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Dong, M., Fotios, S. and Lin, Y. (2015) The influence of luminance, observation duration and procedure on the recognition of pedestrians faces. Lighting Research and Technology, 47 (6). 693 - 704. ISSN 1477-1535

https://doi.org/10.1177/1477153514539781

The Influence of Observation Duration and Procedure on Luminance Required for Recognition of Pedestrian' Faces

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Abstract

Past studies carried out to determine whether the spectral power distribution (SPD) of a lamp affects facial recognition led to mixed results, and one reason for this could be that different studies presented different levels of task difficulty, this being a function of target size, observation duration and type of procedure. This article presents two facial recognition experiments carried out using matching and identification procedures to explore task difficulty as defined by observation duration and target luminance. It was confirmed that identification is more difficult than matching. A relationship between task difficulty (luminance and duration) and recognition probability was found and this allows the luminance to be determined for a given probability.

1. Introduction

An important role of road lighting is to facilitate the visual appraisal of other people, to be able to identify their attitude and expression (e.g. friendly, indifferent or aggressive) at sufficient distance that an alert subject can take evasive or defensive action if necessary. This article concerns recognition of identity from observation of the face (facial recognition).

Several studies have been carried out to determine whether the spectral power distribution (SPD) of a lamp affects facial recognition: the work of Yip and Sinha[1] suggests that colour cues can play a role in facial recognition and thus that an effect of SPD is expected. These studies used different methods and led to mixed results: in four[2-5] it was reported that facial recognition was affected by the lamp SPD, although evidence of statistical significance was not presented in all reports, while three further studies[6-8] reported that SPD did not affect facial recognition.

These mixed conclusions are likely the result of variations in experimental method.[9] Research carried out to investigate methodology concluded that an effect of SPD is expected when the task is difficult, with task difficulty being a factor of target size, observation duration and the procedure used.[10] The task difficulty proposal is supported by experiments carried out by Fotios et al[11] who found that luminance exhibits a plateau-escarpment relationship[12] with performance of a facial expression recognition task. The results suggest an effect of SPD is possible in the escarpment region but not within the plateau region.

Consider the duration of observation on a target face; past studies of lighting and facial recognition[2-8] have tended to encourage continuous observation of the target face, other than Lin and Fotios[10] who used two limited observation durations (1 s and 3 s). Studies in the wider field have also tended to use limited observation duration, such as Johnston et al[13] who used durations of 750 ms and 2,000 ms, and Harries et al[14] who used a duration of 1,000 ms. Eye tracking studies suggest that fixation on other pedestrians tends to be for less than 1 s, typically around 500 ms for unfamiliar people[15, 16] so the continuous observation used in many studies may not be realistic for pedestrians in natural settings. If a shorter duration presents a more difficult task this may influence conclusions drawn regarding optimum lighting characteristics.

Two procedures commonly used in past facial recognition studies are identification and matching.[17] Identification requires test participants to state the name of a target person, this usually being the photograph of a celebrity such as a well-known actor, singer or athlete[2, 3, 5, 10]. In the matching procedure, test participants are required to match a target person with one of a small sample of faces in a reference set: while the reference set is usually a series of photographs, the targets can be real people[7, 8] or images.

Lin and Fotios[10] suggested the identification procedure to be more difficult than matching. Identification requires recollection of the name of a celebrity: however, whilst they need to be well-known, they appear unexpectedly and are thus unfamiliar at the moment of observation. One reason that the matching task is easier is that prior inspection of the reference set raises familiarity with the faces and there is some evidence for this in the study by Persike et al[18] who found that familiar faces were found more quickly than unfamiliar faces in a search task.

The results of past studies provide evidence that these two procedures present different levels of difficulty. Two studies using matching found mean recognition distances ranging from 12 metres[7] to 24.9 metres.[8] In contrast, three studies using an identification procedure report mean recognition distances in the range of 5.4 metres to 8.45 metres[2, 3, 5]: the shorter distance (and hence larger visual size) suggesting the identification procedure to be more difficult.

The aim of this article is to explore task difficulty in the facial recognition task, with task difficulty varied as five levels of observation duration (0.1 to 10 s), three luminances (0.1 to 10 cd/m^2) and two procedures (matching and identification). These results will enable a better understanding of why past studies led to mixed results.

