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Title

Motion perception at mesopic light levels: effects of physiological ageing and eccentricity

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Motion perception, ageing, mesopic vision, global motion coherence, biological motion

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Abstract

Purpose

To explore the differential effects of age and eccentricity on the perception of motion at photopic and mesopic light levels.

Methods

Thirty-six visually normal participants (18 younger; mean age 25 years, range: 20-31) and (18 older; mean age 70 years, range: 60-79) underwent two testing sessions, one at photopic and one at mesopic light levels. In each session, motion perception was tested binocularly at two eccentricities (centrally, and peripherally at 15° rightwards and 5° superior to the horizontal) for four motion tasks: minimum contrast of a drifting Gabor to identify motion direction (motion contrast); translational global motion coherence; biological motion embedded in noise and the minimum duration of a high-contrast Gabor to determine the direction of motion, using two Gabor sizes to measure spatial surround suppression of motion.

Results

There was a significant main effect of light condition (higher thresholds in mesopic) for motion contrast ($p<0.001$), translational global motion ($p=0.001$) and biological motion ($p<0.001$); a

significant main effect of age (higher thresholds in older adults) for motion contrast ($p<0.001$) and biological motion ($p=0.04$) and a significant main effect of eccentricity (higher thresholds peripherally) for motion contrast ($p<0.001$) and biological motion ($p<0.001$). Additionally, we found a significant three-way interaction between light levels, age and eccentricity for translational global motion (similar increase in mesopic thresholds centrally for both groups, but a much larger deterioration in older adult's peripheral mesopic thresholds, $p=0.02$). Finally, we found a two-way interaction between light condition and eccentricity for translational global motion (higher values in central mesopic relative to peripheral photopic, $p=0.001$) and for biological motion (higher values in peripheral mesopic relative to central photopic, $p<0.001$).

Conclusions

For the majority of tasks assessed, motion perception was reduced in mesopic relative to photopic conditions, to a similar extent in both age groups. However, because some older adults exhibited elevated thresholds even under photopic conditions, particularly in the periphery, the ability to detect mesopic moving stimuli even at high contrast was markedly impaired in some individuals. Our results imply age-related differences in the detection of peripheral moving stimuli at night that might impact hazard avoidance and night driving ability.

Introduction

The human visual system can operate under a wide range of luminance levels, ranging from bright, sunny days, when the cone photoreceptors are operating, to night-time illuminated only by starlight, where vision is mediated by the rods. Mesopic vision refers to situations where both types of photoreceptor work together, such as night driving, where a driver's view of a dark rural road is illuminated only by car headlights.[1]

Under mesopic conditions, many visual functions deteriorate in central vision, including visual acuity[2] and contrast sensitivity.[3] In addition, evidence has shown that contrast sensitivity at low light levels is further reduced with advanced age.[4] These deficits are particularly relevant in an applied context such as driving. Previous research has shown that the rate of fatal involvement in traffic accidents is higher in older drivers,[5] with this group being more likely to be involved in crashes due to unseen objects.[6] Furthermore, evidence has shown an association between reductions in visual acuity and contrast sensitivity at low light levels and night driving performance as assessed on closed road circuits.[7,8] Studies have also shown that crash rates are increased under low light levels,[9] with crashes decreasing with increased street lighting.[10]

Motion perception is relevant in terms of the visual requirements for driving, as both the driver and the environment are in motion. Numerous studies[7,11-16] have reported a link between poorer performance on motion perception tasks and driving difficulties, including difficulties driving at night,[7] and the ability to recognise pedestrians at night-time.[17] The perception of motion is a multi-stage process that starts in the retina by signalling local changes in an object's position. These local motion signals are integrated at higher cortical regions such as area MT/V5[18] and area STS,[19] allowing correct interpretation of motion information contained within larger or more complex motion patterns, such as for global motion (from random dot kinematograms) and biological motion, respectively. Under mesopic conditions, the retinal output changes to a combination of signals from cones and rods, creating a potential conflict for signal processing, as rod responses are slower than cones.[20,21] In addition, these two types of photoreceptors are not equally distributed across the retina,[22] with the highest density of cones located in the central region, and the highest density of rods located approximately 10° to 15° from the fovea.[22] Consequently, the change in retinal output under mesopic light conditions resulting from varying distributions of photoreceptors in central and peripheral vision may impact the perception of motion differentially, depending on the location of the stimulus within the visual field. Although previous research has shown that some components of motion perception are impaired under low light levels, such as velocity perception,[23] global motion coherence[24-26] and biological motion,[24-26] to our knowledge the effect of mesopic light levels on peripheral motion perception has not been reported.

