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The effects of ageing on reaction times to motion onset

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Abstract

We have measured reaction time (RT) to motion onset in two groups of subjects (average ages: 70 and 29 years), for horizontal gratings of 1 c deg^{-1}, modulated in either luminance or colour (equiluminant red–green), for various contrasts and speeds. For both old and young subjects, RTs depended on both speed and contrast, being faster at high speeds and high contrasts, and showed a stronger contrast dependency for chromatic gratings. The older subjects were systematically slower than the younger subjects. The difference between old and young RTs varied with condition, being 30–40 ms more at the slow than at the fast speed. The relative difference in RTs in different stimulus conditions shows that at least some of the increase in response time with age has a sensory origin. The results relate well to previous work on visual evoked potentials. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Reaction times (RTs) to simple sensory stimuli (auditory stimuli or light flashes) are known to increase with age (e.g. Woodruff & Kramer, 1979; Gottsdanker, 1982; Fozard, Vercryssen, Reynolds, Hancock & Quilter 1994; Inui, 1997). However, it is not clear whether the increase results from increases in sensory or motor components, and very little is known about the effects of ageing on the responses to more complex visual stimuli.

Reaction to moving stimuli is important in many real life situations. Pronounced increases in RT to moving stimuli may have dangerous consequences for old people. In a previous study (Burr, Fiorentini & Morrone, 1998) it was shown that, irrespective of physical stimulus velocity, RT to grating motion onset depends upon the apparent velocity of the stimulus, both for gratings of pure luminance and pure colour contrast (see also Ball & Sekuler, 1980). The increase of RT with decreasing stimulus contrast follows closely the reduction of apparent velocity for low contrast stimuli, for both luminance and equiluminant gratings, where the contrast-dependence is particularly steep (Burr et al., 1998).

Given the lack of information about the processes responsible for the increase of RT with age, we investigated RTs in the aged for a set of visual stimuli that varied in velocity, contrast and chromatic content. It is now well established that contrast thresholds for sinusoidal gratings deteriorate in older subjects, particularly at high temporal frequencies (Tulunay-Keesey, Ver Hoeve, & Terkla-McGrane, 1988; Elliott, Whitaker & MacVeigh, 1990). VEP studies have also shown visual impairments for supra-threshold contrasts, with increased latencies of VEP responses to pattern reversal, for both luminance and chromatic gratings in aged people (Fiorentini, Porciatti, Morrone & Burr, 1996). The increase in both psychophysical thresholds and VEP latencies with age was similar for luminance and chromatic stimuli, indicating a non-selective deterioration. To investigate further the specificity of the alteration for the attribute of the visual stimulus we measured the RT response to motion onset of luminance and chromatic gratings. We also analysed the RTs to tease out the relative effects of ageing on the motor and sensory contributions.

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In two groups of subjects, of average age 29 and 70 years, we measured RT to motion onset for sinusoidal gratings drifting at two different velocities (1 and 10 deg s^{-1}), as a function of contrast. The gratings had either pure luminance contrast (yellow–black gratings), or pure colour contrast (red–green equiluminant gratings). RTs in the aged group were found to significantly exceed those of the younger group for both stimulus velocities and approximately by the same amount for the achromatic and the chromatic patterns, despite a much stronger dependence of RT on chromatic contrast. Consideration of the speed dependency of RTs, together with comparison with the increased VEP latencies, suggests that the RT increase with age is largely due to sensory factors.

2. Methods

2.1. Stimuli

The stimuli for this study were horizontal sinusoidal gratings of 1 c deg^{-1}, modulated either in luminance or in chromaticity (red–green equiluminant), generated by framestore (Cambridge VSG) and displayed on the face of a Barco monitor at 120 frames s^{-1}. The display area was 35×25 cm, subtending $20 \times 14°$ at the viewing distance of 1 m. Only the red and green guns of the monitor were activated, so the background colour was yellowish when viewed through Kodak 16 wratten filters (heavily attenuating wavelengths shorter than 500 nm). Chromatic gratings were constructed by combining red and green gratings of equal but opposite contrast, as is now standard. The mean luminance of the red gun was fixed at 50% maximum value, while the green mean luminance could be adjusted to vary the ratio of red-to-total luminance to establish equiluminance for each observer. This is described in Section 3. At equiluminance the mean luminance was 20 cd m^{-2}.

