Effect of an intervening screen on accommodation to a distant object

Lawrence R Stark BAppSc(Optom) (Hons) PhD
David A Atchison BScOptom MScOptom PhD GradCertEd FAAO
Centre for Eye Research, School of Optometry, Queensland University of Technology

Accepted for publication: 26 May 1998

Background: An intervening screen has been suggested to induce an inward shift of accommodation when viewing a distant object. This is an example of the Mandelbaum effect. However, there have been no objective measures of the magnitude of this effect in this particular situation.

Methods: Accommodation was recorded with an infra-red optometer, while subjects (n = 16) viewed a distant letter target with or without an intervening screen. Screens were placed near the individual dark focus distance or at 50 cm. In a second experiment the contrast of the distant target was varied and subjects (n = 5) viewed the target directly or through a screen placed near the individual dark focus distance.

Results: In the main experiment, the Mandelbaum effect was not significantly different from zero and was less than 0.5 D in every subject. In addition, accommodation was not more variable when viewing through the screen. However, it may be that some subjects do demonstrate a Mandelbaum effect while others do not. The individual dark focus level did not predict susceptibility to the Mandelbaum effect for a screen at the dark focus. Subjects reported their perceptions of the tasks and some noted changes in the perceived distances of objects when viewing through a screen. In the second experiment, the Mandelbaum effect (< 0.6 D) did not vary with distant target contrast.

Conclusions: When viewing a distant object through a screen there is a small (< 0.6 D) or negligible inward shift of accommodation.


Key words: accommodation, conflicting stimuli, contrast, Mandelbaum effect, motor vehicles, perceived distance

In his paper ‘An accommodation phenomenon’, Mandelbaum1 described the difficulty he had when trying to focus distant buildings through the window screen of his hospital room. This undesired shift in accommodation towards a conflicting object has since become known as the Mandelbaum effect. There are a number of common situations where it may occur. For example, when looking through a window there may be conflicting stimuli such as wire insect screens,1 venetian blinds and dirt and scratches on the glass pane. When driving a vehicle or piloting an aircraft there may be conflicting stimuli such as windshield pillars,2,3 water, dirt and scratches on the windshield4 which all have the potential to induce a Mandelbaum effect. In rural areas of Australia, some cars and off-road vehicles have a wire screen mounted in front of the windshield to protect against damage by stones. If the wire screen is mounted sufficiently close to the driver then it is likely, based on Mandelbaum’s findings,1 that both the screen and the entrapped insects could act as conflicting stimuli to accommodation. In the home, office and school, specular reflections in the screens of visual display terminals can act as conflicting stimuli to accommodation, although their effect on accommodation is negligible (less than 0.125 dioptres).5

Even though there have been many studies of the Mandelbaum effect6–11 there is little information on the likely magnitude of the effect in many natural viewing situations (Table 1). The largest effects have been reported when viewing in the
### The Mandelbaum effect