Under photopic conditions, age-related differences in motion perception have been shown to depend on the nature of the motion task,[27-31] with some complex motion tasks (such as global motion coherence) being less affected by the effects of healthy ageing.[30,31] As mentioned earlier, in central vision, contrast sensitivity at low light levels is reduced in older compared to younger adults.[4] As, regardless of age, contrast sensitivity decreases in the periphery under photopic conditions,[32] it is likely that under low light levels this reduction in peripheral contrast sensitivity would be exacerbated in older adults; however, this has not been well studied. In this experiment we hypothesised that older adults would experience impaired motion perception at mesopic levels for those motion perception tasks that are highly dependent on stimulus contrast, such as the identification of motion direction of low-contrast Gabor targets (motion contrast). Typical implementations of global motion coherence and biological motion stimuli are high contrast; consequently, we predicted these functions would be less impacted by age-related alterations in contrast sensitivity under mesopic conditions. Additionally, we expect that mesopic levels may have an impact on temporal aspects of motion detection such as the stimulus duration required to discriminate the direction of motion of high contrast Gabor patches of different sizes.

Therefore, the present study aimed to explore whether the perception of motion is impaired under mesopic light conditions relative to photopic levels and how this relationship was affected by age and eccentricity. In addition, we explored possible relationships between mesopic motion perception and visual acuity and contrast sensitivity at mesopic levels.

Methods

Participants

Participants were 18 younger (mean age 24.94 years, SD: 2.70, range: 20-31) and 18 older (mean age 69.67 years, SD: 5.39, range: 60-79) adults. Recruitment was performed through advertisements placed around The University of Melbourne, local newspapers, University online portals, and from a database of participants previously tested in our laboratory. Ethics approval was obtained from The University of Melbourne Human Research Ethics Committee (HREC 1749806), and all procedures complied with the tenets of the Declaration of Helsinki. A $20 (AUD) gift voucher per session was provided to participants to help offset any expenses incurred in attending each experimental session.

To confirm they met the inclusion and exclusion criteria, participants underwent an abbreviated visual screening assessment, which consisted of monocular and binocular visual acuity testing using a standard wall-mounted, high-contrast Early Treatment Diabetic Retinopathy Study (ETDRS) chart at 3 metres viewing distance. Clarity of the ocular media was assessed using a slit lamp and scored according to the Lens Opacities Classification grading System (LOCS).[33] A macular high-resolution scan was obtained from each participant using the Spectralis OCT (www.heidelbergengineering.com) to verify macular status. To assess that peripheral vision was normal, participants performed a monocular visual field screening test of each eye (the O600 screening test)[34] using the Octopus 600 perimeter (www.haag-streit.com).

The cognitive function of participants was assessed using the Mini-Mental State Examination (MMSE)[35], with normal cognition indicated by a score of 23 or higher. All participants had scores higher than 27.

Inclusion criteria

Inclusion criteria consisted of distance binocular visual acuity better than 6/9.5 with patient's best refractive correction, lens opacities less than NO3, C3 or P2 in the LOCS III grading system[33], no macular defect visible on OCT within the central 10 degrees, and no more than three missed points located contiguously within the visual field with no missed points located immediately within the tested region (15° of eccentricity).

Testing procedure

Participants attended two testing sessions on separate days, one for each of the photopic and mesopic conditions. Testing order was approximately counterbalanced between participants, with a similar number of subjects starting either in photopic or mesopic light levels and for targets in

central or peripheral vision. Experiments were developed in Python using the coder module of Psychopy v1.85.2.[36] Stimuli were displayed on a calibrated 32-inch Display++ monitor (www.crsltd.com/), with a refresh rate of 120 Hz, a spatial resolution of 1920 x 1080 pixels and a pixel size of 0.36 mm. For each experiment, the viewing distance was 100 cm, with older participants optically corrected for this viewing distance.

Mesopic viewing levels were achieved using neutral density filters (2.5 ND, www.edmundoptics.co.uk) mounted in a plastic frame and placed in a spectacle trial frame with the participant's distance refractive correction. For this testing condition, participants were dark adapted for 15 minutes prior to testing with all lights off (including the screen) wearing the ND filters which were not removed for the duration of the experiment. The maximum luminance of the screen was either 0.54 cd/m^2 or 200 cd/m^2 (viewing with or without the ND filters, respectively). Mesopic visual acuity was assessed using a wall-mounted, high-contrast ETDRS chart at a 3 metre viewing distance with participants wearing the ND filters over their distance refraction.

