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DOI:
10.1007/s00221-016-4816-0

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Document Version
Peer reviewed version

Citation for published version (Harvard):
Schofield, A, Curzon-Jones, B & Hollands, M 2017, 'Reduced sensitivity for visual textures affects judgments of shape-from-shading and step climbing behaviour in older adults', *Experimental Brain Research*, vol. 235, no. 2, pp. 573-583. https://doi.org/10.1007/s00221-016-4816-0

Link to publication on Research at Birmingham portal

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Reduced sensitivity for visual textures affects judgments of shape-from-shading and step climbing behaviour in older adults.

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Abstract

Falls on stairs are a major hazard for older adults. Visual decline in normal aging can affect step climbing ability, altering gait and reducing toe clearance. Here we show that a loss of fine-grained visual information associated with age can affect the perception of surface undulations in patterned surfaces. We go on to show that such cues affect the limb trajectories of young adults, but due to their lack of sensitivity, not that of older adults. Interestingly neither the perceived height of a step nor conscious awareness are altered by our visual manipulation but stepping behaviour is: suggesting that the influence of shape perception on stepping behaviour is via the unconscious, action-centred, dorsal visual pathway.

Key words:
Vision, texture, shape-from-shading, step climbing

Introduction

Around 30% of community-dwelling adults over the age of 65 fall each year. Falls are a major cause of disability and the leading cause of mortality due to injury among people aged over 75, and falls on or from stairs and steps are the most common type of fall in this age group (Fuller, 2000; Baker & Harvey, 1985; Nelson & Amin, 1990; Dowswell, et al., 1999). Adults over 65 account for around 70% of deaths from falls on stairs (Dowswell et al., 1999). While falls are caused by many factors including decline in musculo-skeletal function, visual factors known to affect toe elevation and stepping behaviour in older adults include illumination (Simoneua Cavanagh, Ulbrecht, Leibowitz & Tyrrell, 1991; Hamel, Okita, Higginson & Cavanagh, 2005) optical blur (Heasley, Bukley, Scally, Twigg & Elliot, 2004; 2005), altered gaze patterns (Chapman & Hollands, 2006; Young, Wing and Hollands, 2012), and reductions in useful visual field (J. G. Reed-Jones, R. J. Reed-Jones and Hollands, 2011). It is well known that visual function deteriorates with age (Owlsey, 2011; Weale, 1986; Humphrey & Kramer, 1997; Snowden & Kavanagh, 2006; Scialfa, 2002). This visual decline has multiple causes including deteriorating optics, and neural loss in the sensory regions of the brain Owlsey, 2011; Weale, 1986).

There are two characteristic changes to perception caused by age-related decline in the brain's ability to process visual information. First, for static or slow moving stimuli in full illumination there is a loss of sensitivity to high spatial frequencies (fine detail) while low spatial frequencies are spared (Weale, 1986). Second, thresholds for detecting and discriminating motion are higher in older adults at all spatial frequencies (Snowden & Kavanagh, 2006). Here we are interested in the loss of high-frequency information in static stimuli as this may reduce the observer's ability to perceive variations in visual textures. Neural loss may affect visual performance even after optical factors have, as far as is possible, been corrected; and it is possible that these more subtle factors also contribute to altered gait parameters in older adults. Specifically whereas Owlsey (2011) discounts high-spatial frequency neural losses as being unlikely to have functional relevance we will show that they can lead to poor discrimination between shading and material changes in an image that in turn has implications for everyday tasks such as step climbing.

It seems sensible that people should adjust their gait to take account of perceived undulations in the surface to be navigated and adjust toe elevation when stepping to take account of step heights and tread depths. Lu, Chen & Chen (2006) showed that both younger and older adults vary their toe heights when crossing obstacles of different height. However, whereas younger adults maintain a fixed toe-obstacle clearance, older adults allow increased clearance with increasing obstacle height. Here we consider visual cues that might change perceived step height. Gross changes in the orientation of stripes leading to size illusions have been shown to affect toe elevation for young adults when climbing steps (Elliot, Vale, Whitaker & Buckley, 2009). Specifically vertically stripes on step risers make the step look higher and result in elevated toe clearance relative to horizontal stripes. Here we consider more subtle effects of visual texture on step climbing behaviour. There are a range of visual cues available to aid the judgement of such surface variations and one such cue is shape-from-shading (Pentland, 1988). Shading is the intensity of illumination received by a surface due to its orientation with respect to the light source and it varies smoothly in the absence of full shadowing. Shape-from-shading is our ability to infer the underlying surface undulations from variations in shading. This information is primarily conveyed via low spatial frequency (coarse scale) components in the image. However, such low-frequency components also arise due to reflectance changes (changes in the colour/albedo of the surface) where one type of material abuts another. Thus the origins of low-frequency signals are ambiguous and other cues such as colour and visual texture are employed by the visual system to disambiguate each luminance signal (Kingdom, 2008). Visual texture is defined by high-frequency (fine scale) variations in either hue or luminance. Strictly, visual texture can arise from the micro-shading and shadowing of a physical texture such as stucco but here we use the term to refer to the patterns produced by fine-scale changes in the reflectance of flat surfaces (for example, wallpaper) that can only be perceived visually. As another example, carpet displays both forms of visual texture but its appearance is often dominated by fine-scale reflectance changes. As visual texture is defined by high-frequency components it follows that a loss of sensitivity to such components with age should make discriminations based on variations in visual texture more difficult, and may in turn make it harder to discriminate between shading changes and coarse changes in reflectance. That is, surface undulations may be misperceived as coarse-scale changes in the reflectance or material properties of the surface such that undulating surfaces appear flatter than they really are. We hypothesise that such misperceptions might affect gait and toe elevation and thus lead to more falls in older adults.

Figure 1a shows stripes created by varying the local luminance amplitude of a visual texture. The difference between the light and dark pixels in the texture is larger in high amplitude regions (note that for this stimulus variations in texture amplitude and contrast are equivalent). Older adults are less sensitive to variations in the contrast of visual textures than young adults (Habak & Faubert, 2000). The detection of such contrast (amplitude) modulations is thought to depend on a 2-stage filtering process in early visual cortex: the filter-rectify-filter model (Wilson, Ferrara and Yo, 1992). The first-stage, “texture grabber” filters are tuned to fine detail (high-spatial frequencies) whereas the second-stage filters process the lower-frequency contrast modulations (Sutter, Sperling & Chubb, 1995; Dakin & Mareschal, 2000; Schofield, 2000). If either set of filters is compromised the stripes become harder to see. Thus a loss of sensitivity to higher spatial frequencies would effectively reduce the signal strength at the output of the first-stage filters and thus reduce sensitivity to the contrast modulations (Schofield & Georgeson, 1999).