**Stark and Atchison**

**Table 1. Summary of the Mandelbaum effect in natural viewing conditions**

<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
<th>n\textsuperscript{a}</th>
<th>Mandelbaum effect (D)\textsuperscript{b}</th>
<th>Visual performance measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distant target viewed through screen</strong></td>
<td>Letter target viewed through screen</td>
<td>21</td>
<td>n.m.\textsuperscript{e} but likely $\leq 0.50$ D\textsuperscript{d}</td>
<td>6/6.7 letters unrecognisable</td>
</tr>
<tr>
<td>Mandelbaum (1960)\textsuperscript{1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roscoe, Couchman (1987)\textsuperscript{8}</td>
<td>Snellen chart viewed with or without screen</td>
<td>3</td>
<td>n.m.</td>
<td>VA poorer through screen, but this decrement smaller after voluntary accommodation training</td>
</tr>
<tr>
<td><strong>Aircraft &amp; vehicle windshield pillars</strong></td>
<td>Clear blue sky or same with narrow or wide aircraft window post</td>
<td>10\textsuperscript{e}</td>
<td>1.45 D (narrow post), 1.7 D (wide post)</td>
<td>n.m.</td>
</tr>
<tr>
<td>Roscoe, Hull (1982)\textsuperscript{2} Expt. 1</td>
<td>Simulated aircraft contrails\textsuperscript{1} on white Ganzfeld\textsuperscript{9} viewed past posts (of Expt. 1). Expt. 2: 10 young non-pilots. Expt. 4: 3 presbyopic certified pilots.</td>
<td>-</td>
<td>n.m</td>
<td>Expt. 2. Probability of detection lower with wider post. Expts 2 &amp; 4. Presbyopic subjects possibly had better detection thresholds than non-presbyopes</td>
</tr>
<tr>
<td>Roscoe, Hull (1982)\textsuperscript{2} Expts. 2, 4</td>
<td>Small discs on projected road scenes viewed directly or with intervening solid post or open post</td>
<td>30\textsuperscript{h}, 20\textsuperscript{h}</td>
<td>0.98 D (solid post), 0.13 D (open post)</td>
<td>Detection performance poorer with solid post versus no post or open post</td>
</tr>
<tr>
<td>Chong, Triggs (1989)\textsuperscript{3} Expt. 1</td>
<td>As per Expt. 1, except open post had variable width aperture</td>
<td>80</td>
<td>n.m.\textsuperscript{i} but accommodation more accurate with larger apertures</td>
<td>Detection better for largest aperture</td>
</tr>
<tr>
<td><strong>Vehicle windshields</strong></td>
<td>Distant sign, or same through windshield that was: clear; droplet covered; scratched.</td>
<td>9</td>
<td>-0.06 $\leq +0.08$ D</td>
<td>n.m.</td>
</tr>
<tr>
<td>Chauhan, Charman\textsuperscript{4}</td>
<td>Specular screen reflections imaged in monitor</td>
<td>6</td>
<td>Effects n.s. Largest effect $\leq 0.12$ D\textsuperscript{j}</td>
<td>n.m.</td>
</tr>
<tr>
<td><strong>Visual display terminals</strong></td>
<td>Specular screen reflections</td>
<td>6</td>
<td>Effects n.s. Largest effect $\leq 0.12$ D\textsuperscript{j}</td>
<td>n.m.</td>
</tr>
<tr>
<td>Collins et al. (1994)\textsuperscript{5}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\a number of subjects  
\b accommodation response to the conflicting stimulus configuration less accommodation response to the single object of regard. Values cited are group averages  
\c not measured  
\d based on Hirsch’s formula \(M = D^{0.663}/14.76\), where \(D\) is the denominator (in feet) of the Snellen uncorrected visual acuity (based on a numerator of 20 feet), and \(M\) is the calculated degree of myopia (D)  
\e non-pilots  
\f thin cloud-like trail left by an aircraft  
\g a blank featureless field  
\h two separate subject groups were used, 30 subjects for the detection measurements and 20 for the accommodation measurements  
\i a baseline condition without an intervening post was not included  
\j note that the screen reflection induces a negative Mandelbaum effect because the reflection is imaged behind the screen.

vicinity of aircraft and vehicle windshield pillars (Table 1). However, in most other situations the Mandelbaum effect is, on average, either small (in the order of 0.50 D) or negligible (Table 1). It should be noted that these group averages for the Mandelbaum effect may obscure the responses of a minority of individuals who suffer a larger effect than the group average.

Three studies have investigated accommodation responses to distant targets in the presence of intervening screens under natural viewing conditions.\textsuperscript{1,8,11} In two of these studies, accommodation responses were inferred rather than measured.\textsuperscript{1,8} Mandelbaum\textsuperscript{1} had subjects view a sign (6/6.7 Snellen equivalent letter size) at a distance of 78 metres from within a screen enclosed porch. At intermediate distances from the screen the letters
became unrecognisable. Although accommodation was not measured, it is possible to estimate the degree of myopic defocus using Hirsch’s formula $M = D^{\text{Snellen}} / 14.76$, where $D$ is the Snellen denominator in feet (for a 20-foot numerator) and $M$ is the degree of myopia. From this formula the degree of induced myopia would probably have been greater than 0.5 D. Roscoe and Couchman had subjects view Snellen charts at three, six or 12 metres through a screen placed at the individual dark focus distance or at 50 centimetres beyond the dark focus distance. Accommodation was not measured in this study, although changes in accommodation may be inferred from changes in visual acuity. Visual acuities were significantly lower with the screen in place than when viewing the letter chart directly. This decrement in acuity was smaller after subjects had participated in training to improve their negative voluntary accommodation. However, the difference between pre- and post-training acuity approached, but did not reach, statistical significance. Nevertheless, there was the suggestion that poor acuity through the screen could be due, in part, to the Mandelbaum effect.

In a recent conference abstract, Gleason and Kenyon described their investigation of the Mandelbaum effect. Using an objective optometer they were unable to find a significant Mandelbaum effect when subjects ($n = 5$) viewed a distant letter target through an intervening screen. Two studies have used Badal optical systems to present a letter matrix at a stimulus level of zero dioptries viewed through screens at closer stimulus distances. The Mandelbaum effect was less than about 1.25 D in these situations.

