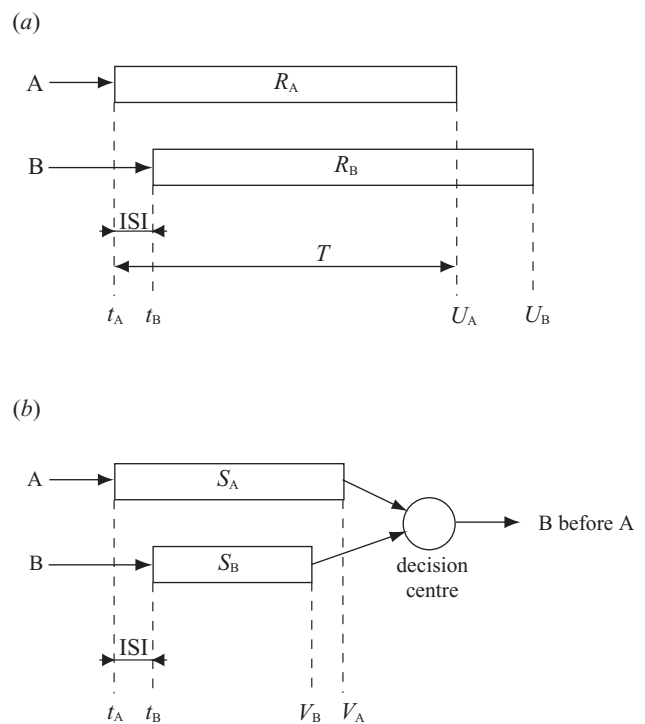


Figure 4. The models for calculating (a) the RTs and (b) the TOJs.

response delay of R_B (figure 4a). These response delays are a combination of visual-processing time and motor-response time. For simplicity, let us measure these response delays relative to the change of object A (i.e. $t_A = 0$). The individual response times, U_A and U_B , for the object changes are therefore: $U_A = R_A$ and $U_B = R_B + t_B = R_B + ISI$.

Following the simplest decision rule, the participant will respond with a RT of T that corresponds to $\min(U_A, U_B)$. For a given ISI, the probability that the RT equals T is therefore:

$$p(T|ISI) = p[(U_A = T) \wedge (U_B \geq T)|ISI] + p[(U_A > T) \wedge (U_B = T)|ISI]. \tag{3.1}$$

Assuming independence between the response delays, we obtain:

$$p(T|ISI) = p(R_A = T) p(R_B \geq T - ISI) + p(R_A > T) p(R_B = T - ISI). \tag{3.2}$$

The response delays, R , for each attribute change were modelled as log-normal distributions (the logarithmic transformation was used to reflect the fact that processing times cannot be negative, but in practice this transformation made little difference to the fitted parameters). Each of the four changes (colour and motion with high and low saliency) provided two parameters, the mean and the variance of the distribution. The resulting model with eight degrees of freedom was fitted to 110 data points (11 ISIs in 10 change combinations). The probability distribution function described by equation (3.2) was fitted to the distribution of RTs for each ISI condition, and the model’s best fit (in the least-squares sense) is shown in figure 2.

(c) Model for temporal-order judgements

As in § 3b, the times that objects A and B change attributes are denoted by t_A and t_B , respectively, and the ISI is given by $ISI = t_B - t_A$ (figure 4b). Let us assume that these changes are detected by the decision centre after some processing latencies represented by the random variables S_A and S_B . The arrival times of the object changes at the decision centre are therefore $V_A = S_A + t_A$ and $V_B = S_B + t_B = S_B + t_A + ISI$. Following the simplest decision rule, the participant will decide that object A changed first if $V_B \geq V_A$. For a given ISI, the probability that the participant will decide that A changed first is therefore

$$p(A \text{ first} | ISI) = p(V_B \geq V_A | ISI) = p(S_B \geq S_A - ISI). \quad (3.3)$$

Assuming that the processing latencies are independent of each other, we obtain:

$$p(A \text{ first} | ISI) = \int_{-\infty}^{+\infty} p(S_A = t) p(S_B \geq t - ISI) dt. \quad (3.4)$$