The contrast of the chromatic gratings was expressed in RMS cone-contrast units. This was calculated by transforming the CIE co-ordinates of the stimuli into cone excitations using the Smith and Pokorny (1975) primaries. In practice it was equivalent to dividing the Michelson contrast by 3.6. The CEI co-ordinates were 0.65, 0.34 and 0.40, 0.60 for red and green, respectively, producing maximum cone contrasts of 0.13 and 0.37 at equiluminance.

2.2. Reaction times

Gratings of two speeds (1 and 10 deg s^{-1}) and several values of luminance and chromatic contrast were used as stimuli. The equiluminance value was determined for each subject (see Section 3) and detection thresholds measured for the four types of stimuli (two speeds, luminance and colour) with the methods of limits: the experimenter decreased the contrast of the stimulus until the observer reported that the stimulus was no longer visible. The contrast was then lowered by 0.2–0.3 log-unit steps and increased by 0.05 log-unit steps until the subject reported seeing it, to yield threshold. The measure was repeated at least four times for each subject and stimulus condition. We evaluated discrimination thresholds for the direction of motion from the detection thresholds using the factors obtained in the same experimental condition from a different population of subjects of similar age (Fiorentini et al., 1996). The detection and discrimination thresholds are very similar except for equiluminant gratings drifted at 1 deg s^{-1}, for which detection thresholds were lower than direction discrimination thresholds by an average factor of 2.4, independently of subject age (Fiorentini et al., 1996).

To measure reaction times, observers were required to respond as quickly as possible to the onset of motion. Sinusoidal gratings were stationary on the screen, until observers initiated a trial by release of a response button. After a brief delay of 1–2 s, the grating moved abruptly upwards or downwards (at random). The observer responded to the motion as quickly as possible by button-press, and released the button to initiate the next trial when ready. The observer simply responded to the motion, irrespective of its direction (simple reaction times). However, a series of control experiments (not reported here) where a young observer was required to indicate motion direction (choice reaction time) yielded very similar results to those presented here.

Each subject participated in at least one experimental session. Several contrasts and two grating speeds were intermingled, separately for gratings with luminance contrast and colour contrast, giving a minimum of 20 trials per condition. The mean reaction time, together with its standard error, was calculated after elimination of outliers (further than 2.5 standard deviations from the mean). Trials shorter than 100 ms or longer than 2 s were discarded. The reaction time distributions were inspected by eye for each condition, and were always seen to follow a reasonable approximation to Gaussian, with median similar to the mean.

2.3. Subjects

Ten young (mean age 28.8, S.D. 6, three males, seven females) and ten aged subjects (mean age 69.5, S.D. 5, four males, six females) took part in the experiment. All subjects had a routine ophthalmological examination that excluded ocular diseases, particularly lens opacities. Refractive errors, when present, were less than two spherical and one cylindrical diopters, and were fully corrected. The corrected visual acuity was equal to or better than 1.0 and suitable correcting lenses were used, as required, for the viewing distance of 1 m. Normal trichromatic vision was checked by the Ishihara cards and the results confirmed subsequently by the equiluminant value of the red–green stimuli. One male subject found to be deuteranomalous was discarded. Informed consent was obtained from all observers after the aim of the research and the nature of the technique were fully explained.

3. Results

3.1. Thresholds

For each subject, equiluminance was carefully determined at the beginning of the experimental session by the method of minimal flicker. With the aid of the experimenter, the subject adjusted the ratio of red-to-total luminance, in a grating of 50% contrast caused to counter-phase at 15 Hz. The mean estimates and their standard errors of the equiluminance point for the young and old group were: 0.5 ± 0.015, 0.47 ± 0.04. The equiluminance point for the old subjects was lower than that for the young, implying that they needed more green in the mix to produce equiluminance. This is to be expected from the yellowing of the lens, that will attenuate the shorter wavelengths (Said & Weale, 1959; van den Berg & Ijspeert, 1995).