At each session, four motion perception tasks of different complexities were assessed binocularly in central vision (centre of the stimulus located at 0° eccentricity) and peripheral vision (stimulus centre located at 15° to the right and 5° upwards from the screen centre). The stimulus location was selected to be consistent with our previous study[30], with the upwards shift of the stimulus allowing the physiological blind spot to be avoided in one eye. These tasks were the following:

A) **Motion contrast:** As reported previously,[30] our version of this task involved measurement of the minimum contrast required to identify the direction of motion of a vertically oriented Gabor patch of σ = 1.35° with the size truncated at ±3σ, with a spatial frequency of 3 c/°, a duration of 250 msec and a drift rate of 2°/s. The use of sine gratings for psychophysical studies is commonly related to the exploration of low levels of processing, such as the measurement of contrast sensitivity. Simple grating stimuli are commonly used to explore early stages of motion processing.[37] Neurons with direction selectivity for these types of stimuli are present in primary visual cortex.[38]

B) **Translational global motion coherence**: This task determined the lowest percentage of signal dots required to detect translational motion of a circular 10° diameter random dot kinematogram (RDK) containing 100 white dots of 5 x 5 pixels moving rightwards/leftwards at a speed of 2°/s over a stimulus duration of 420 msec.[30] The perception of translational global motion corresponds to a more complex stage in motion processing, as it requires the integration of local motion signals over space.[18] Evidence from single cell neurophysiology,[18,39] human brain imaging[40] and lesion studies[41,42] demonstrate that

extrastriate visual areas, such as cortical area MT/V5, are important for global motion perception.

C) **Biological motion:** This task determined the maximum number of noise dots that allowed the detection of the direction of a point light walker embedded in noise. The point light walker was adapted from Shipley and Brumberg[43] and consisted of thirteen animated dots of 5 x 5 pixels that were configured in a rectangular array of approximately 4° wide and 7.4° high, with one gait cycle occurring every 900 msec.[30] This task represents a higher level of processing as it requires the integration of the point light walker shape and motion signal.[44] Evidence has shown that brain area STS is involved in processing this type of motion.[19,45,46]

D) **Duration thresholds for identifying the direction of motion :** following the work of Tadin and colleagues,[47] this task measures the minimum duration to identify the direction of motion of high contrast Gabor patches (92% Michelson contrast) with a spatial frequency of 1 c/°, a drift rate of 2°/s and of two sizes: 3σ = 4.05° and 15°. In addition to comparing the duration thresholds between groups, we also calculated a spatial surround suppression index by comparing the thresholds for individuals for the larger and smaller sized patches. A suppression index (SI) was calculated by subtracting the log threshold of the larger stimulus from the log threshold of the smaller stimulus. This task explores surround suppression of motion properties, which refers to the decrease in the neural response to a suprathreshold stimuli when it is surrounded by a pattern with similar characteristics**.** Tadin and colleagues[47] suggested that the stimulus size at which suppression was strongly observed was consistent with the size of MT/V5 neuron's receptive fields.

Additionally, we tested static contrast sensitivity in central and peripheral vision determining the minimum contrast required to detect the orientation of a diagonal Gabor patch (45° or 135° orientation). The characteristics of the Gabor patch were similar to those used for the motion contrast task: 3 cycles per degree, 250 msec of duration and a size truncated at ±3σ = 4.05°. To determine the threshold, we used a three-down, one-up staircase with six reversals. The initial Michelson contrast was 92%, decreasing logarithmically in step sizes of 0.5 for the first reversal, 0.3 for the second and 0.1 for the final four. Full details of the staircase thresholding strategies used for the motion tasks are described elsewhere.[30]

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows, version 26.0.0.0 (www.ibm.com/uk-en/products/spss-statistics) and figures were plotted using R Studio version 1.1.456[4] (www.rstudio.com). A repeated measures multi-factorial analysis of covariance (ANCOVA) was used (two light conditions: photopic-mesopic; two age groups: younger-older and two

eccentricities: central-peripheral). Values of photopic static contrast sensitivity in central vision were included as a covariate. In our data analysis we explored three-way interactions (light condition, age and eccentricity), two-way interactions (between light condition and eccentricity; light conditions and age and age and eccentricity) and the main effect of light levels. We transformed raw values into log values to allow the use of parametric statistical tests and also to be consistent in terms of units with our previously published work.[30] For the analysis, the level of statistical significance was $p<0.05$ unless specified otherwise. It should be noted that for the motion contrast task, five older individuals were unable to correctly judge the direction of motion for the highest available contrast of the task in peripheral mesopic vision. For data analysis purposes, these subjects were assigned the maximum contrast value (2 log units, or 100% contrast). In addition, for the biological motion task, one older subject could not correctly identify the direction of the point light walker even in the absence of noise dots in peripheral mesopic vision, hence their data was removed for analysis of data for this task only. As visual acuity and contrast sensitivity decrease with mesopic vision, we explored possible relationships between these two visual functions at mesopic levels and mesopic motion task performance. For this purpose, we conducted a correlational analysis. In the case of mesopic visual acuity, the data of one younger participant was not recorded, so this participant's data was removed from the correlational analysis. A Bonferroni correction was applied to the correlational analysis and to the post hoc t-tests to adjust the level of statistical significance for multiple comparisons. This correction was not applied to the ANCOVA.