The processing latencies, S , for each type of attribute change were modelled as log-normal distributions. Each of the four changes (colour and motion with high and low saliency) provided two parameters, the mean and the variance of the distribution. However, we cannot determine the absolute processing times for all conditions, only the differences between conditions. For the *point* and *choice* tasks, one mean was therefore arbitrarily fixed, and the other three means were estimated relative to that. The resulting model with seven degrees of freedom was fitted to 110 data points (11 ISIs in 10 change combinations). The best fit was obtained by simulated annealing separately for the two tasks and is shown in figure 3.

(d) Saliency effects

Figure 5 shows a summary of the mean and spread of the fitted processing-time distributions. These have been averaged across the five observers. Figure 5a–c shows the fitted means of the processing times. Saliency is plotted along the horizontal axis. Each plot corresponds to one task condition. Circular symbols and dashed lines show relative processing times for motion changes; squares and solid lines indicate relative processing times for colour changes. As outlined in § 3c, it is impossible to determine the absolute processing time for any of the tasks. For each observer and task, the processing times for the two attributes and two saliency levels were normalized (such that they average zero). Positive values correspond to larger processing times. The clear downward slope in all three tasks shows the strong effect of saliency on the processing of both colour and motion changes (an ANOVA showed this to be significant: $F_{1,4} = 72.8$, $p < 0.01$). This confirms the notion that increasing the difference between two stimuli can reduce the time taken to respond to the change, for both motion (Dzhafarov *et al.* 1993) and colour (Nissen & Pokorny 1977).

The average effect of saliency on processing time (collapsed across task) was 56 ms for colour and 81 ms for motion. However, limited conclusions can be drawn from the different magnitudes of the effect of saliency on colour and motion as the pattern varied across observers, with some showing a larger effect of saliency on colour.

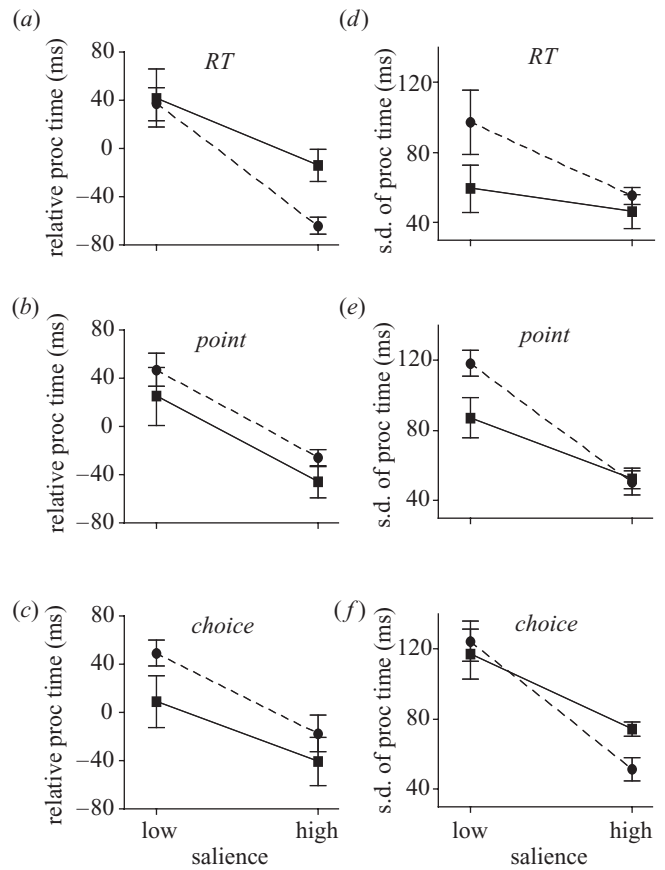


Figure 5. The effect of saliency. Mean results across five observers. (a–c) The mean normalized processing time (ms), for each of the three response conditions. Saliency is plotted on the abscissa. Motion is shown by filled circles and dashed lines; colour is shown by squares and solid lines. (d–f) The standard deviation of the fitted processing time, with the same key. Error bars give ± 1 s.e. across observers; proc, processing.