After determining equiluminance, we measured detection thresholds for each subject for four conditions: luminance and chromatic gratings drifting at 1 and 10 deg s^{-1} (see Table 1). The results are in broad agreement with our previous study (Fiorentini et al., 1996), showing a general superiority in sensitivity for the young group, under all conditions.

3.2. Reaction times

For one well-practised elderly subject (AF, Fig. 1), and for several other old and young subjects, reaction times were measured for a range of colour ratios around the equiluminance. For both young and old subjects, for both fast and slow drift speeds, reaction times were slowest at the point of equiluminance (indicated by the arrow), becoming much faster for slight deviations from equiluminance (up to 200 ms for 5% differences).

Table 1
Mean detection contrast+ (%) thresholds and standard errors for young and old subjects

	Luminance		Colour	
1 deg s^{-1}	Young 0.47 ± 0.04	Old 0.537 ± 0.04	Young 0.42 ± 0.08	Old 0.66 ± 0.08
10 deg s^{-1}	Young 0.46 ± 0.02	Old 0.700 ± 0.08	Young 1.80 ± 0.23	Old 2.20 ± 0.15

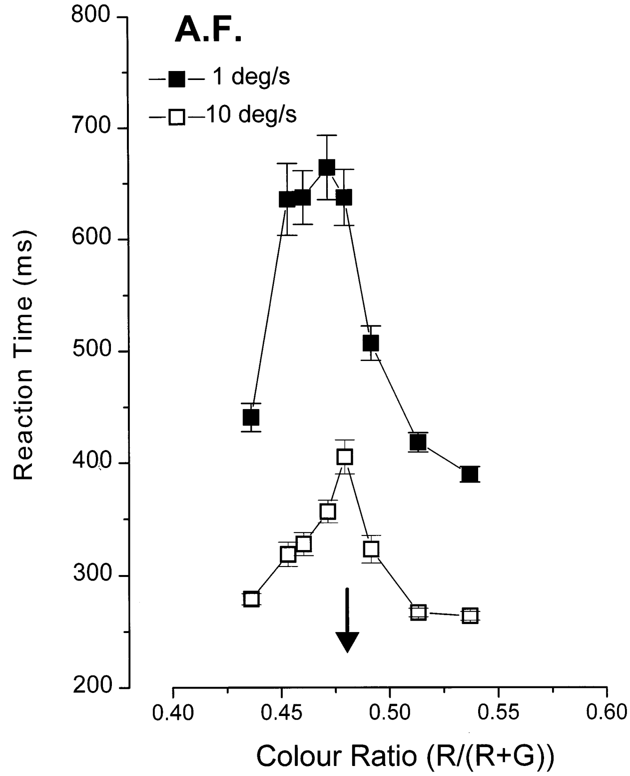

Fig. 1. RTs to motion onset as a function of colour ratio, for one well-practised elderly subject, for two stimulus speeds. In both cases, RTs were longest at a colour ratio around 0.48, and rapidly decreased for nearby colour-ratios. The maximal RT occurred very near the equiluminant point, assessed by minimum flicker, indicated by the arrow.

For every subject, we measured reaction times to motion onset as a function of contrast, for chromatic and luminance gratings drifting at 1 and 10 deg s^{-1}. Fig. 2 shows examples for a typical young and old subject. The pattern of results was similar for both subjects, quite like that previously reported (Burr et al., 1998). For both colour and luminance, reaction times decreased with increasing contrast, but the dependency was stronger for colour than for luminance. Reaction times to chromatic stimuli were roughly similar to those of luminance stimuli at high contrasts, but the two curves diverged rapidly at lower contrasts to asymptote to infinity at discrimination threshold (see arrows).