In summary, based on previous studies, it would appear that the Mandelbaum effect is either small or absent when viewing a distant target through a screen. Nevertheless, more research is needed before the Mandelbaum effect can be dismissed as unimportant in this particular situation. It may be that a minority of individuals do suffer a Mandelbaum effect but that group averages obscure these effects. Also, larger subject samples are needed to estimate better the range of Mandelbaum effect values that occur in various situations.

The most important two side-effects of the Mandelbaum effect are a reduction in visual acuity and an increase in detection thresholds (Table 1).

Nevertheless, there are no representative values to indicate the degree to which changes in visual acuity or visual performance are directly attributable to the Mandelbaum effect. Poorer performance may be due to other causes independent of accommodation. For example, a window post may reduce detection performance due to ‘edge effects’ or by monocular obscuration. A screen may reduce acuity by obscuring parts of the distant target letter target. However, there is some qualitative evidence that the Mandelbaum effect does reduce acuity. Mandelbaum found that an intervening screen led to blurring of a distant target in eyes treated with phenylephrine, but not in those that had been treated with cyclopentolate. Cyclopentolate paralyses accommodation, while phenylephrine leaves accommodation virtually intact, and so Mandelbaum’s finding is good evidence that inappropriate accommodation can lead to poorer acuity.

As discussed previously, Roscoe and Couchman found a small but insignificant improvement in visual acuity through a screen following training to improve negative voluntary accommodation. Finally, Roscoe and Hull found that presbyopic pilots performed better than younger non-pilots at detecting simulated contrails near a window post. A contrail is a thin cloud-like trail sometimes left by an aircraft. The presbyopic subjects may have performed better at the task because they had lower accommodative amplitudes and so were less susceptible to the Mandelbaum effect. However, this explanation is tentative because the older subjects were certified pilots and presumably were more practiced at performing this type of detection task than the non-pilots.

Another side-effect of the Mandelbaum effect is a change in size perception due to accommodation micropsia or macropsia. It has been speculated, although not demonstrated, that these misjudgments of size could lead to misjudgments of distance and thus could be a factor in vehicle collisions or aircraft landing mishaps.

It was once thought that the Mandelbaum effect induced by specular reflections in the screen of a visual display terminal could lead to asthenopia. However, the Mandelbaum effect is smaller than 0.125 D in this situation (Table 1) and probably would not account for asthenopic complaints.

In this present study we investigated the effect of an intervening screen on the accommodation response to a distant target. Accommodation was recorded objectively while subjects viewed either a distant letter target or the same distant target through an intervening screen. The Mandelbaum effect was small in this natural situation: the screen induced an inward shift in accommodation of no more than 0.6 D.

### METHODS

#### Subjects

Nineteen subjects participated in the study, of whom three were excluded from the analysis due to either spurious readings from the Autoref infra-red optometer (two subjects) or misinterpretation of the instructions (one subject). The 16 remaining subjects were aged between 16 and 39 years and had right eye subjective amplitudes of accommodation in the range 4.2 to 12.5 D. Visual acuities in the right eye ranged between 6/3 and 6/6-2. Right eye best sphere ocular refractive errors varied in the range -2.1 to +1.0 D and cylindrical components of the ocular refractive errors were less than or equal to 0.5 D. Of the 16 subjects, five had no previous experience in accommodation experiments, nine had some experience and two had extensive experience.

Subjects were optometry students of the Queensland University of Technology School of Optometry, academic and research staff of the school and members of the public. This study followed the tenets of the Declaration of Helsinki and was approved by the QUT Biomedical Ethics Committee. Informed consent to partici-
The Mandelbaum effect  

Stark and Atchison

A pate was obtained from each subject after the nature of the study had been explained.

Apparatus

Accommodation responses were measured with a Canon Autoref R-1 infra-red optometer. This optometer provides an open field of view so that targets may be presented in natural viewing situations. A calibration equation was obtained for the Autoref by measuring both subjective refraction and Autoref reading in a number of cyclopleged eyes (n = 3) in which various amounts of refractive error had been simulated using soft contact lenses. This calibration equation was later used to correct the raw Autoref readings.

The distant target was a block of nine black on white 6/60 Snellen equivalent Landolt Cs (Figure 1a), viewed at a distance of 3.8 m. The white background of the distant target had a luminance of 55 to 68 cd.m² and the letters had an estimated Michelson contrast of 58 per cent. As proximal accommodation is independent of target distance beyond three metres, a distance of 3.8 m was considered to be adequate to simulate natural conditions.