Schofield and colleagues (Schofield, Heese, Rock & Georgeson, 2006; Schofield, Rock, Sun, Jiang & Georgeson, 2010; Sun & Schofield, 2011) have recently shown that modulations in the luminance amplitude of visual textures (texture amplitude) can be used to discriminate between changes in illumination – such as shading and shadows – and changes in the reflectance properties of a surface. For example, Figure 1b shows two, coarse-scale, orthogonal, luminance modulations imposed on a visual texture. The right leaning component is paired with a positively correlated change in texture amplitude (regions of high amplitude texture align with regions of high luminance) and thus simulates, and is perceived as, a shaded, corrugated surface. The left leaning component has been paired with a negatively correlated change in texture amplitude and appears as a flat reflectance change: like strips of material laid across the undulations (Schofield et al., 2006; 2010; Schofield, Rock & Georgeson, 2011). This apparent distinction between undulations and material changes is especially strong in the plaid configuration depicted in Figure 1b. Such correlated parings of luminance and texture amplitude variations are common in the environment where shadows fall across textures and where undulations produce shading on visually textured surfaces (Schofield, 2000; Schofield et al. 2010). Computational modelling of human performance with a 2 stage filtering mechanism as described above has shown that successful discrimination between shading and reflectance indeed depends on the high-frequency, fine detail, elements in the texture (Schofield et al., 2010; Sun & Schofield, 2011). However, the work described above had not established whether the high-frequency losses associated with ageing are sufficiently large and of the correct nature to influence the discrimination or shading and material changes.

Experiment 1 aimed to test whether the loss in sensitivity to fine detail associated with age reduces the discriminability of simulated illumination vs. reflectance / material changes. We achieved this by comparing discrimination performance between older and younger adults with shape-from-shading stimuli like those of Figure 1 based on increasingly fine-grained textures. We predicted that older adults would find the discrimination of shading vs. material changes harder than younger adults but only for the finer textures. In Experiment 2, we proceeded to test the influence of such texture manipulations on stepping behaviour.

Experiment 1: Discriminating Shading and material changes

Method

Design

We tested sensitivity to modulations of texture amplitude (equivalent to second order contrast in Habak & Faubert's, 2000) study in a single-interval two-alternative forced-choice experiment in which observers had to discriminate between simulated stripes and undulations on textured surfaces. We employed a 2 (age: younger vs. older) x 2 (instructions: report stripes vs. undulations) x 3 (texture type: binary, coarse, and fine) mixed design. Within a given session only the strength of the amplitude modulations (see below) varied and the dependent variable was the strength of these modulations required to discriminate stripes from undulations.

Stimuli

Figures 1b-d show representations of our stimuli which were based on three visual textures. One visual texture (Figure 1b&c) comprised binary noise samples in which each 2x2 pixel square could take one of two grey levels (base contrast = 0.2 rms). Such textures contain both fine and coarse spatial detail and are usually perceived as resulting from changes in the reflectance of the 'ink' making up the texture. The other two textures, both represented here by Figure 1d, comprised either *relatively* coarse (8 cpd) or fine (12 cpd) vertical, luminance ripples derived from Gabor pattern elements as described in the supplementary materials (S1.1). The rms contrast of these textures was 0.18 which we regard as negligibly different from 0.2 but see Discussion. These textures can be perceived as resulting either from either fine scale surface ripples or as changes in local surface reflectance/albedo. We superimposed very coarse scale (0.6 cpd) modulations of local mean luminance and texture amplitude onto these textures, varying these properties as the sine of the position of each pixel in the image (sine wave modulation) along two directions (±45°) to create a visual plaid. Each luminance modulation was paired with a texture amplitude modulation. To simulate a corrugated, shaded surface the two modulations varied in-phase (LM+AM, high luminance coinciding with high texture amplitude) as seen in the right-oblique component of Figure 1b. To simulate coarse scale reflectance changes, the two modulations varied in anti-phase (LM-AM, high luminance coinciding with low texture amplitude: left- oblique component of Figure 1b). On a given trial the in-phase and anti-phase relationships were randomly assigned to the two orientations. The difference between simulated shading and reflectance changes is especially strong when the two signal types are combined in this plaid configuration. When the amplitude modulation depth is sufficiently high the anti-phase pair is seen as if flat strips of material laid across undulations formed by the in-phase pair. The absolute phases of the generating sine waves were chosen at random on each trial and were different; discouraging participants from inspecting local regions of each image. Each image was windowed by a circular raised cosine function with half-height diameter of 12 deg and a gradual contrast reducing portion of 2 deg at the edge of the window.

The contrast of the luminance components (component contrast = 0.1) was kept constant throughout the experiment but the modulation depth of the texture amplitude components was varied with modulations depths of the two oblique components being set to the same value in any one trial. Figures 1b&d show examples when the amplitude modulation component was strong and the two signals are easily discriminated. Figure 1c shows an example with zero amplitude modulation: here the two components cannot be discriminated and the image appears as if a doubly corrugated surface.

Equipment

Stimuli were created in Visual C++ (Microsoft Inc, Redmond, WA) and presented at pseudo 14 bit greyscale resolution on either a Viewsonic P225f monitor (Viewsonic Inc, Walnut, CA) or Sony Trinitron GDM F520 (Sony Inc, Japan) with a 170Hz frame rate controlled by a VSG2/5 graphics card (Cambridge Research Systems Ltd, Rochester, UK). The gamma non-linearity of the monitors was estimated using the four parameter model proposed by Brainard, Pelli & Robson, (2002) fit to luminance measurements taken with a CRS ColourCal device using MatLab (Mathworks Inc, Natik, MA) and corrected using lookup tables in the VSG. Allowing for our frame interleaved presentation method (supplementary materials S1.2), the overall refresh rate was 56.6Hz: sufficiently above flicker fusion for our relatively low contrast stimuli.

Procedure

Participants sat in a darkened room and undertook six sessions; two for each texture type in randomised order. Sessions were conducted during a single visit and lasted about 10 minutes each. In separate sessions they were instructed to indicate either the orientation of the coarse undulations or the broad stripes. Stimuli were displayed for 1011.76 ms (172 frames) with gradual (100 ms) onsets and offsets. After seeing each image participants indicated the orientation of the targeted component with a button press on a CRS CB3 button box. The next trial was initiated following a 1 second delay. The strength of the amplitude modulated components required for the participant to discriminate the two signals was estimated by an adaptive threshold estimation method (Levitt, 1971) targeting the 79.4% correct performance level (see supplementary materials S1.3 for details). Recall that only the modulation depth of the amplitude modulated components varied the contrast of the luminance components and the base or mean contrast of the textures was fixed throughout. Data from one older adult were excluded as the threshold estimator was unable to determine their threshold in one condition.

Participants, power analysis, and Ethical Considerations

Ten younger (mean[sd] age 23.8[2.6] years) and 11 older (68.7[5.8]) adults completed the study. Participant numbers were determined by a power analysis based on data for the detection static texture amplitude modulations (contrast modulations) as found by Habak and Faubert (2000: μ_y=.064, μo=.113, σ=.0406, α=0.05, power=80%). All participants had normal or corrected to normal visual acuity as verified with a Snellen letter chart at 6m and at 114cm using two sets of light on grey letters presented on the monitor at 25% contrast with heights 0.2 and 0.15 deg. Reading the larger string was considered sufficient and one older adult who could not achieve this was excluded from the study. Older adults prescribed multiple optical corrections were told to use whichever correction best enabled them to read the letters at 114 cm (usually their distance correction). Participants' contrast sensitivity was assessed as within the normal range using a Peli-Robson Contrast Sensitivity chart. All experiments were conducted according to the Helsinki Declaration and were approved by the University of Birmingham Research Ethics Committee.