The actual magnitudes are a function of our method for determining the upper and lower saliency levels for the two attributes.

The average effects of saliency on processing time (collapsed across attributes) were 84, 65 and 57 ms for the *RT*, *point* and *choice* tasks, respectively. Such task differences have previously been found when measuring the effects of various stimulus attributes on processing latencies. For example, increasing a target's luminance, at low luminance values, leads to a greater reduction in latency when measured by a simple *RT* task than when measured using simultaneity judgements (Roufs 1963, 1974). Williams & Lit (1983) found a similar dissociation between latencies in a *RT* task and those calculated from the Hess and Pulfrich effects. In a similar vein, Tappe *et al.* (1994) measured the effect of SF on a simple *RT* task and compared the pattern of results with that from a task judging the simultaneity of visual and auditory stimulus onsets. In agreement with our results, they found a much larger effect of SF using the *RT* task than using TOJ. They suggest that in the *RT* task the response criterion is lower than for TOJ tasks. Similar explanations for task differences have been proposed by Sternberg & Knoll (1973) and Miller & Ulrich (2003).

The standard deviation of the fitted processing-time dis-

tributions is a measure of the dispersion of the processing time. These standard deviations are shown in figure 5*d–f* using the same symbols as in the previous plots in that figure. As might be expected, when processing times are larger, they are also more variable. Thus high-salience changes, with smaller mean processing times, produce narrower distributions. The effect of salience on processing-time dispersion is of the same order as the effect on processing time: 30, 44 and 50 ms for the *RT*, *point* and *choice* tasks, respectively.

(e) Task effects

One interesting aspect of our experimental design is the ability to test the interaction between stimulus attribute and type of task. Such an interaction would be consistent with the idea of separate processing channels that have specific sensory attributes as inputs and particular motor actions as outputs (Jeannerod & Biguer 1982).

In figure 6*a*, the means of the fitted distributions have been plotted, separately for each participant, to examine the effect of changing the task on processing time. Motion is plotted on the left side of each figure and colour is plotted on the right. Salience is also given on the horizontal axis. The interaction between attribute and task is shown by the reversal in height ordering of the lines for the colour and motion data. In the motion plots, the *RT* data (solid lines with open diamonds) are at the bottom, indicating a relative advantage for motion processing in the *RT* task. By contrast, in the colour plots, the *RT* data sit at the top, showing a disadvantage for colour processing: processing times for colour are longer in the *RT* task than in the other tasks. The exception is observer PM who shows no clear task effects. The error bars give conservative estimates of the standard deviation of the mean processing time. This estimate of variability is derived by Monte Carlo simulations, in which the data are sampled randomly with replacement (Wichmann & Hill 2001).

Figure 6*b* allows us to examine the interaction between attribute and task directly. The ‘relative motion advantage’ for each task was calculated by simply subtracting the fitted average latency for motion from that for colour and then normalizing across task. This shows the relative advantage that motion has over colour for each task, in other words, how much faster motion was processed relative to colour as a function of task. This has been calculated separately for low salience (light bars) and high salience (dark bars). Error bars indicate ± 1 s.d. of the relative difference between colour and motion. The similar pattern followed by the light and dark bars shows that the form of the interaction was similar for high and low saliences. The large bars on the right show that motion had a greater advantage in the *RT* task than in the other two tasks for four out of the five observers for both low- and high-salience stimuli (the exception is PM). For all four of these observers, this difference between the *RT* task and the other two tasks was significant at a 95% level (calculated using Monte Carlo simulations) for either high- or low-salience stimuli, or both: the motion advantage for the *RT* task relative to the *point* task was significant for high-salience stimuli for all four observers and for low-salience stimuli for two observers (BB and LOK). The motion advantage for *RT* relative to the *choice* condition was significant for high-salience changes for three