Fig. 3 shows the average reaction times of all the subjects in the study, plotted separately for luminance and for colour. For all conditions (speed, contrast and colour), the young subjects were systematically faster than the old subjects. A three-way analysis of variance confirmed that this effect was significant (see Table 2). There were significant effects for age, speed and colour. However, there were no significant interactions between

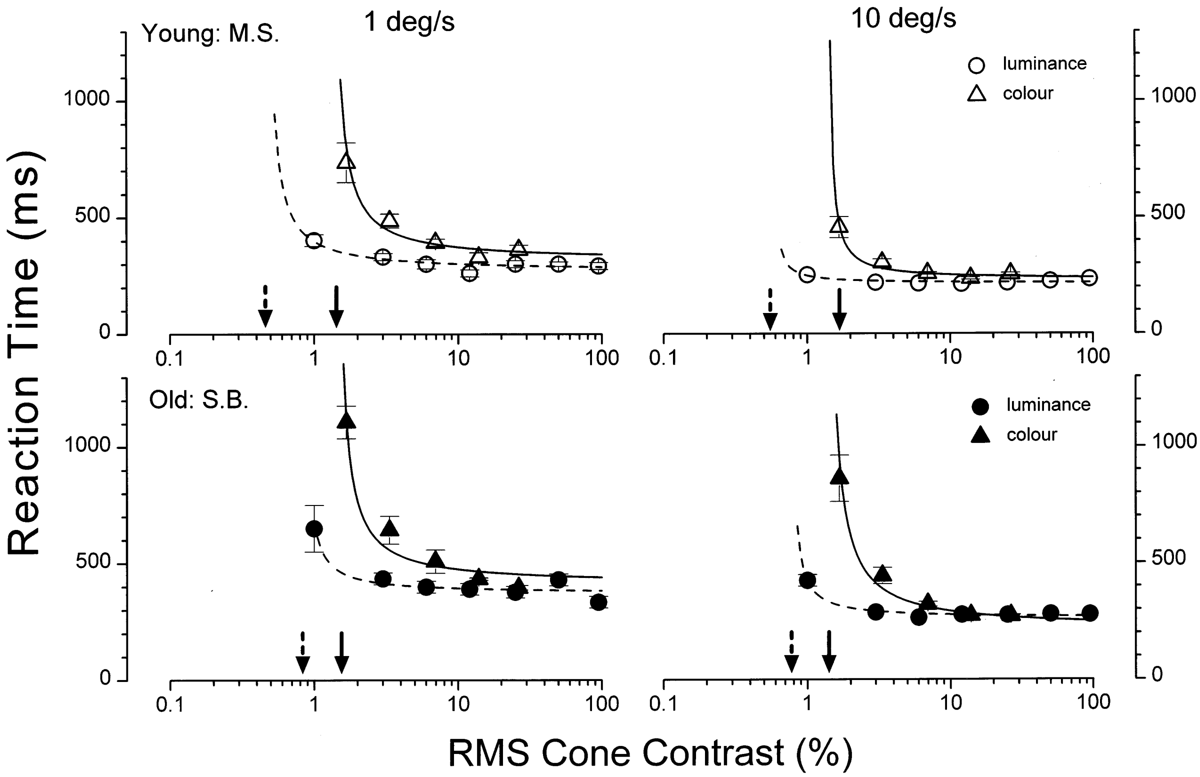

Fig. 2. Dependency of RTs on contrast for representative young and old observers, at low and high speeds, for luminance and chromatic gratings. As observed previously, the strongest contrast dependency was for slowly moving chromatic gratings. The curves passing through the data are best fits of Eq. (2), discussed further in Fig. 4. The results are qualitatively similar for the young and old subject. The arrows indicate direction discrimination thresholds estimated from detection threshold for either subject (see text).

age and any other variable. The arrows in Fig. 3 plot the mean discrimination thresholds evaluated from the detection thresholds (see Section 2). Note that these do not always correspond to the upper limit of the RT response, given the variability of thresholds and RT between subjects.