Results

Figure 2 shows threshold amplitude modulation depths for discriminating between corrugations and stripes averaged within each group. A mixed design ANOVA showed main effects of age (F(1,19)=6.67, η_p^2=.26, p=.018) - older adults were worse than young adults; texture type

($F(2,19)=53.52$, $\eta_p^2=.74$, $p<0.001$) - fine textures were harder than coarse, and coarse harder than binary; and instruction type ($F(1,19)=6.2$, $\eta_p^2=.25$, $p=.022$) – discriminating stripe orientation was a little easier than discriminating the orientation of the undulations even though only the instructions varied between these conditions. There was a significant interaction between age and texture type ($F(1,19)=11.41$, $\eta_p^2=.38$, $p<0.001$). Post-hoc t-tests showed that the difference in thresholds between younger and older participants was significant only for the fine texture in the 'look for stripes' condition ($t(19)=-4.695, p<0.001$) although the fine texture 'look for undulations' pairing also approached significance and averaging across the two instruction sets showed that age was overall significant for the fine texture case ($t(19)=-3.689$, $p=0.002$). All texture pairings produced significantly different thresholds within the older adult group (Coarse v. Binary, $t(10)=7.95, p=0.001$; Fine v. Binary, $t(10)=10.32, p<0.001$; Fine v. Coarse, $t(10)=4.75, p=0.001$). For the younger adults only comparisons involving the binary texture were significant (Coarse v. Binary, $t(9)=4.34$, $p=0.02$; Fine v. Binary, $t(9)=3.37$, $p=0.01$) the difference in thresholds for fine versus coarse textures was not significant in this age group.

Discussion

The results of Experiment 1 are consistent with the idea that older adults are selectively impaired in their ability to process amplitude-modulated stimuli when those stimuli are imposed on high frequency textures. Experiment 1 also shows that this deficit is neither general nor cognitive as the older adults performed about as well as the younger adults for binary and coarse textures. These results suggest that the poor performance in the fine texture case is a result of insensitivity to high-frequency image content in the older adult group. Importantly the known deficiency for texture processing (Habak & Faubert, 2000) transfers into shape judgement tasks: our hypothesis is supported. While it is possible that the slight difference in base contrast between the binary and fine/coarse textures explained the differences in performance for some texture pairings, the effect of such a small contrast change is likely to be very much less than the difference observed here (Schofield & Georgeson, 1999). Further, this contrast difference cannot explain the difference in performance between the coarse and fine textures for the older adults as they had the same base contrast.

The performance difference between the two instruction sets (judge the orientation of the stripes or undulations) is intriguing. We speculate that this may relate to our tendency to process shading and shadows differently from material cues to object identity (see for example, Lovell, Gilchrist, Tolhurst, & Troscianko, 2009). Perhaps this tendency results in the undulations – which are simulated here only via shading – being slightly harder to process than the simulated reflectance changes.

What is unknown is whether the age-related visual decline identified in Experiment 1 has an impact on the ability of older adults to detect trip hazards such as steps and undulations. If it does, then this would suggest a previously unconsidered mechanism underlying older adults' increased susceptibility to trips and falls. Experiment 2 assesses the practical impact of the visual impairments revealed in Experiment 1 by having participants climb a kerb which has had its surface texture manipulated so as to represent either a properly shaded kerb (with luminance and texture amplitude varying in phase, LM+AM) or a potential reflectance change (with luminance and texture amplitude varying in anti-phase, LM-AM). The two kerb treatments produced effects similar to the two components of the plaid stimuli used in Experiment 1 once combined with a spotlight. The anti-phase, reflectance-like pairing should cause younger participants to vary their foot trajectory although the nature of the change is difficult to predict especially as the anti-phase pairing is often seen as quite undulated when presented alone. If the kerb is perceived as flatter we might predict lower toe elevation. If it is seen as longer we predict an elongated stride. However, if the kerb is seen as steeper, or if a cue conflict occurs between stereoscopic and shading cues we might expect toe elevation to increase. Critically, however we hypothesise that, if texture cues are impoverished due to a loss of fine grained information with ageing, this should affect older adults' ability to differentiate between shading and reflectance/material changes, thereby compromising surface shape judgements thus altering step climbing behaviour. Consequently, we expect less variation in toe elevation between the two texture treatments in the older age group as compared to the younger adults who we predict will adjust toe elevation in response to perceived changes in step profile.

Experiment 2: Stepping task

Method

Design

We compared older and younger adults in step height estimation and step climbing tasks using a 2(age: younger vs. older) x 2(step treatment: uniform vs. low texture contrast) mixed factorial design. Estimated step height and maximum toe height while mounting the step were measured as separate dependent variables as were a number of other parameters of the step trajectory.

Equipment

A 150 mm high platform was placed in the middle of a large test area. The leading edge (kerb) of this platform had a curved profile that followed one half cycle of a sinusoid with its mid-point half way up the step (Figure 3a). The kerb, platform and part of the floor in front of the step were covered in a printed texture pattern. The kerb was illuminated by a photographer's spotlight placed behind the participant at a distance of 2.85 m from the mid-point of the kerb and offset to the right (with respect to the participant) by 0.8 m. The spotlight was 0.9 m from the floor and angled towards the kerb to produce an illumination highlight on the riser. The luminance profile of this highlight was approximately sinusoidal with a peak at the midpoint of the kerb (see Schofield et al., 2011, for a discussion of why this is the case) as was verified using a Minolta LS110 luminance meter (Minolta Inc, Japan). We draped a black cloth to the left of and behind the kerb to disguise any shadows (Figure 3b). Within the visible spectrum, the room was illuminated only by the spotlight.

Participants' motion was monitored using a 13 camera Vicon MX infra-red (IR) motion capture system (Vicon Motion Systems LTD, Oxford, UK) at a sampling frequency of 100Hz. IR reflective markers were placed on the corners of the platform as a guide to analysis. Before each block of trials we passed a T-shaped calibration rod with an IR marker at the tips of its arms over the kerb such that one marker was in contact with the kerb. We thus verified the kerbs location and shape after each change of texture. The participants wore plastic shoe covers over their normal footwear (so as not to mark the paper textures). These shoe covers likely decreased friction on the shoe surface although we did not measure this. The covers were designed for this purpose. Participants and had four IR markers placed on the outside of their shoes on the calcaneous of the heel, on the middle of the front, top surface of each shoe, and equidistant between these two markers on the medial and lateral sides of each shoe.