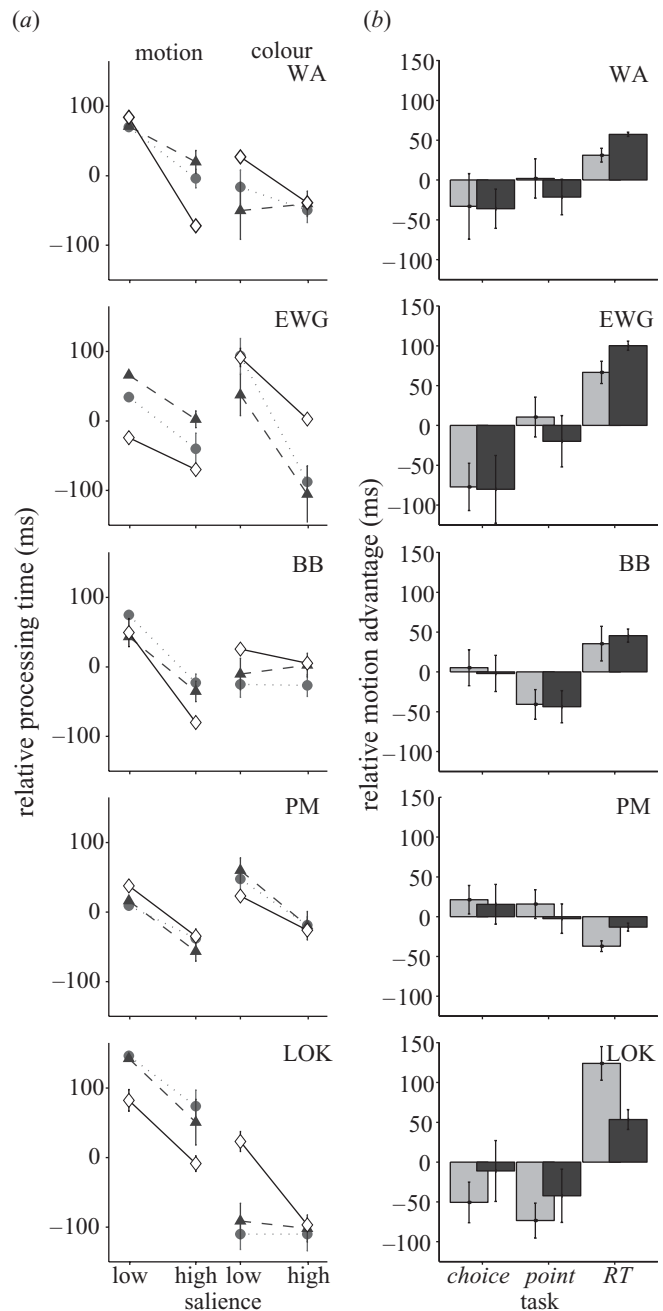


Figure 6. The effect of task. Results are plotted separately for each observer. (a) Relative processing time is given on the ordinate. The abscissa gives the salience. Motion-processing times are given on the left of each plot and colour-processing times are given on the right. *RT* data are shown by open diamonds and solid lines. *Point* data are given by filled grey circles and dotted lines. *Choice* data are given by black triangles and dashed lines. (b) Relative motion advantage is given on the ordinate. The abscissa gives the task. Low salience is shown by light bars, high salience by dark bars. Data have been normalized across task, separately for the two salience conditions.

observers (WA, EWG and BB) and for low-salience changes in two observers (EWG and LOK).

The difference between the *choice* and *point* tasks is less consistent. For observers WA and EWG the *choice* condition produced the shortest processing times (greatest advantage) for colour and the longest processing times (largest disadvantage) for motion. For observers BB and

LOK the *point* task produced the greatest advantage for colour and the largest disadvantage for motion. However, the differences between these two tasks were not significant, with the exception of EWG who showed a significantly greater advantage for motion over colour in the *point* task than in the *choice* task.

On average, across all five observers and the two salience levels, the relative motion advantages were 46.4, -21.6 and -24.8 ms for the *RT*, *point* and *choice* tasks, respectively. These values should be interpreted with care because of the large variability between observers.