The screens used to test for the Mandelbaum effect were printed on transparent plastic sheets (Figure 1b). The screen consisted of black vertical and horizontal limbs that were three minutes of arc wide separated by six minutes of arc gaps. The screen pattern was five degrees square, and completely overlapped all the Landolt Cs of the distant target. The spacing of the limbs of the screen (six minutes of arc) was sufficiently small to prevent subjects adopting an eccentric position of gaze that might otherwise have reduced the effectiveness of the screen limb as a stimulus to accommodation. A number of individual screens were constructed to have equal angular dimensions when placed at diopteric distances between 0.5 D and 2.0 D in 0.25 D increments. Estimated Michelson screen contrasts were in the range 40 to 61 per cent.

Main study

Right eye monocular viewing was used throughout the experiment. Binocular viewing was not used because it would introduce the complicating factors of vergence and vergence-accommodation interactions. In addition, for an object with repetitive vertical detail such as the screen used in this study, there are many possible conflicting stimuli to the vergence system.

Subjects’ refractive errors were approximately corrected with ophthalmic trial lenses. Cylindrical components of 0.25 DC were usually not corrected and cylindrical components of two subjects with 0.50 DC were inadvertently left uncorrected. Pre-task measurements of the subject’s dark focus were made first. The subject sat in the completely darkened experimental room (3.8 m long) for five minutes to allow any possible accommodative adaptation effects to subside.

While the room was still dark, the subject was instructed to ‘look straight ahead at
The end of the room’ and several readings of accommodation were made with the Autorefr optometer. The experimenter monitored eye position using the Autorefr’s infra-red alignment system.14

Accommodation responses were measured under three different stimulus conditions, presented in counterbalanced order for a total of two trials of each condition. The subject was instructed:18 ‘You must keep your head very still while measurements are being taken. You should look at the middle C on the wall and view it naturally, the same as you would when normally reading a book or sign at the same distance’. The three conditions were:

1. Distant target condition. The subject viewed a block of 6/60 Landolt Cs at a distance of 3.8 m.
2. Mandelbaum effect condition with screen close to the dark focus. The subject viewed the same Landolt Cs but through a screen superimposed close to the estimated individual dark focus value. 
3. Mandelbaum effect condition with screen at 50 cm. The subject viewed the same Landolt Cs but through a screen superimposed at 50 cm.

A screen placed at the individual dark focus possibly induces the greatest Mandelbaum effect.7 A fixed distance of 50 cm was also included and is representative of the distance between a car windshield and the driver’s eye.4

Twenty readings of accommodation were taken with the Autorefr at each trial. Pupil diameters in the study varied in the range 3.5 to 7.6 millimetres. At the end of each trial, the subject was asked the following questions:

1. ‘How did the target appear? Was it blurred or clear?’
2. ‘What were you trying to do while looking at the target?’

The subject’s post-task dark focus was measured at the end of the experimental session.

Experiment 2. Effect of contrast
An analysis of data from the main experiment demonstrated that the average Mandelbaum effect in the group was not significantly different from zero (see Results). One possible explanation of this finding is that the letter C target provided a much better stimulus to accommodation than the intervening screen. This explanation seemed unlikely given the design, contrast and spatial frequency content of the screen. Nevertheless, in this second experiment we reduced the contrast of the distant C target to induce a greater Mandelbaum effect. Accommodation is poorer at low contrast19 and thus a greater inward shift of accommodation would be expected with a low contrast distant target. If the screen is of low contrast then accommodation is more accurate for the distant target.7

The experimental design and stimuli were similar to the main study. Instead of one high contrast distance target (block of Landolt Cs), the C target was made in contrasts of zero, five, 16 and 68 per cent. Contrast of zero per cent corresponds to a blank sheet with no letters. The block

![Figure 2. Median accommodation responses of subject B. The screens were placed (a) close to the individual dark focus level or (b) at a 50 cm distance. Error bars denote the total range of response values for this subject. Key: C target (C), Screen (S), Trial 1 (1), Trial 2 (2), Dark focus (DF)](image)
The Mandelbaum effect

Stark and Atchison

of nine Landolt Cs was centred on a white background that was 9.6 degrees square. The screens were identical to those in the main study (Figure 1b). Screens were presented only at the individual dark focus level and not at 50 cm. Ten readings of accommodation were taken with the Autoref at each trial.