Results

Participant characteristics are shown in Table 1, showing that as expected, visual acuity and contrast sensitivity were significantly reduced in older adults. Figure 1 illustrates the results for the motion perception tasks as a function of light level, eccentricity, and age group, whereas Table 2 shows the results of the ANCOVA. Only statistically significant main effects and interactions are reported (for full results, refer to Supplementary Table 1). After considering central photopic contrast sensitivity as a covariate, the only motion task that demonstrated a three-way interaction between light condition, age and eccentricity was translational global motion coherence [$F(1,67)=5.29$, $p=0.02$]. A post hoc analysis showed that this three-way interaction is mainly driven by the differences between thresholds of younger adults in central photopic vision and older adults' thresholds in mesopic conditions in central [$t(34)=-4.61$, $p<0.0001$] and peripheral vision [$t(34)=-4.71$, $p<0.0001$], as seen in Figure 1B.

Additionally, we found a significant two-way interaction between light condition and eccentricity for translational global motion coherence and biological motion. In the case of global motion coherence (Figure 1B), higher thresholds were found in central mesopic viewing relative to peripheral photopic thresholds [$F(1,67)=12.33$, $p=0.001$], while for biological motion (Figure 1C) higher thresholds were found in mesopic peripheral vision relative to the central photopic condition [$F(1,65)=16.54$, $p<0.001$]. We did not find a significant two-way interaction between light condition and age for any of the motion tests.

In terms of the main effect of light condition, mesopic conditions had a detrimental effect on three of the four motion tasks, with a significant effect of light condition on motion contrast [$F(1,67)=269.90$, $p<0.001$, Figure 1A], translational global motion coherence [$F(1,67)=12.99$, $p=0.001$, Figure 1B], and biological motion [$F(1,65)=474.32$, $p<0.001$, Figure 1C]. Mesopic light levels did not affect the duration thresholds for the high contrast Gabors (for either of the two target sizes, Figure 1D) nor the suppression index (Figure 1E).

Although the main focus of this paper was to explore the effects of light levels in the perception of motion, it is also worth noting that this experiment was able to replicate previous findings from our research group[30] with a different group of participants. Previously we have demonstrated that different motion tasks are not equally affected by ageing, with some tasks being more affected than others. Consistent with our previous work, we found that older adults had poorer performance than younger adults for motion contrast [$F(1,67)=30.17$, $p<0.001$] and for the biological motion task [$F(1,65)=4.50$, $p=0.04$]. However, global motion perception was robust to the effect of age. Additionally, we found a reduced suppression index for older adults in central vision compared to

younger observers, but higher suppression in the periphery [significant interaction between age and eccentricity for the suppression index: $F(1,67)=20.88$, $p<0.001$].

Table 1. Summary of participant's characteristics. Visual acuity and contrast sensitivity values are binocular. MMSE: Mini-Mental State Examination

	Younger		Older		
	Mean ±SD	**(Range)**	**Mean ±SD**	**(Range)**	**Difference**
Age (years)	24.9 ±2.70	(20, 31)	69.7 ±5.39	(60, 79)	t(34)=-30.62, p<0.001
MMSE score	30 ±0.51	(28, 30)	29 ±0.91	(27, 30)	t(34)=2.03, p = 0.05
Photopic best corrected visual acuity (logMAR)	-0.05 ±0.08	(-0.22, 0.02)	0.06 ±0.08	(-0.04, 0.20)	t(34)=-4.43, p<0.001
Photopic contrast sensitivity, central (Log_{10} %)	-0.35 ±0.35	(-0.82, 0.35)	0.15 ±0.32	(-0.26, 0.94)	t(34)=-4.48, p<0.001
Photopic contrast sensitivity, peripheral (Log_{10} %)	0.43 ±0.49	(-0.86, 1.38)	0.91 ±0.38	(0.37, 1.62)	t(34)=-3.31, p<0.01
Mesopic best corrected visual acuity (logMAR)†	0.40 ±0.20	(-0.04, 0.76)	0.70 ±0.15	(0.48, 1.00)	t(33)=-5.21, p<0.001
Mesopic contrast sensitivity, central (Log_{10} %)	0.57 ±0.27	(-0.20, 1.01)	1.03 ±0.36	(0.54, 1.53)	t(34)=-4.38, p<0.001
Mesopic contrast sensitivity, peripheral (Log_{10} %)	1.15 ±0.50	(0.38, 1.91)	1.54 ±0.50	(-0.13, 2.00)	t(34)=-2.40, p = 0.02

† Missing data for one younger participant.