It is generally considered that RT data can be decomposed into two components, one dependent and one independent of stimulus parameters:

$$R = R_0 + R(x, t, c) \tag{1}$$

where R is the measured RT, R_0 the stimulus-independent component and $R(x, t, c)$ the stimulus dependent component (indicating a dependency on space, time and contrast). Assuming this simple linear separability, the stimulus independent component can be removed by subtracting RTs taken in one condition from those in another. The bottom graphs of Fig. 3, plot the average difference in RTs measured at 10 and 1 deg s^{-1}, for old and young observers, for both colour and luminance as a function of contrast (subtracting the middle from the top panels of Fig. 3). Contrasts less than twice threshold were omitted. This difference component in the RT, showed consistent age effects. At all contrasts, the difference for the old subjects was higher than that for the young, by 30 ms (on average) for luminance and 40 ms for colour. The differences (separate two-way ANOVA for luminance and colour) were statistically significant for luminance and for colour ($P < 0.01$).

We further analysed the contrast dependency of the RTs by fitting the data of individual subjects (like that reported in Fig. 2) with a function that has previously proven useful for this type of data (Burr et al., 1998):

$$R = \frac{\alpha}{\log(c/\tau)} + R_\infty \tag{2}$$

where R is reaction time, c contrast, τ contrast threshold for direction discrimination. R_∞ is the reaction-time asymptote and α a constant determining steepness of the curve. The equation is useful, in that it provides a full description of the results with only two free variables: the asymptote R_∞ and the contrast dependency α (measured in ms × log-contrast). These curves were fitted to the individual data of each subject (see sample curves in Fig. 2).

Fig. 4 reports for each subject the values of the RT asymptote R_∞ (left panels) and the dependency on contrast (α, right panels). For each of these variables, the results for luminance are plotted against those for colour, separately for old and young subjects. Consider first the data at 1 deg s^{-1} (top panels). For both