Five subjects aged between 16 and 39 years participated in the study. Subjects had right eye subjective amplitudes of accommodation in the range 4.2 to 9.5 D. Right eye visual acuities ranged between 6/3.8 and 6/6. Best sphere ocular refractive errors in the right eye ranged between -1.9 D and +0.5 D, and cylindrical components of the ocular refractive errors were less than or equal to 0.50 D. Three of the subjects had participated in the main experiment between 35 and 84 days previously. These three subjects exhibited the largest, fourth largest and 11th largest values for the average Mandelbaum effect in the main study. The two other subjects had no previous experience in accommodation studies.

Analysis

Spectacle refractions were converted to ocular refractions and actual accommodative stimuli and responses were calculated taking into account the subject’s ocular refraction, the trial lenses in place and the lens vertex distance. As a measure of the Mandelbaum effect (ME), the median response when viewing the C target alone (AR_C) was subtracted from the median response when viewing the C target with screen interposed (AR_C+S), that is, ME = AR_C+S - AR_C. The median response from each trial was used because data in some trials appeared skewed and so might have biased a calculated mean response.

RESULTS

Most subjects demonstrated little or no Mandelbaum effect, although two subjects’ responses will serve to illustrate the small differences between subjects that were observed (Figures 2 and 3). It is important to note that small negative values of accommodation in Figures 2 and 3 are due to the use of a ‘one-fits-all’ calibration equation for the Autoref optometer. However, comparisons between conditions will still be valid.

Subject B demonstrated the largest Mandelbaum effect in the main study (Figure 2). In the first trial a screen placed near her dark focus induced an inward shift of accommodation of 0.45 D. The Mandelbaum effect was smaller when the screen was placed at 50 cm. In contrast, subject H appeared to accommodate more distally when viewing the distant letter target through the screens (Figure 3). He was possibly using voluntary accommodation to obtain a more distal focus. When looking through the screen he described his actions as focusing on the C target and looking at the C target.

The Mandelbaum effect did not vary greatly between subjects and in the group was not significantly different from zero (Figure 4). An analysis of variance revealed the following:

![Figure 3. Median accommodation responses of subject H. The screens were placed (a) close to the individual dark focus level or (b) at a 50 cm distance. Error bars denote the total range of response values for this subject.
Key: C target (C), Screen (S), Trial 1 (1), Trial 2 (2), Dark focus (DF)]
1. No significant difference between data collected in trial 1 and trial 2 ($F_{1,15} = 0.04, p = 0.84$).

2. No significant difference between responses in the three viewing conditions (C target, C target with screen near dark focus, C target with screen at 50 cm), ($F_{2,30} = 1.33, p = 0.28$).

3. No significant interaction between trial number and viewing condition ($F_{2,30} = 1.38, p = 0.27$).

The mean accommodative stimuli were as follows:

1. distant target, +0.24 D (range -0.16 to +0.60 D)
2. screen placed near the dark focus, +0.95 D (range +0.07 to +1.83 D)
3. screen at 50 cm, +1.91 D (range +1.45 to +2.29 D).

Mean pre- and post-task dark focus levels were +0.72 D (range -0.12 to +1.84 D) and +0.48 D (range -0.28 to +1.47 D) respectively.

In a study by Chauhan and Charman,\textsuperscript{4} it appeared that subjects with high dark focus levels exhibited larger inward shifts of accommodation to a scratched or droplet covered car windshield. In this present study, we used principal axis regression\textsuperscript{10} to determine if subjects with high dark focus levels also demonstrated the largest Mandelbaum effects. Data from trials 1 and 2 were averaged for the analysis and the average of pre- and post-task dark focus values was used. For both the screen placed near the dark focus and for the screen at 50 cm the slopes of the regression lines were not significantly different from zero, indicating the absence of a significant correlation between dark focus (DF) and Mandelbaum effect (ME). (Principal axis regression. Screen near dark focus: $ME = 0.096DF - 0.02; r^2 = 0.09; 95$ per cent confidence interval for slope, -0.076 to +0.273. Screen at 50 cm: $ME = 0.011DF + 0.03; r^2 = 0.004; 95$ per cent confidence interval for slope, -0.094 to +0.116.)

The range of accommodation values recorded for each condition and subject was used as a measure of accommodation variability. Differences between conditions were tested with the non-parametric Fried- man test.\textsuperscript{21} Ties in the data were broken...
The Mandelbaum effect
Stark and Atchison

The largest Mandelbaum effect recorded in any condition was +0.57 D. The mean accommodative stimuli for the distant target and the screen placed near the dark focus were +0.21 D (range +0.04 to +0.35 D) and +0.87 D (range +0.56 to +1.33 D) respectively. Mean pre- and post-task dark focus levels were +0.80 D (range +0.13 to +1.39 D) and +0.47 D (range -0.03 to +0.90 D) respectively.