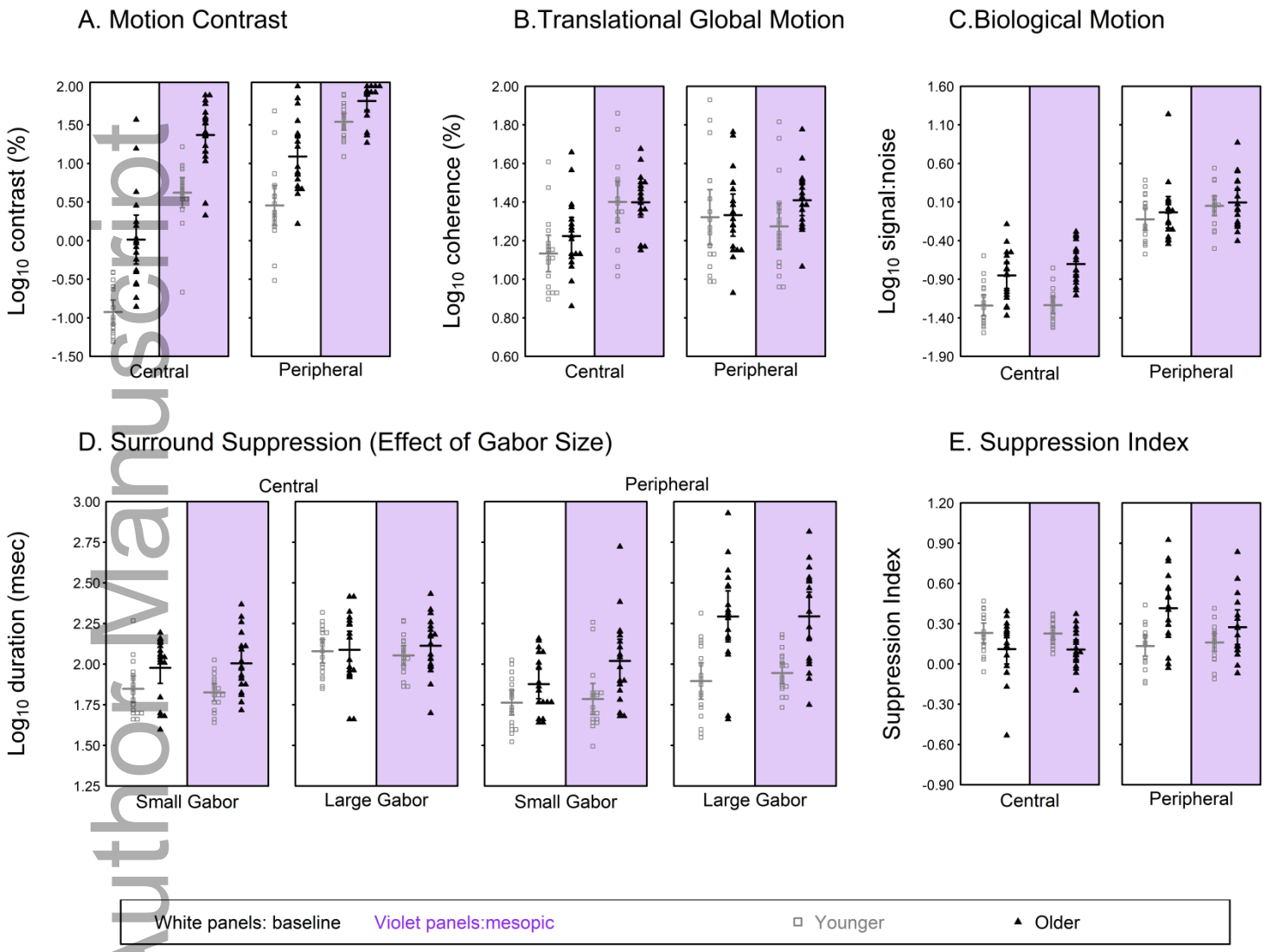

Figure 1. Results of motion tasks at photopic (white panels) and mesopic (violet panels) light levels. A) Motion contrast, B) Global motion coherence, C) Biological motion, D) Raw duration thresholds for the two Gabor sizes, E) Suppression Index. Grey squares: younger adults, black triangles: older adults.

Table 2. Significant results of the Analysis of Covariance (ANCOVA). df: degrees of freedom.