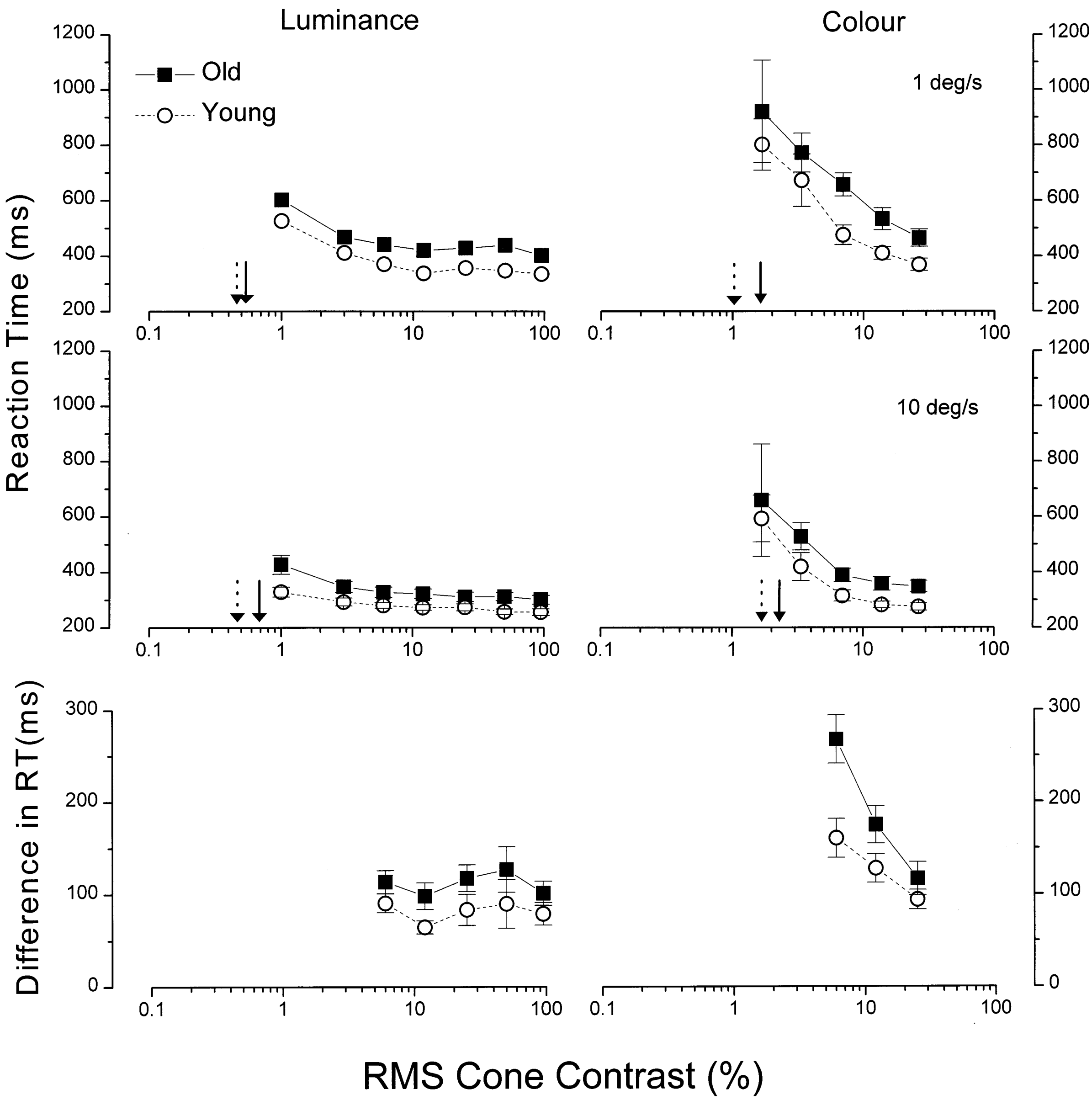

Fig. 3. Upper panels: average reaction times for all ten young and ten old subjects, plotted as a function of contrast. The old subjects show systematically longer RTs than the young. The arrows indicate the average direction discrimination thresholds estimated from the detection thresholds reported in Table 1. Bottom panels: difference between the RT at 1 and 10 deg s^{-1} as a function of contrast, for contrasts above twice discrimination threshold for all subjects. For both luminance and chromatic stimuli, the difference in RT was greater for old than young subjects at all contrasts. Bars show ± 1 S.E.M.

luminance and colour, the asymptotes for the younger subjects tended to be lower than for the older subjects, by about 80 ms (means indicated by arrows on the axes). Both these differences were statistically significant (Student t-test, $P < 0.03$). For both young and old, asymptotes for luminance and colour covaried strongly, with $r = 0.74$ and 0.94, respectively. The contrast dependency was also greater for old than for young, but the difference was not significant.

A similar pattern of results occurred at 10 deg s^{-1} (bottom panels). There is a clear advantage of young versus old in asymptote, with a difference now of about 45 ms, statistically significant at $P < 0.05$. Again the asymptote measures are well correlated for luminance and colour. There was little covariation in the contrast dependency indices and the differences between young and old were not statistically significant for the equiluminant stimuli.

One advantage of using the asymptotes as estimates of RT is that the effects of contrast threshold have been removed in the fitting process (and it is known that thresholds increase with age). We therefore considered the velocity difference in the asymptotes, by subtracting those estimated from the 10 deg s^{-1} data from those at

Table 2
Three-way ANOVA on reaction times of young and old subjects

	Luminance	*P*	Colour	*P*
Age	$F(1,279)=57.3$	<0.001	$F(1,159)=25.1$	<0.001
Velocity	$F(1,279)=174.3$	<0.001	$F(1,159)=75.1$	<0.001
Contrast	$F(6,279)=19.8$	<0.001	$F(3,159)=24.8$	<0.001
Age × Contrast	$F(6,279)=0.282$	0.945	$F(3,159)=0.18$	0.910
Age × Velocity	$F(1,279)=1.18$	0.279	$F(1,159)=1.02$	0.320
Velocity × Contrast	$F(6,279)=2.35$	0.032	$F(3,159)=2.36$	0.070
Age × Velocity × Contrast	$F(6,279)=0.228$	0.967	$F(3,159)=0.35$	0.790