An alternative analysis is to compare the responses to the various C target–screen combinations using the response to the high contrast (68 per cent) C target as a baseline. This analysis demonstrates whether the combination of screen and low contrast distance target lead to any significant defocus compared to that for a high contrast distance target viewed directly. Using t-tests following analysis of variance, responses to the screen plus 68 per cent contrast C target and to the screen plus 16 per cent contrast C target were significantly different from baseline at the 0.05 significance level. Responses for the other two target contrasts (screen plus five per cent contrast C target, screen plus zero per cent contrast C target) were significant at the more stringent Bonferroni corrected significance level of 0.0125 (that is, 0.05/4 tests).

**DISCUSSION**

The average Mandelbaum effect in the main study was not significantly different from zero, and individual values never exceeded +0.45 D (Figure 4). Thus the average Mandelbaum effect appears to be negligible (less than 0.12 D) when viewing a distant target through a screen. In contrast, the average Mandelbaum effect in a similar previous study was probably 0.50 D or greater (Table 1). A cause for this difference is uncertain. In this present study it may be argued that the Mandelbaum effect was low because the distant target provided a much better stimulus to accommodation than the screen. However, the results of the contrast experiment show that the Mandelbaum effect did not increase for low target contrasts, even when the contrast of the distant target was reduced to zero per cent (Figure 6). Thus,

<table>
<thead>
<tr>
<th>Subject observation</th>
<th>Proportion subjects (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Target</td>
<td>C and Screen</td>
</tr>
</tbody>
</table>

I. Changes in perceived size and distance
1. Screen on top of C and both at the same distance.
   This distance:
   a. unspecified 1
   b. further than actual distance of C 1
   c. between actual distances of C and Screen 1
   d. closer than actual distance of Screen 1
2. C closer than screen 1
3. C closer than screen and vice versa alternately 1

II. Target clarity
4. C clear (or reasonably so) 14 10
5. C intermittently blurred 4 11
6. C blurred 2 7
7. Screen clear (or reasonably so) 0
8. Screen intermittently blurred 4
9. Screen blurred 3

III. Other observations
10. Fading of target 2 2

Subjects could report more than one observation per condition, so the columns do not necessarily sum to 16.

by adding a small random number (in the range ± 0.5 x 10^-5 D) to each datum point. The responses when viewing two conflicting stimuli were not significantly more variable than when viewing a single distant target (Pairwise comparisons following Friedman test. Critical value of test statistic at p = 0.05 was ± 0.865. Screen near dark focus: trial 1, Ψ = -0.06; trial 2, Ψ = -0.31. Screen at 50 cm: trial 1, Ψ = -0.5; trial 2, Ψ = +0.13). These results have been plotted in Figure 5.

Subjects’ responses to the question ‘How did the target appear? Was it blurred or clear?’ are summarised in Table 2. Subjects’ responses to the question ‘What were you trying to do while looking at the target?’ are summarised in Table 3.

**Effect of contrast**

An analysis of variance was performed to determine if the Mandelbaum effect increased for low contrast distant targets. Respective responses from trials 1 and 2 were averaged and the resultant averages used in the analysis. Overall there was a significant Mandelbaum effect (F = 11.6, p = 0.027) and the accommodation response tended to increase for lower target contrasts (F = 4.68, p = 0.022). The interaction between target contrast and Mandelbaum effect was not significant (F = 0.29, p = 0.83), indicating that the Mandelbaum effect did not increase with low contrast distant targets. These effects are demonstrated in Figure 6. For low contrast distant targets, there was an inward shift of accommodation regardless of whether the target was viewed directly or through the screen (Figure 6), but the Mandelbaum effect was roughly constant regardless of distant target contrast. The mean Mandelbaum effect values for 68 per cent, 16 per cent, five per cent and zero per cent distant targets were +0.15 D, +0.12 D, +0.21 D and +0.16 D respectively.

Clinical and Experimental Optometry 81.3 May–June 1998
the spatial detail and contrast of the letter target and screen are unlikely to have caused the small Mandelbaum effect values found in the main study.