Effects of light conditions

Motion contrast	***df***	**F**	**p**
Condition	1,67	269.90	<0.001
Translational global motion			
Condition	1,67	12.99	0.001
Condition x Location	1,67	12.33	0.001
Condition x Age x Location	1,67	5.29	0.02
Biological motion			
Condition	1,65	474.32	<0.001
Condition x Contrast sensitivity	1,65	4.24	0.04
Condition x Location	1,65	16.54	<0.001

Effects of age and eccentricity

Motion Contrast	***df***	**F**	**p**
Age	1,67	30.17	<0.001
Location	1,67	44.61	<0.001
Age x Location	1,67	6.60	0.01
Biological motion			
Age	1,65	4.50	0.04
Location	1,65	35.64	<0.001
Suppression index			
Location	1,67	3.92	0.05
Age x Location	1,67	20.88	<0.001

As noted in the Introduction, it is well known that some low-level visual functions such as visual acuity and contrast sensitivity are impaired under low light levels. Thus, we explored whether mesopic visual acuity and contrast sensitivity were associated with the performance of motion tasks under mesopic conditions in central and peripheral vision (mesopic visual acuity was only measured centrally). The correlational analysis is shown in Table 2. After adjusting for 15 comparisons (adjusted p-value for significance <0.003), we found that in central vision the only significant correlations were for motion contrast and visual acuity and contrast sensitivity, and for biological motion and visual acuity. In peripheral vision, there were significant correlations between mesopic

contrast sensitivity and motion contrast, and the minimum stimulus duration for the larger and smaller Gabor.

Table 3. Pearson's correlation coefficients between motion tasks thresholds at mesopic levels and mesopic static contrast sensitivity and mesopic visual acuity in central vision, corrected for multiple comparisons.

Central vision

Task	Contrast sensitivity	p-value	Visual acuity	p-value
Motion contrast	0.61*	< 0.001	0.59*	< 0.001
Global motion coherence	0.10	0.57	0.04	0.83
Biological motion	0.37	0.03	0.50*	< 0.01
Duration threshold (small Gabor)	0.30	0.08	0.35	0.04
Duration threshold (large Gabor)	0.09	0.61	-0.07	0.71

Peripheral Vision

Task	Contrast sensitivity	p-value
Motion contrast	0.63*	<0.001
Global motion coherence	0.28	0.10
Biological motion	-0.08	0.67
Duration threshold (small Gabor)	0.53*	<0.001
Duration threshold (large Gabor)	0.55*	<0.001

**: significant correlations (p < 0.003)*

Discussion

Our study compared the perception of motion under photopic and mesopic light levels, being the first study to include the effects of participant age and retinal eccentricity. After comparing the thresholds of four motion tasks of different complexities under photopic and mesopic viewing conditions, we found that global motion coherence was the only task that demonstrated a three-

way interaction between light condition, age and eccentricity. For this task, both age groups exhibited an elevation of coherence thresholds in central vision under mesopic light levels relative to photopic, but in peripheral vision older adults had elevated coherence thresholds in mesopic vision relative to younger. Additionally, we found significant two-way interactions between light levels and eccentricity for translational global motion (higher thresholds at mesopic levels centrally) and for biological motion (higher thresholds at mesopic levels peripherally). We did not find a significant two-way interaction between age and light levels for any of the motion tasks. Mesopic light conditions also negatively impacted thresholds for motion contrast, translational global motion coherence and biological motion but not motion duration thresholds nor the related measure of motion spatial surround suppression.

We found that the translational global motion task was the only task where physiological ageing interacted with lighting level and eccentricity. In central vision, the increase in translational global motion coherence thresholds exhibited by both groups under mesopic levels may be caused by the change from the predominantly cone system to a combination of rods and cones. Previous research[50] has reported that at luminances of 0.43 cd/m^2 (similar to the 0.54 cd/m^2 used in this experiment), cone signals are predominant within a radius of 5° from the fovea, which represents a considerable proportion of the area stimulated by our 10° diameter RDK pattern. However, the contribution of rods at this eccentricity is still relevant. There is evidence that rods have a delayed response of about 50-70 msec relative to cones.[20,21] Furthermore, there is evidence that depending on light intensity, rod response can either be fast or slow.[51] The presence of slow signals from rods and fast signals from cones may create a conflict in the processing of the coherent RDK signals, regardless of age in central vision. A novel key finding from our experiment was that in peripheral vision, older adults had a deterioration in thresholds under mesopic vision, which was not evident in our younger adult group.

In the case of biological motion, we found that the signal to noise ratio required for correct identification of the point-light-walker increased under mesopic conditions (i.e., reduced sensitivity), and that this effect was more noticeable in peripheral vision for both age groups. The perception of biological motion is complex, requiring participants to integrate the perception of the object form and motion and to separate the point light walker signal from noise.[52] Our findings in central vision agree with a previous study[25] that demonstrated increased thresholds under mesopic conditions. Billino and colleagues[25] found that the perception of biological motion deteriorates under mesopic levels, and suggested that the presence of slower signals from rods and faster signals from cones could create conflicts in velocity perception of the point light walker. Burton and colleagues[26] reported that the elevation of biological motion thresholds is even more noticeable under light