1 deg s^{-1}. This is similar to the analysis performed in Fig. 3 (bottom panels), except that the data have been normalised for threshold before estimating an RT asymptote. Pooling together luminance and colour, the difference in the asymptotes was 30 ms more in the old than the young subjects, statistically significant (*t*-test, $P<0.05$). Thus the stimulus-dependent increase in RT in the aged does not result solely from increases in contrast threshold.

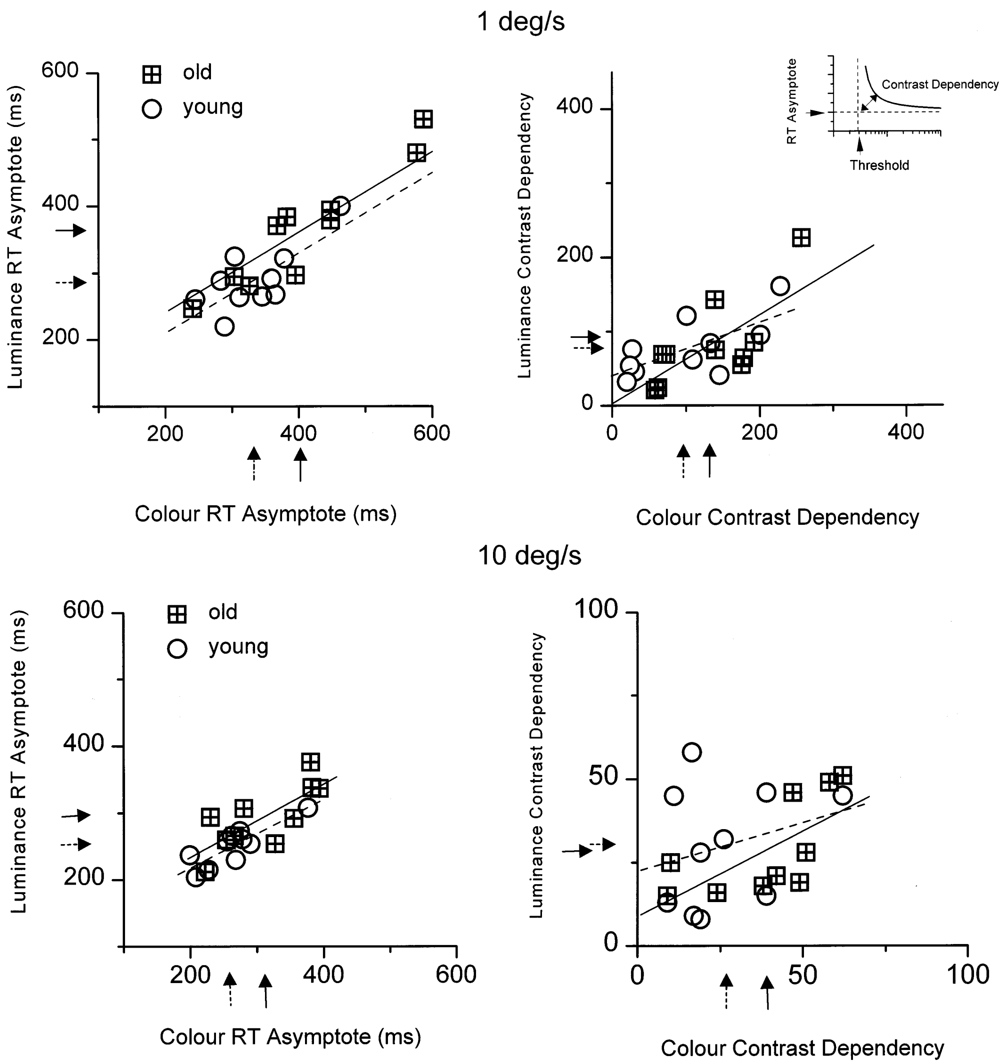

Fig. 4. Scatter plots of the two parameters from Eq. (2) that describe the RT asymptotes (left panels) and the contrast dependency (right panels). Top panels: 1 deg s^{-1}. For both colour and luminance, the RT asymptotes were significantly higher for the old than the young subjects (Student *t*-test, $P<0.03$). The contrast dependencies were not significantly different. Bottom panels: 10 deg s^{-1}. At this speed there was little dependency on contrast for either luminance or colour, and no significant difference for young and old subjects. The asymptotes were significantly higher for the old group, for both colour and luminance ($P<0.05$). The broken and solid arrows indicate the means for the young and old subjects, respectively.

4. Discussion

The effects of ageing on RTs to patterned visual stimuli have not been widely investigated. The present findings indicate that the RTs to the onset of motion of a stimulus pattern, defined either by luminance or by colour contrast, are slowed down in the aged by approximately 75 ms at low velocity (1 deg s^{-1}) and by 44 ms at high velocity (10 deg s^{-1}). This appreciable increase in RT may be partly due to the slowing of motor responses. However, the dependency on the velocity of the stimulus shows that the increase is not only in the motor response, but has also a sensory component of 30–40 ms, observed in the difference of RTs to fast and slow stimuli, for which the motor component was removed. It was also observed in the estimates of RT asymptotes after contrast normalisation, so does not result simply from an increase in contrast thresholds.

This result agrees with previous findings showing a 30–40 ms increase with age of VEP latencies in response to contrast-reversal of luminance or colour gratings (Fiorentini et al., 1996), reinforcing the suggestion that changes in the speed of visual processing contribute substantially to the increase of motion onset RTs in the elderly. As with the RT data, the age-related increase in VEP latency did not depend strongly on the chromatic content of the stimulus. Comparison with the VEP data is particularly relevant given that the experimental conditions were very similar.