**Between- and within-subject variability**

Although the Mandelbaum effect was not significant in the main group, this may not be true for all subjects on all occasions due to between-subject and within-subject variability, respectively. It is possible that some members of the main group did suffer from a Mandelbaum effect, but that group averaging obscured these between-subject differences. To test this hypothesis it would require that subjects be examined on a number of different days using single-subject experimental designs. It would then be possible to determine whether a particular subject is susceptible to the Mandelbaum effect. Some qualitative support for the hypothesis is provided by the contrast experiment, where a smaller group of five subjects did happen to demonstrate a significant Mandelbaum effect. In this group, the average Mandelbaum effect was still only +0.15 D for a high-contrast distant target.

At present, there are few explanations for why some subjects would be more susceptible to the Mandelbaum effect than others. Some subjects perform better after they have had practice at viewing conflicting targets. This practice effect could be due to initial unfamiliarity with the optical apparatus. There are some suggestions that voluntary accommodation may play a role in the Mandelbaum effect. For example, subjects state that they must make a continual ‘effort’ when viewing a distant target through the screen. This ‘effort’ could either be an effort aimed at directing attention to the distant target or it could be an active negative voluntary accommodation.

The individual resting level of accommodation may play a role in the Mandelbaum effect. Intervening screens tend to induce the greatest Mandelbaum effect at an intermediate distance, and there is some evidence that this distance is correlated with the individual dark focus level. Also, the response to a conflicting stimulus...
The Mandelbaum effect  Stark and Atchison

lus pair tends to be correlated with the individual dark focus level, if the subject is not instructed to attend to any particular target.\textsuperscript{10} In this study, we tested whether the individual dark focus explains some of the variability in Mandelbaum effect values. Dark focus and Mandelbaum effect were not significantly correlated for a screen placed near the individual dark focus distance nor for a screen placed at 50 cm. Thus, if the screen is placed near the dark focus or at around 50 cm, people with high dark focus levels are not more susceptible to the Mandelbaum effect than those with low dark focus levels. Of course, this does not imply that the Mandelbaum effect for a particular subject does not vary with screen distance, as found in previous studies.\textsuperscript{1,6,7} However, it might be reasonable to argue that there should have been a correlation between dark focus and the Mandelbaum effect for a 50 cm screen distance. If it can be assumed that the Mandelbaum effect is greatest at the individual dark focus, then subjects with dark focus values close to 50 cm should have shown the greatest Mandelbaum effects, while those with higher or lower dark focus values should have shown reduced effects. Testing for such curvilinear trends in the data was not possible because no subject in the study had a dark focus distance closer than 50 cm. Thus, our present analysis for the 50 cm screen distance is limited by a lack of subjects with very proximal dark focus levels.

Within-subject variability in the Mandelbaum effect can be obscured by averaging readings within a trial. Thus, the subject who occasionally finds herself focusing to the intervening screen may not demonstrate an average Mandelbaum effect if for most of the time she can focus to the distant target. Accordingly, we investigated if responses were more variable when viewing through a screen. For the group as a whole, the response to the distant target was just as variable whether viewed directly or through the screen (Figure 5). This finding was similar to previous reports.\textsuperscript{8,10} However, the variability measures in this present study are somewhat limited due to the slow and irregular frequency at which the response was sampled, typically one reading per five to 10 seconds. Even if the sample frequency had been regular, oscillations in the accommodation response at temporal frequencies greater than about 0.05 to 0.1 Hz would not have been resolved. (Temporal frequencies in a sample cannot be resolved if they are greater than half the sampling frequency.)\textsuperscript{24} In situations such as driving a car or piloting an aircraft, transient fluctuations of accommodation may be important when viewing objects such as flashing lights or when performing a fine task such as detecting another aircraft against a background of sky. If there is some blurring just when the eye is directed at the object, the object may not be detected so easily.

Target contrast and the Mandelbaum effect
The results of the contrast experiment may have applications to situations such as driving and flying where there can be low-contrast distant objects, for example, poorly lit objects at night or objects viewed through cloud or fog. In this study, there was an inward shift of accommodation for low-contrast distant targets regardless of whether the target was viewed directly or through a screen (Figure 6). The Mandelbaum effect did not change with contrast. Thus the normal inward shift of accommodation that occurs under degraded stimulus conditions is compounded by a small Mandelbaum effect when a screen is present (Figure 6). Even so, the findings of this study are applicable only to situations where there is a low contrast distant target viewed through an intervening screen.