4. DISCUSSION AND CONCLUSIONS

Our study suggests that processing times are not fixed for a particular stimulus attribute, but are modulated by salience and by the prevailing task. In particular, we found that increasing the salience of the change to be detected decreased the processing time. This finding adds weight to the recent assertion by Walsh (2002) that the salience levels of stimuli should be equated to compare processing latencies directly. We have used detection rates and RTs in an attempt to match our stimuli. However, the issue of how best to quantify the salience of events varying along different dimensions is unresolved. Indeed, the present study suggests that measures of salience may depend upon the prevailing task requirements. By using more- and less-salient stimuli we have been able to investigate the effect of this variable on processing time. To the extent that our measures of salience can be compared with the luminance manipulations used by Roufs (1963, 1974) and Williams & Lit (1983), our data seem to support the notion that salience affects RT measures more than TOJs.

Both Moutoussis & Zeki (1997) and Arnold *et al.* (2001) found a relative advantage for colour over motion. This is consistent with our findings for the perceptual *choice* task. In their studies, observers were making perceptual judgements about the stimuli, rather than performing a motor task. The changes used in those experiments were well above threshold, and are best compared with our high-salience conditions, but it is difficult to make quantitative comparisons between their data and ours, as they did not attempt to equate salience between attributes.

Our second finding was an interaction between task and attribute. In our *RT* task, motion processing seemed to have an advantage. By contrast, in the perceptual *choice* task, there appeared to be an advantage for colour processing. For a couple of participants, the *point* task showed a small advantage for motion and disadvantage for colour, relative to the *choice* task. Nishida & Johnston (2002) have also found differences between *RT* tasks and subjective simultaneity judgements using colour and motion changes, where an advantage appeared for colour in the subjective task that was not apparent in the *RT* task. However, it should be noted that the stimuli in their two tasks were slightly different, and the large effect in the subjective task disappeared for low temporal frequency changes. The strength of our study lies in the fact that the stimuli used in all three tasks were identical and we consider only single unpredictable changes.

There are several kinds of explanation that could be offered to account for our task effects. Perhaps the most appealing one is that different pathways may be primarily

responsible for visual processing in the two tasks. The *RT* task is a straightforward motor task, and so the dorsal pathway might be more involved in this than in the perceptual *choice* task. Ansorge *et al.* (1998) proposed that such a pathway separation might explain the differences between the effects of a prime in *RT* and detection tasks observed in the metacontrast dissociation. There are suggestions (e.g. Milner & Goodale 1995) that the motor pathway can be segregated from the perceptual pathway as early as the magno-parvo divide and certainly there is evidence that motion is processed quite differently by these two streams (Gegenfurtner & Hawken 1996).

The tasks might also be contrasted in terms of the level of processing they required. In the *RT* task, the observer can respond without determining which object changed, or which attribute changed, or localizing either object. By contrast, the *point* task requires the observer to locate the object that changed. Finally, the *choice* task requires the greatest amount of processing, as the observer has to determine which object changed and identify it by its shape. The added cost involved in these extra processing steps might be greater for motion than for colour.

This latter suggestion is related to the temporal marker explanation that Nishida & Johnston (2002) have proposed to explain apparent processing asynchronies. The *RT* task can be completed without making any temporal judgements about the changes. By contrast, in the framework of Nishida & Johnston (2002), the *choice* task would involve comparing temporal markers assigned to the colour and motion changes, and it might be at this stage that the apparent differences in temporal judgements arise. The *point* task may or may not involve temporal markers, depending on the strategy employed by individual observers. However, this explanation has been put forward to account for asynchronies that arise at fast change rates, when assigning flags to motion changes becomes difficult. Our tasks involved only single changes and so it is difficult to see how the theory could account for task differences in our study.

In summary, our observations highlight the need to consider a number of factors before making comparisons between processing latencies for different visual attributes. These factors include saliency and the observer's task, although the source of the task interaction is, as yet, undetermined. We have shown that differences between processing latencies do exist for single changes of different attributes and appear not to be compensated for by any binding or temporal-marker mechanisms.

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