Previous studies of contrast thresholds and VEPs in ageing have suggested a general deterioration of vision with ageing, with no signs of selective deterioration to luminance or chromatic pathways, that may imply selective degradation to either the magno- or the parvocellular systems. The present study is consistent, showing no significant selective impairment to luminance or chromatic stimuli, either in absolute RTs or in the dependency on contrast. There was an age related difference in RTs at different speeds, but this does not necessarily imply preferential impairment of the P-system, (but does demonstrate a sensory component in the RT increase with age).

Experiments on animals fail to provide evidence for a substantial neuronal loss in the aged, but suggest that a major change taking place in the brain with ageing is a loss of the myelin sheet of nervous fibres (Peters, Leahu, Moss & McNally, 1994). The same may be true for the human brain in normal ageing (Wickelgren, 1996) and this might affect the speed of the afferent visual signals, the time course of intra-cortical visual processes, and the speed of the efferent motor signals. From our findings it is difficult to establish if the deficit in ageing can be ascribed to a loss of myelin. However, the fact that there is a strong sensory component is consistent with the demyelination of the visual pathway.

It is interesting that the dependence of RT on stimulus contrast does not differ significantly between the older and younger groups of subjects, once the contrasts are scaled to the respective thresholds. Since the contrast thresholds of the aged subjects are significantly greater, however, it remains true that the responses to a given objective contrast are delayed for the elder subject, particularly for relatively low chromatic contrast. As was shown in a previous paper (Burr et al., 1998), the increase of RT at low contrasts is related to the decrease of apparent speed of the stimulus. It has recently been pointed out that the apparent slowing of stimuli of low contrast may be responsible for car accidents when driving in the fog (Snowden, Treue, Erickson & Anderson, 1991). The driver would underestimate the velocity of other vehicles as well as his/her own velocity, thus failing to reduce the car speed to safe values. This dangerous consequence of the decrease of apparent speed, reflected at a higher degree in the RT of elder subjects, may become particularly dangerous in the old age.

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