Stimuli: Kerb treatments

Kerb treatments were designed to give the kerb a visual appearance similar to the separate ±45° components of the plaid stimuli in Experiment 1 while also being ecologically valid. We printed smooth visual textures onto sheets of thick, matte paper that were attached to the kerb using Velcro tabs. The textures were generated using a Gabor scattering technique which produces a similar result to phase randomisation described for Experiment 1 in the supplementary materials but allows the Gabor patterns to have different spatial frequencies at different locations. The Gabors were oriented perpendicular to the participants' line of travel (that is, visually horizontal). The spatial frequency of the Gabor template approximated 12 cpd at the start point of the walk. The frequency of the Gabor patterns was adjusted on the riser portion of the step so as to counter the apparent reduction in spatial frequency that would otherwise occur on the riser as the texture became oriented more towards the participant on this portion of the step and thus suffered less compression due to perspective distortion than the texture on the flat portions of the track. Thus, when stood at the start of the track the kerb appeared to be covered in a texture with uniform spatial properties as was the case for the stimuli in Experiment 1 and changes in the apparent spatial frequency of the texture that might otherwise have been present could not be used as a cue to shape. There were two main step treatments. In the first (Figure 3c) the contrast of the texture was unchanged such that any shading due to illumination would produce the normal, yoked (in-phase), combination of luminance and texture amplitude (but not contrast) changes that results from multiplicative (real) shading of a matte surface: we call this the Uniform condition. Due to the natural properties of shaded textures (see Schofield et al., 2006, 2010) this condition resulted in the peak of the luminance highlight caused by the spotlight to co-inside with a peak in texture amplitude (LM+AM; *cf* Experiment 1). In the second treatment (Figure 3d) the contrast of the texture was reduced on the riser such that once illuminated the luminance and texture amplitude varied in anti-phase across the riser. That is, texture amplitude was at its minimum at the mid-point of the kerb where luminance was at its maximum (LM-AM; *cf* Experiment 1): Low-contrast condition. In this treatment the reduction in texture amplitude followed a sinusoidal profile approximately matching the luminance change. Note that the texture treatments alone (as presented in Figure 3) do not mimic the conditions of Experiment 1. Nor do they represent the final stimuli seen by the participants. However, once paired with the luminance changes induced by the spotlight the visual image available to the observer at the step riser location did mimic the conditions of the previous experiment with two notable exceptions. First, the spatial frequency of the modulations was higher in the first experiment and more cycles of modulation were visible. In Experiment 2 only one cycle of modulation was visible at the riser. Second, in Experiment 1 the LM+AM and LM-AM cues were presented together within each stimulus creating the impression of a corrugated surface with material stripes running across it; but in Experiment 2 the cues were presented alone. Imposing both cues at once could, in one condition, have produced the appearance of a kerb that undulated in the direction orthogonal to its true riser. This might have severely affected participants' gait, making comparisons between conditions difficult. Presenting the two cues separately reduces any perceived differences (Schofield et al., 2010) thus this difference between the experiments makes the observation of behavioural changes in Experiment 2 less likely.

Procedure

Participants stood facing the kerb at a distance of about 2.5 times their normal step length. On each trial they were asked to view the kerb and raise their lead foot (that which they most comfortably move first when walking) to estimate the height of the step. They then returned to a two-footed standing position (double stance phase) before walking onto the platform. Each walk comprised three normal steps plus a half step alternating lead foot, other foot. The participant climbed the kerb on the third step and obtained a standing position with their two feet side-by-side on top of the platform on the fourth, partial step. This procedure was repeated 10 times for each of two kerb treatments with the order of the kerb treatments counter-balanced across participants. The two conditions were completed in a single visit with each condition taking less than 10 minutes to complete.

Participants, power analysis and ethical considerations

Elliot et al. (2009) obtained a highly significant ($p<.001$) within participants effect of texture treatment on toe elevation using 21 participants. They observed a change in toe elevation of about 5mm (s.d.= 22mm) leading us to conclude that there must have been a strong correlation ($r\sim.975$) between the toe elevations for the two treatments. Based on this analysis we estimated that around 10 participants per group would be sufficient to detect a 5mm difference in toe height with $\alpha=.05$ and power = 80%. We therefore set out to test 10 people in each group however two older adults had to be removed at the analysis stage as they could not maintain good balance in the kerb height estimation task. Thus there were 8 participants in each age group (mean[sd] ages: younger=28[5.7] and older =69.75[7.32]) to obtain a balanced design. All wore their most appropriate optical correction for a walking task. Those who were unable to hold a steady one foot pose even with the aid of a support were excluded from the study. An experimenter observed participants' step actions to ensure that a safe step clearance was maintained; but never had to intervene. Different groups of participants were used in the two experiments but where a participant happened to take part in both experiments the two visits were separated by several months. All other participant information is as Experiment 1.

Analysis

Kinematic data was filtered using a 2nd order, dual-pass Butterworth filter with a cut-off frequency of 10 Hz. The toe position data were used to estimate the height relative to the stance position for both the kerb height estimation task and the stepping task whereby we measured the maximum vertical displacement of the toe marker during the third (climbing) step. The anterior-posterior distance during the lead stride onto the platform was used to calculate stride length. Stride speed was calculated as peak foot velocity (calculated using two-point differentiation of anterior-posterior toe marker displacement) during the lead limb's swing phase. The minimum distance between the toe marker and the top edge of the kerb, in both the vertical and anterior-posterior directions (i.e. the length of the two-dimensional vector) was calculated as an indicator of toe clearance with the kerb surface. Data from each dependent variable were averaged over the 10 repetitions per condition and a mixed design ANOVA test was performed to assess the effects of kerb treatment and age on each stepping characteristic.

Results

Height estimation task

Figure 4a shows the mean kerb height estimation results. Participants routinely over-estimated the height of the kerb: the older adults significantly more so than the younger participants ($F(1,14)=8.97$, $\eta_p^2=.39$, $p=.01$) but there was no effect of texture treatment nor any interaction.

Toe elevation during kerb climbing

Figure 4b shows the mean toe elevations in the stepping task. There was no significant main effect of age ($F(1,14)=1.56$, $p=.23$). There was, however, a main effect of texture treatment ($F(1,14)=5.0$, $\eta_p^2=.26$, $p=0.042$) and an interaction between age and texture treatment ($F(1,14)=7.19$, $\eta_p^2=.34=.24$, $p=.018$). Older adults made no adjustment for the different texture treatments ($t(7)=0.3$, $d=0.11$, $p=0.77$) whereas the younger adults lifted their limb 9.6 mm higher when mounting the low-contrast step ($t(7)=-3.63$, $d=1.28$, $p_{corrected}=0.016$). When questioned after the experiment, no participants reported noticing any difference between the two step treatments.

Stride length

There was no significant main effect of age ($F(1,14)=2.79$, $\eta_p^2=.166$, $p = 0.12$) on the length of the stride onto the raised platform (older adults: 1225±74 mm young adults 1308±117 mm). There were also no main (F(1,14)=1.72, η_p^2=0.11, p=0.2) or interaction effects (F(1,14)=0.176, η_p^2=.012, p = 0.68) of kerb treatments on mean stride length.