levels lower than those used here (0.027 cd/m^2 versus 0.54 cd/m^2 in our study). With regards to peripheral vision, as far as we are aware this is the first time that the perception of biological motion has been compared under photopic and mesopic light levels. Biological motion thresholds at mesopic light levels were in part related to mesopic visual acuity and mesopic contrast sensitivity in central vision, which was not the case for peripheral vision, where the correlations were not significant. This finding may demonstrate that the greater deterioration of biological motion thresholds in peripheral vision at mesopic light levels may have additional causes that are not related to visual processing at a retinal level. For instance, our biological motion experimental paradigm required observers to separate the point light walker signal from noise dots, a task that previously has shown to be deficient in peripheral vision.[53] The high level of difficulty that people experience when extracting biological motion cues from noise in peripheral vision may possibly be explained by perceptual crowding of the object/form information in the point light walker[54].

Mesopic light levels negatively affected the thresholds for the motion contrast task regardless of age and eccentricity. It might be assumed that older adults would have worse performance for this task, as previous research has shown that static contrast sensitivity at low light levels deteriorates with increasing age.[4] However, we did not find an interaction between age and light levels. Of note is our finding that for our motion contrast task, several older adults could not determine the direction of motion of the Gabor at the highest contrast level in the periphery under mesopic conditions, despite having age-normal values of static contrast sensitivity under mesopic conditions at the same location. Notably, stimulus duration in this case was fixed at 250ms. When we measured the minimum stimulus duration for correct identification of the direction of motion using very similar Gabor stimuli, the same people were able to perform the task, but required the stimulus to be present for longer than 250ms to do so. As can be seen in Figure 1, some thresholds were higher than 300 msec. Our observations for these high contrast targets in the periphery may be highly relevant in an applied context such as night driving. Although our experiment did not measure reaction times, the fact that some older adults require long stimulus durations to correctly identify the direction of motion of high contrast objects in peripheral vision implies significantly delayed responses to potential hazards. These findings support those of our previous research,[30] where we also demonstrated elevated surround suppression of motion (leading to longer stimulus duration thresholds for high contrast stimuli) in the periphery for older adults under photopic conditions. Behaviourally, surround suppression of motion is thought to be related to object segmentation (the differentiation of an object from its background),[55] although its specific perceptual role in natural vision is still yet to be fully understood.

When interpreting the findings of this study there are some factors that should be considered. Because we tested adults who voluntarily joined our study, the older adults tended to be highly functional, with some having had previous experience in behavioural testing at our laboratory. Therefore, it is unlikely that our results are explained by difficulties understanding instructions or executing the task. In addition, as is necessary when testing visual performance under mesopic conditions, participants were required to sit in a dark room and dark adapt for a period of time which extends the period involved in the experiment. Observers also had to wear the neutral density filters and refractive correction during the duration of the experiment. However, to minimise any fatigue effects we provided participant with regular breaks, and the main experimenter accompanied participants during the dark adaptation period.

In summary, both age groups exhibited increased thresholds under low light levels for three of the four motion tasks: motion contrast, global motion coherence and biological motion. The mesopic deterioration of thresholds in central vision for motion contrast, global motion coherence and biological motion tasks, regardless of participant age, may imply that mesopic vision results in inaccuracies in encoding relevant signals for motion perception that originate from the retina. In peripheral vision, older adults require longer stimulus durations to identify correctly high contrast motion patterns either under photopic or mesopic light conditions. These findings may be relevant in the context of hazard avoidance and driving safety, as they imply the presence of specific deficits in detecting motion in stimuli that are otherwise readily visible.

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Figures and Tables - Legends

Table 1. Summary of participant's characteristics. Visual acuity and contrast sensitivity values are binocular.

Figure 1. Results of motion tasks at photopic (white panels) and mesopic (violet panels) light levels. A) Motion contrast, B) Global motion coherence, C) Biological motion, D) Raw duration thresholds for the two Gabor sizes, E) Suppression Index. Grey squares: younger adults, black triangles: older adults.

Table 2. Significant results of the Analysis of Covariance. df: degrees of freedom.

Table 3. Pearson's correlation coefficients between motion tasks thresholds at mesopic levels and mesopic static contrast sensitivity and mesopic visual acuity in central vision, corrected for multiple comparisons.