Perceived distance through a screen
Several subjects noticed that the distant letter target and the screen sometimes appeared to lie at the same distance. There are a few possible explanations for these observations. When a real distant scene is viewed through a window frame there is a perceptual flattening of the scene.\textsuperscript{25} In our study, the screen may have made the scene appear flatter. Alternately, some of the observed changes in perceived target distance may relate to Gestalt figure-ground relationships. Sometimes when a subject focused accurately for the distant target, the screen became very blurred appearing as a ‘background colour’. To these subjects the screen may have appeared as a ground on which the figure, the C target, rested. These observations of perceptual flattening raise the issue of whether wire screens on vehicles could lead to a perceptual flattening of the road scene and, consequently, an increased risk of collision. These observations also suggest that the Mandelbaum effect could be due, in part, to inappropriate proximal cues.

Wire screens on vehicles
It is not uncommon in Australia for vehicles to have a wire screen mounted in front of the windshield to protect against damage by flying stones. One type of screen commonly used on forward cab trucks is about 30 to 35 cm deep and is mounted at the bottom and a little in front of the regular windshield. We suspect that the driver would look through the screen only when manoeuvring at low speed and so any effects on accommodation would not be critical. A second type of wire screen is available for cars and is rarely seen in urban areas. These screens cover the entire field of view of the regular windshield and are mounted about 10 to 20 cm in front of the windshield. With several reservations, the findings of the present study suggest that this type of design would probably not induce a Mandelbaum effect in most drivers, but possibly a small effect (less than 0.5 D) in some. Further research on wire screens would need to address factors such as screen type and wire spacing, viewing distance, obstructions to the visual field caused by insects trapped in the screen, relative lateral motion of driver and screen when the vehicle is in motion, binocular viewing and viewing time.

Implications for visual performance
For high contrast letter targets, the Mandelbaum effect induced by a screen
is of a similar order or less than the depth of focus over a wide range of letter and pupil sizes. The depth of focus for a high contrast 6/45 Snellen equivalent letter (similar to the 6/60 letters in this present study) and for a six-millimetre pupil is about ±0.35 D. In the present main study, only three of the 16 subjects experienced a Mandelbaum effect greater than ±0.35 D in any of the various conditions. Assuming that subjects accommodated accurately for the distant target, this suggests that the Mandelbaum effect should have been imperceptible to most subjects. In contrast, it appears that subjects tended to report target blur more frequently when viewing through the screen (Table 2).

There is also good qualitative support for an influence of the Mandelbaum effect on visual acuity provided by a previous study. These contradictions suggest the need for further research.

Contrast sensitivity for small letters (6/7.5) can be influenced by small amounts of defocus: decrements of approximately 0.2 and 0.5 log units have been reported for defocus levels of +0.25 DS and +0.50 DS respectively. The effects of small amounts of defocus on increment thresholds is uncertain. Some studies have found small decrements in sensitivity of approximately 0.12 to 0.15 log units with +1.00 DS of defocus and when using 26 minutes of arc test spots within the central visual field (30 degrees or less). However, these studies were performed under cycloplegia and the resultant dilated pupils may not be representative of everyday viewing conditions. One study with natural pupils and a background luminance of 10 cd.m⁻² found for a single subject a decrement in sensitivity of approximately 0.2 log units with ±1.00 DS of defocus for test spots smaller than 26 minutes of arc presented in the central field (5 degrees to 20 degrees).

In summary, the influence of the Mandelbaum effect on increment thresholds is likely to be small or negligible and limited to small targets (26 minutes of arc or less) in the central visual field (30 degrees or less).

CONCLUSIONS

When viewing a distant object through a screen, there is a small (less than 0.6 D) or negligible inward shift of accommodation. It is possible that a minority of subjects demonstrate a small Mandelbaum effect, but that the majority do not. Accommodation is not more variable when viewing through a screen. Individual dark focus level does not predict susceptibility to the Mandelbaum effect for a screen at the dark focus. Subject reports of perceptual flattening through screens may have implications for distance perception through these screens. Finally, the Mandelbaum effect (less than 0.6 D) does not vary with distant target contrast.

ACKNOWLEDGEMENTS

We thank Graham R Stark for his investigations on vehicle and truck screens.

This research was supported by an Australian Postgraduate Research Award to LR Stark from the Commonwealth Department of Employment, Education and Training.

This material was presented at the Fifth Scientific Meeting in Optometry, Melbourne, Australia, 5–6 July 1993.

Neither of the authors has any proprietary interest in any aspect of this research.

REFERENCES

24. Pugh JR, Edie AS, Winn B, Heron G. Power


Author’s address:
Lawrence Stark
College of Optometry
State University of New York
100 East 24th St
New York
New York 10010
USA