Stride speed

There was a significant main effect of age (F(1,14)=259.5, η_p^2=.95, $p < 0.0001$) on the peak lead leg forward velocity during the swing phase of the stride onto the platform. Older adults made significantly slower strides (1.30 m/s±.13) than younger adults (3.34 m/s±.33). There were no main (F(1,14)=3.60 η_p^2=.20, p=0.08) or interaction effects (F(1,14)=0.79, η_p^2=.05 p = 0.39) of kerb treatments on mean stride speed.

Toe clearance with top edge of kerb

There was no significant main effect of age (F(1,14)=2.91, η_p^2=.95, p =0.11, η_p^2=.172) on the minimum distance between the toe marker and the kerb's top edge (older adults: 43.8±12.5 mm young adults 53.5±11.5 mm). There were no also no main (F(1,14)=0.016 η_p^2=.001, p=0.9) or interaction effects (F(1,14)=1.06, η_p^2=.07 p = 0.32) of kerb treatments on this measure of toe clearance.

Post-hoc power analysis

As we tested fewer participants than planned we conducted a fresh power analysis. The difference in toe elevation in the kerb climbing task for the younger adults was 9.6mm and the standard deviation for this difference was 7.4mm. We thus estimate that 7 participants would be sufficient for 80% power with α=0.01. We conclude that we had sufficient power to find within participant differences of the magnitude observed.

General discussion

In the two experiments presented here we manipulated the luminance amplitude of pattern elements within a visual texture in combination with a gross change in mean luminance in order to simulate either the shading of a textured, gently undulating surface or coarse changes in surface reflectance/albedo. This manipulation is useful as it leaves the primary luminance cue unaffected yet can produce quite distinct precepts based on a relatively simple and easily controlled manipulation. In the first experiment we employed both the shading and reflectance simulations in a plaid configuration that has been shown to maximise the difference in appearance between the two cues (Schofield et al., 2006; 2010). Further, the efficacy of the manipulation employed is known to depend on high-frequency (fine) components in the underlying texture (Sun & Schofield, 2011). Since older adults are known to be less sensitive to such fine detail than young adults (Weale, 1986) and also less sensitive to modulations of texture contrast/amplitude (Habak, 2000) we predicted that they would be less able to distinguish between the corrugations and stripes in our simulations especially when a fine-grained texture was used. This prediction was borne out in the data from Experiment 1 which showed that, despite being able to do the task about as well as the younger participants, when binary and relatively coarse grained textures were used, older adults required significantly stronger modulations of texture amplitude when fine-grained textures were used. This result adds further weight to the idea that high spatial frequencies are critical for tasks involving second-order vision.

In Experiment 2 we tested to see if the perceptual deficit found in Experiment 1 would translate into behavioural differences in a stepping task. Here we used only one type of stimulation at a time. The uniform texture condition faithfully represented the shading of the curved step that participants were required to climb while the low-contrast condition masked the shape of the kerb by presenting a texture amplitude profile more consistent with a simulated reflectance change. However, when presented alone in this fashion the two treatments are known to appear rather similar (Schofield et al., 2006;2010). Indeed participants were unaware of the difference between the two kerb treatments in the stepping task as evidenced by both subjective report and the lack of any effect for texture type in the kerb height estimation part of Experiment 2. Nonetheless, for the younger participants, mean peak toe elevation was 10mm higher in the low-contrast condition compared to the normal-contrast condition suggesting that they responded to the step treatments in the kerb climbing task. Critically, the older adults did not increase their toe elevation when stepping in the low-contrast condition; thus we show that losses in sensitivity to high spatial frequency can have functional implications. Our second hypothesis, that younger adults would vary toe elevation in response to the texture treatments but older adults would fail to do so, is supported.

We discount the notion that older adults were simply not able to vary their toe elevation when stepping and were thus incapable of exhibiting a behaviour change in response to the texture variations. Lu et al. (2006) showed that older adults of similar age to our participants exhibited considerable variation in both absolute toe elevation and toe clearance when crossing obstacles of different height. Further, we analysed the data from individual trials and note that toe elevations were normally distributed for both groups with standard deviations of about 20mm. Thus older adults had sufficient natural variability to exhibit a 10mm variation in toe elevation should then need to, and there was no indication that they were working close to their maximum toe elevation. While it is possible that older adults simply ignored the visual appearance of the step we feel this is unlikely as participants were instructed to view the step then estimate its height on every trial prior to climbing the step.

It should be noted that whereas the younger participants made much lower estimates of kerb height than the older adults, maximum toe elevation when climbing the kerb was about the same, and closer to the higher level. We wonder if the exaggerated peak toe elevation is caused by the gentle nature of the kerb requiring greater elevation so as to extend the stride. Could this also explain why the younger participants lifted the toe higher in the low-contrast condition? One might expect that if the low-contrast step seemed less like a shaded surface it would appear flatter and therefore lower, reducing toe elevation. However, given that participants had both binocular and (after the first trial) sensory-motor cues to the actual height of the kerb, any flattening effect of the low-contrast texture could have made the rise appear more gradual and therefore longer than in the uniform condition. This apparent elongation of the kerb may have resulted in additional toe clearance to prolong the step even further. However, we can rule this out as stride length did not vary with age or step treatment.

Another possibility is that the low-contrast kerb created a cue conflict between pictorial and binocular shape cues and thus instilled greater implicit caution into the younger participants. However, had this been the case we might have expected more hesitant (slower) stepping in the low-contrast condition and we did not find this. A third possibility is that the low contrast manipulation made the curved part of the riser appear more planar but as a consequence steeper. Participants may have been encouraged to graze the gently curved top of the kerb in the uniform case but, younger participant may have lifted their toe higher to avoid the implied sharper upper edge in the low contrast case. If this were so we might expect to see reduced toe clearance with respect to the top of the kerb edge. However, we found no group or condition differences between the minimum distance between the toe marker and the top edge of the kerb.

Regardless of the cause for the greater toe elevation while stepping in younger adults it is clear that the failure of older adults to process the texture cue well would result in the two kerb treatments appearing more similar and hence produce similar limb trajectories: as observed. While this failure could be due to uncorrected optical factors associated with non-ideal viewing conditions and variable correction within the available eye-wear such effects were as far as is possible minimised and there are known neural declines that could equally explain the data Owsley (2011).

The dissociation between perception and behaviour is itself interesting as certain visual illusions have been shown to affect perceptual tasks such as size estimation more than behavioural tasks such as grasping (Aglioti, DeSouza & Goodale, 1995). Here we have the opposite: a subtle visual cue affects stepping behaviour but not perceptual judgments. This finding supports the notion that the task relates to our ability to judge surface shape. The visual system has two main pathways with the ventral pathway being broadly responsible for recognition type tasks and the dorsal pathway for location, navigation and movement based tasks. The ventral pathway is thought to be more closely involved in conscious perception while the dorsal pathway drives behaviour. Specifically, the neural locus of shape-from-shading is very close to functional area V5/MT in humans (Georgieva, Todd, Peeters & Orban, 2008) and the latter region is part of the dorsal, behavioural, pathway. Thus altered shape perception is more likely to affect a behavioural task than a perceptual one. Importantly for the case of falls our results imply that older adults may unconsciously treat surface undulations and changes in the material properties of surfaces in the same way: either adjusting their gait and stepping trajectories as if to navigate an undulating surface when in fact the surface is flat but subject to changes in material composition, or assuming flat surfaces with material changes when in fact undulations are present. Either scenario could result in falls. Thus navigating surfaces such as "crazy paving" or poorly laid paving slabs and transitions between surfaces types may be more problematic for visually guided gait control than previously thought. In particular small undulations that correspond with scuffing on carpets might produce effects similar to our low-contrast condition if the visual texture in the carpet is weakened in the scuffed area.