	Younger		Older		
	Mean ±SD	**(Range)**	**Mean ±SD**	**(Range)**	**Difference**
Age (years)	24.9 ±2.70	(20, 31)	69.7 ±5.39	(60, 79)	t(34)=-30.62, p<0.001
MMSE score	30 ±0.51	(28, 30)	29 ±0.91	(27, 30)	t(34)=2.03, p= 0.05
Photopic best corrected visual acuity (logMAR)	-0.05 ±0.08	(-0.22, 0.02)	0.06 ±0.08	(-0.04, 0.20)	t(34)=-4.43, p<0.001
Photopic contrast sensitivity, central (Log_{10} %)	-0.35 ±0.35	(-0.82, 0.35)	0.15 ±0.32	(-0.26, 0.94)	t(34)=-4.48, p<0.001
Photopic contrast sensitivity, peripheral (Log_{10} %)	0.43 ±0.49	(-0.86, 1.38)	0.91 ±0.38	(0.37, 1.62)	t(34)=-3.31, p<0.01
Mesopic best corrected visual acuity (logMAR)†	0.40 ±0.20	(-0.04, 0.76)	0.70 ±0.15	(0.48, 1.00)	t(33)=-5.21, p<0.001
Mesopic contrast sensitivity, central (Log_{10} %)	0.57 ±0.27	(-0.20, 1.01)	1.03 ±0.36	(0.54, 1.53)	t(34)=-4.38, p<0.001
Mesopic contrast sensitivity, peripheral (Log_{10} %)	1.15 ±0.50	(0.38, 1.91)	1.54 ±0.50	(-0.13, 2.00)	t(34)=-2.40, p=0.02

† Missing data for one younger participant.

Effects of light conditions

Motion contrast	***df***	**F**	**p**
Condition	1,67	269.90	<0.001
Translational global motion			
Condition	1,67	12.99	0.001
Condition x Location	1,67	12.33	0.001
Condition x Age x Location	1,67	5.29	0.02
Biological motion			
Condition	1,65	474.32	<0.001
Condition x Contrast sensitivity	1,65	4.24	0.04
Condition x Location	1,65	16.54	<0.001

Effects of age and eccentricity

Motion Contrast	***df***	**F**	**p**
Age	1,67	30.17	<0.001
Location	1,67	44.61	<0.001
Age x Location	1,67	6.60	0.01
Biological motion			
Age	1,65	4.50	0.04
Location	1,65	35.64	<0.001
Suppression index			
Location	1,67	3.92	0.05
Age x Location	1,67	20.88	<0.001

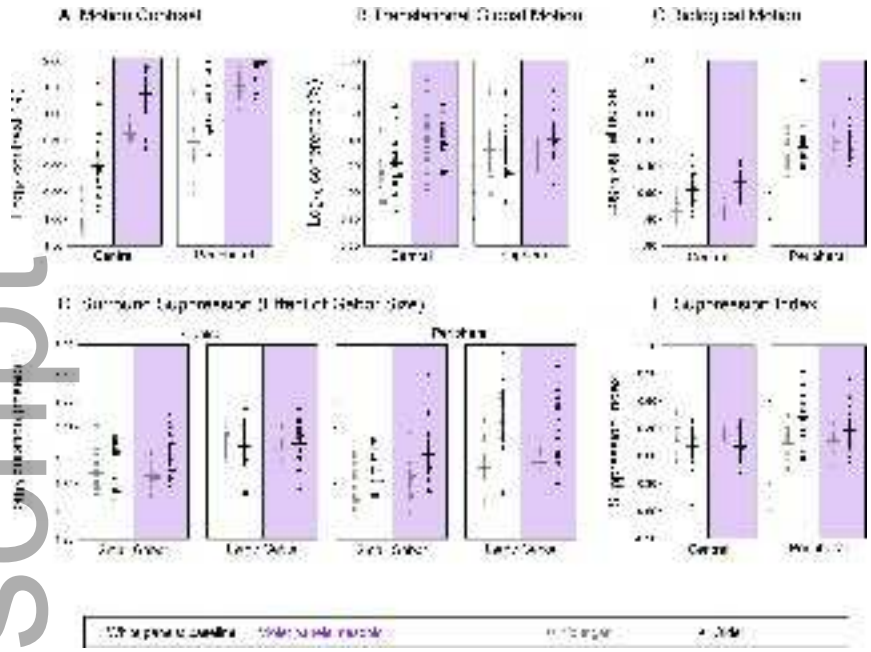
Central vision

Task	Contrast sensitivity	p-value	Visual acuity	p-value
Motion contrast	0.61*	< 0.001	0.59*	< 0.001
Global motion coherence	0.10	0.57	0.04	0.83
Biological motion	0.37	0.03	0.50*	< 0.01
Duration threshold (small Gabor)	0.30	0.08	0.35	0.04
Duration threshold (large Gabor)	0.09	0.61	-0.07	0.71

Peripheral Vision

Task	Contrast sensitivity	p-value
Motion contrast	0.63*	<0.001
Global motion coherence	0.28	0.10
Biological motion	-0.08	0.67
Duration threshold (small Gabor)	0.53*	<0.001
Duration threshold (large Gabor)	0.55*	<0.001

**: significant correlations (p < 0.003)*



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