Acknowledgment

BC-J was supported by and AgeUK Research into Ageing studentship. We thank Helen Jebbitt for her assistance with data collection.

References

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size Constrast illusions deceive the eye but not the hand, *Current Biology, 5*, 679-685.

Baker, S. P., & Harvey, A. H. (1985) Fall injuries in the elderly, *Clinical Geriatric Medicine*, 1: 501-512.

Brainard, D. H., Pelli, D. G., & Robson, T. (2002) Display characterization. In J Hornak (Ed.), *Encyclopaedia of Imaging Science and Technology* (pp 172-188). New York, NY: Wiley.

Chapman, G. J., & Hollands, M. A. (2006) Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion, *Gait and Posture, 24,* 288-94.

Dakin S. C., & Mareschal, I. (2000) Sensitivity to contrast modulation depends on carrier spatial frequency and orientation, *Vision Research, 40,* 311-329.

Dowswell T., Towner E., Cryer C., Jarvis, S., Edwards, P., Lowe, P. (1999) *Accidental falls: fatalities and injuries. An examination of the data sources and review of the literature on preventive strategies. A report prepared for the Department of Trade and Industry*. Newcastle upon Tyne , UK: University of Newcastle upon Tyne.

Elliot, D. B., Vale, A., Whitaker, D., Buckley, J. G. (2009) Does my step look big is this? A visual illusion leads to safer stepping behaviour, *PLoS ONE* 4(2) e4577.

Fuller, G. F. (2000). Falls in the elderly, American Family Physician, 61; 2159-2168.

Georgieva, S. S., Todd, J. T., Peeters, R., Orban, G. A. (2008) The extraction of 3D shape form texture and shading in the human brain, Cerebal Cotex, 18,2416-2438.

Habak, C, & Faubert, J. (2000) Larger effect of aging on the perception of higher-order stimuli. *Vision Research, 40*, 943-950.

Hamel, K. A., Okita N., Higginson, J. S., Cavanah P. R., (2005) Foot clearance during stair descent: effects of age and illumination, *Gait & Posture, 21*, 135-140.

Heasley, K., Bukley, J. G., Scally, A., Twigg, P., Elliot, D. B. (2004) Stepping Up to a New Level: Effects of Blurring Vision in the Elderly, Investigative Ophthalmology &. *Vision Science, 45*, 2122-2128.

Heasley, K., Bukley, J. G., Scally, A., Twigg, P., Elliot, D. B. (2005) Falls in Older People: Effects of Age and Blurring Vision on the Dynamics of Stepping. *Investigative Ophthalmology & Vision Science, 46*, 3584-3588.

Humphrey, D. G., Kramer A. F. (1997) Age differences in visual search for feature, conjunction, and triple-conjunction targets, *Psychology and Aging, 12,* 704-717.

Kingdom, F. A. A. (2008) Perceiving light versus material. *Vision Research, 48*, 2090-2105.

Levitt, H. (1971) Transformed up-down methods in psychoacoustics. *Journal of the Acoustic Society of America, 70*, 1458-1471.

Lovell, P. G., Gilchrist, I. D., Tolhurst, D. J., & Troscianko, T. (2009). Search for gross illumination discrepancies in images of natural objects. *Journal of Vision*, *9*(1), 1-14.

Lu, T-W., Chen H-L., Chen, S-C. (2206) Comparisons of the lower limb kinematics between young and older adults when crossing obstacles of different heights. Gait & Posture, 23, 471-479.

Nelson, R. C., & Amin M. A. (1990) Falls in the elderly, *Emergency Medical Clinics of North America, 8*, 309-324.

Owlsey C. (2011) Aging and vision, *Vision Research, 51*, 1610-1622.

Pentland, A. (1988) Shape from Shading; A theory about human perception, *Spatial Vision, 4*, 165-182.

Reed-Jones, J. G., Reed-Jones, R. J., Hollands, M. A. (2014) Is the size of the useful field of view affected by postural demands associated with standing and stepping? *Neuroscience Letters, 566*, 27-31

Schofield A. J. (2000) What does Second-order vision see in an image, *Perception, 29*, 1071-1086.

Schofield A. J., & Georgeson, M. A. (1999) Sensitivity to modulations of luminance and contrast in visual white noise: separate mechanisms with similar behaviour, *Vision Research, 39*, 2697-2716.

Schofield, A. J., Heese, G, Rock, P. B., Georgeson, M.A. (2006) Local luminance amplitude modulates the interpretation of shape-from-shading in textured surfaces. *Vision Research, 46*, 3462-3482.

Schofield, A. J., Rock, P.B., & Georgeson, M. A. (2011) Sun and sky: Does human vision assume a mixture of point and diffuse illumination when interpreting shape-from-shading? *Vision Research, 51*, (21-22), 2317-2330

Schofield, A. J., Rock, P. B., Sun, P., Jiang, X, Georgeson M. A., (2010) What is second-order vision for? Discriminating illumination versus material changes, *Journal of Vision, 10* (9):2.

Scialfa, C. T., (2002) The role of sensory factors in cognitive ageing research, *Canadian Journal of Experimental Psychology, 56*, 153-163.

Simoneau, G. G., Cavanagh, P. R., Ulbrecht, J. S., Leibowitz, H. W., Tyrrell, R. A. (1991) The influence of visual factors on fall-related kinematic variables during stair descent by older women, *Journal of Gerontology, 46*, M188-M195.

Snowden, R., Kavanagh, E. (2006) Motion perception in the ageing visual system: Minimum motion, motion coherence, and speed discrimination thresholds, *Perception, 35*, 9 – 24

Sun P., & Schofield A. J. (2011) The efficacy of local luminance amplitude in disambiguating the origin of luminance signals depends on carrier frequency: Further evidence for the active role of second-order vision in layer decomposition, *Vision Research, 51*, 496-507.

Sutter A., Sperling, G., & Chubb, C. (1995) Measuring the spatial frequency selectivity of second-order texture mechanisms, *Vision Research, 35,* 915-924.

Wilson, H. R., Ferrara, V. P., & Yo C. (1992) A psychophysically motivated model for two-dimensional motion perception, *Visual Neuroscience, 9,* 79-97.

Weale, R. A. (1986) Aging and vision, *Vision Research, 26*, 1507–1512.

Young, W. R., Wing, A. M., Hollands M. A. (2012) Influences of State Anxiety on Gaze Behavior and Stepping Accuracy in Older Adults During Adaptive Locomotion, *Journals of Gerontology Series B, 67B*, 43-51.

Figure Legends

Figure 1 a) Example amplitude modulated noise sample (not a stimulus). b-d) Example stimuli: b) Binary noise texture with LM+AM mix on the right oblique and LM-AM mix on the left oblique, AM level about 2x threshold for older adults. c) Binary noise texture with LM/AM plaid but with AM modulation depth of zero. The two luminance modulations are indistinguishable. d) Narrow band Gabor noise texture LM+AM on right oblique, LM-AM on left Oblique, AM level at approximately 2x older adults threshold for fine noise. This example stimulus was originally drawn with noise at 8cpd but is here adequately representative of both coarse and fine textures as they vary only in spatial scale which is in any case dependent on the readers viewing distance

Figure 2 Results from Experiment 1 showing threshold AM modulation depths as a function of instructions, texture type and age. Error bars show 95% CIs

Figure 3 Stepping Experiment: a) Step rise profile view. b) Step in situ with texture and illumination applied. c) Example texture for the uniform condition note the area of spatial compression would normally sit on the riser. The areas of texture top and bottom would lie on horizontal surfaces and appear compressed vertically to match the riser. This compression would also equate the apparent contrasts of the three regions these being physically equal in this figure, if different in appearance. d) Example texture for the low-contrast condition. Here the contrast of the central region is lower than that of the upper and lower flanks. Note panels c) and d) represent the textures as applied to the kerb not the final stimuli presented. The latter were generated as the result of applying a spotlight to the textures when mounted on the kerb and is to a limited extent represented in panel b). Textures are draw at reduced scale

Figure 4 Results for Experiment 2 showing maximum toe elevations in the two phases of the experiment. a) mean curb height estimations. b) mean maximum toe displacement during curb mounting. Error bars show 95% CI's

Figure 1

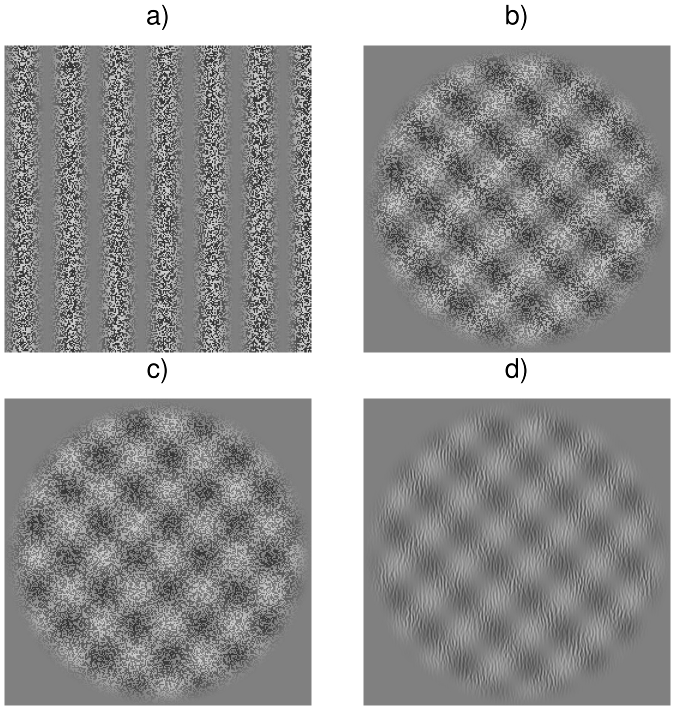


Figure 2

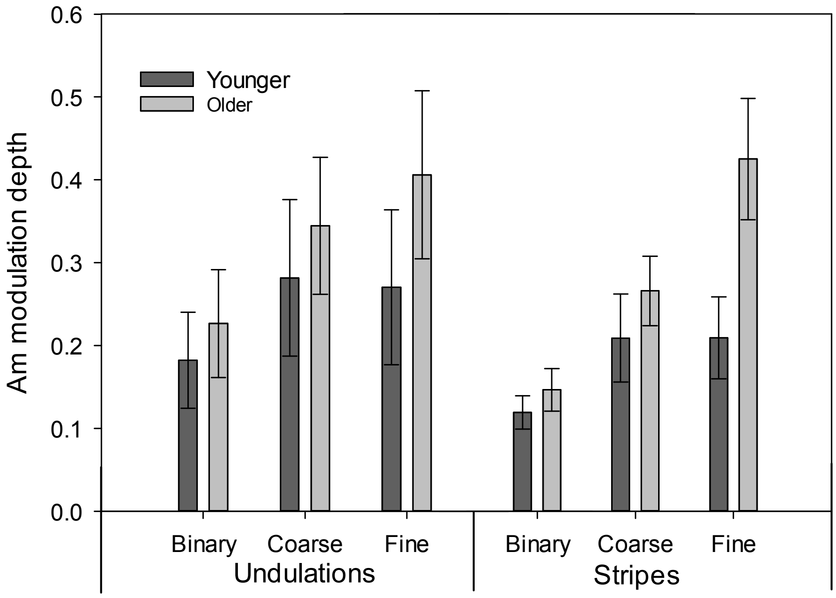


Figure 3

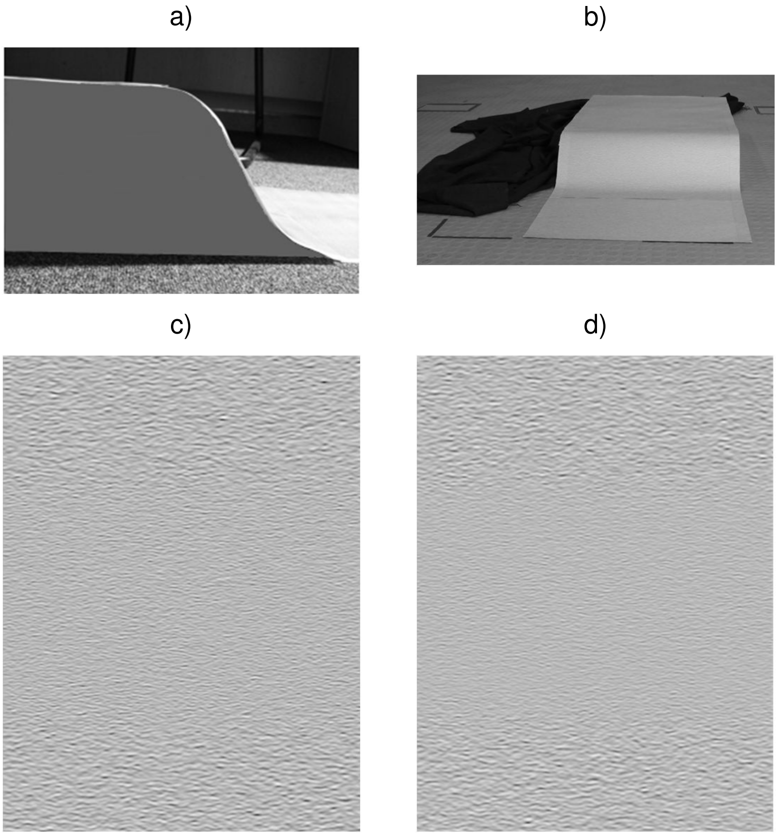
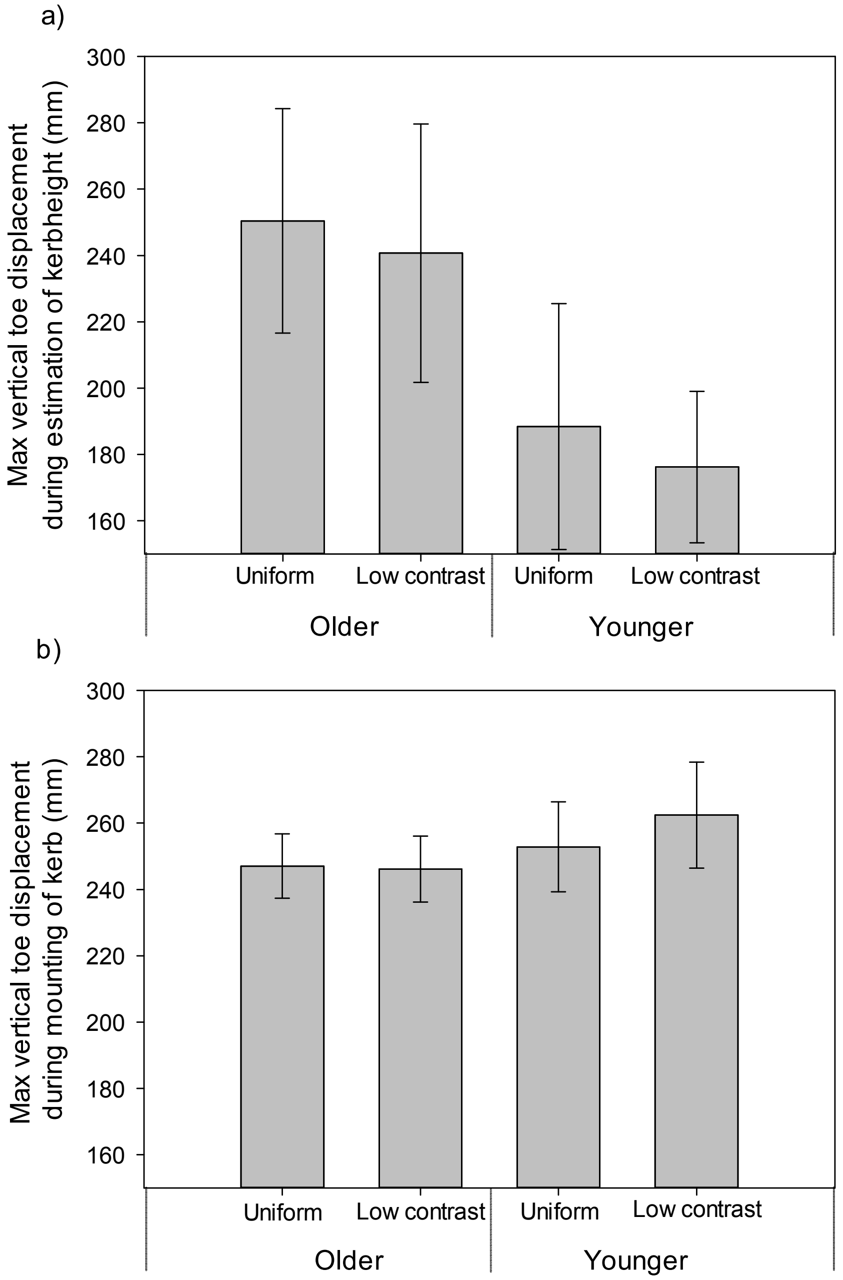


Figure 4


a)
Max vertical toe displacement during estimation of kerbheight (mm)
300
280
260
240
220
200
180
160
Uniform
Low contrast
Uniform
Low contrast
Older
Younger
b)
Max vertical toe displacement during mounting of kerb (mm)
300
280
260
240
220
200
180
160
Uniform
Low contrast
Uniform
Low contrast
Older
Younger

Reduced sensitivity for visual textures affects judgments of shape-from-shading and step climbing behaviour in older adults.

Andrew J. Schofield, Benjamin Curzon-Jones, and Mark A. Hollands

Supplementary materials

S1. Methodological details for Experiment 1.

While our main methods section provides sufficient detail to allow replication of the study using preferred stimulus generation and experimental software procedures it does not specify in detail the precise methods used in our laboratory, those details are provided here.

S1.1 Texture composition.

Binary noise textures were created by setting each texture element (2x2 pixel square) to either dark or light at random. The fine- and coarse-rippled textures comprised a vertically oriented Gabor patch constructed by multiplying a sine wave luminance signal centred on the appropriate spatial frequency (8 or 12 cpd) multiplied by a circular Gaussian window with its space constant (σ) set to half the period of the sine wave. Working in the Fourier domain, on each trial the phase spectrum of the template Gabor was randomised creating the effect of scattering Gabor patches densely over the image once transformed back into the space domain. The un-modulated rms contrast of the textures was measured 0.2 for the binary noise textures. Contrast for the coarse and fine rippled textures is less easy to define as different metrics (e.g. root mean square and Michelson) produce different results. In some places positive superposition leads to locally high contrast while in others negative superposition leads to low contrast. The final, rms contrast was 0.18 for both forms of rippled texture which we regard as negligibly different from that of the binary noise.

S1.2 Stimulus construction and frame interleaving.

Stimuli were constructed as three images (texture alone, version of the same texture sample modulated in amplitude by a plaid, and a luminance modulated plaid) each occupying a separate location in the graphics card's frame-store and each with a base contrast three times the desired final value. The initial modulation depth of the amplitude modulated texture was set to 200%. These images were then optically added by frame interleaving with each image given its own display contrast via lookup tables in the graphics card with final contrasts being divided by 3 due to the frame interleave process. The addition of a 200% amplitude modulated texture sample to the texture alone produces a final modulation depth equal to the ratio of the two display contrasts; the further addition of the luminance image creating the final percept. The overall refresh rate following frame interleaving was 56.6Hz.

S1.3 Adaptive threshold estimation procedure.

The threshold estimation procedure consisted of two adaptive staircase routines running in parallel with stimulus control switching between routines at random so that participants could not predict the activity of either routine or the next stimulus level presented. The estimation routines incremented or decremented the modulation depth of the texture amplitude components in logarithmic steps. Three consecutive correct answers produced a signal decrement - one incorrect answer an increment (one-up, three-down); with each change in direction termed a reversal. Within each routine signal increment (or decrement) size reduced from 8 to 1 dB over the initial 3 reversals then continued for a further 12 reversals. Discrimination thresholds were taken as the average of last 12 reversals from each of the two estimators (24 reversals in all). In the case of very poor performance, individual staircase routines were abandoned after 200 trials. If either routine in a session completed its 12 reversals with this time its estimate alone was used, but if both terminated early no threshold was recorded. One older participant was removed from the study due to such a loss.