Distance between the observer and target pedestrian is also likely to matter, with a greater distance leading to a smaller size subtended at the observer's eye and thus a more difficult task. Rombauts et al[19] demonstrated that more light (in their case, a higher semi-cylindrical illuminance) is needed at greater distances. In past studies interpersonal distances were somewhat arbitrary, being either a series of fixed distances with a trial at each,[6] or that distance found when the participant indicated recognition in a stop-distance procedure.[2] Neither approach considered the difference at which it might be desirable to make an interpersonal judgement. Investigation of this desirable distance using data from eye tracking and perceived comfort suggested a distance of 15 m[16, 20] although this requires validation. The current article does not explore the effect of distance but simulates a distance of 10 m in all trials, this being the distance suggested by van Bommel and Caminada[21] to be ideal for facial recognition.

2. Experiment 1: Matching

2.1 Method

An experiment was carried out to investigate the influence of luminance and observation duration on facial recognition using a matching procedure similar to that used by Boyce and Rea[8] and Rea et al[7] except with trials at a fixed distance rather than using stop-distance. The apparatus, shown in Figure 1, consisted of two display screens, display screen 1 which presented target images and display screen 2 which presented reference images. Display screen 1 was a self-luminous screens (EIZO Color Edge CG241W, 24.1 inch display, resolution 1920 pixels × 1200 pixels). Display screen 2 was an iPad, which is also a self-luminous screen (9.7 inch display, resolution 1024 pixels × 768 pixels).

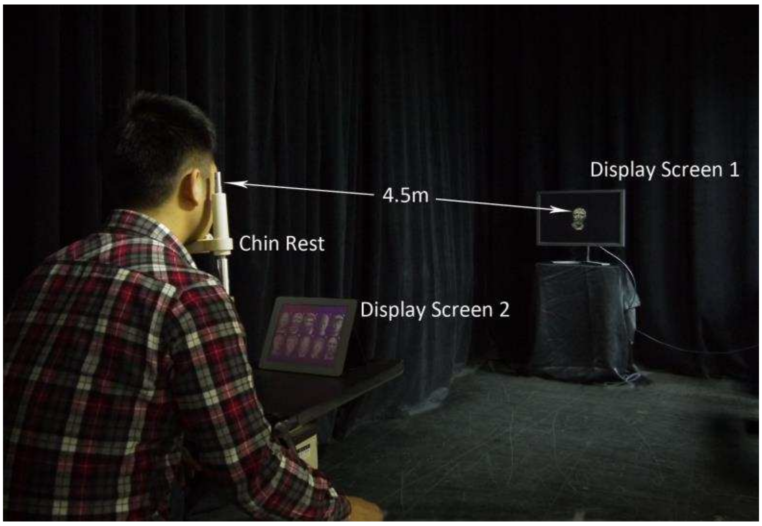

Figure 1. View of the test laboratory.
Note 1: During an experiment the room lighting was not switched on.
Note 2: Display screen 2 was not used in experiment 2.

The target images were 16 photographs of sculptures of human faces (Figure 2). These faces were not known to test participants and this was confirmed at the start of each test. The images were obtained from internet sources and subsequently the backgrounds were digitally modified so that all were black. When presented on display screen 1 the target images were approximately 90 mm in height, and this was observed at a distance of 4.5 m as maintained using a chin rest. For a typical face height of 200 mm (underside of chin to top of head) this simulates an equivalent distance of approximately 10 m.

For trials with a particular test participant, eight photographs were selected at random from the set of 16 and used as target images, presented individually on display screen 1. Display screen 2 presented ten reference images, these being seven from the eight target images and three further images chosen from those remaining in the set. Hence, three of the reference images did not appear as targets, and for one target image there was no match in the reference set. Harries et al[14] also used distractor faces in their study, their task being to report whether the observed face was familiar or novel, but distractors were not used in past matching studies.[7, 8]

Figure 2. The faces used as targets in experiment 1.

The five durations used were 0.1, 0.3, 1.0, 3.0 and 10 s, these presenting regular intervals on a logarithmic scale. The trials were carried out at three luminances, 0.1, 1.0 and 10.0 cd/m^2, chosen to cover the illumination levels typical of road lighting. These luminances were the average value over the whole area of the face, measured using an image-based luminance meter (Everfine CX-2B). In trials there was no ambient lighting in the room: illumination was provided only from the display screens, and hence adjustment of display screen 1 was used to vary target luminance. Display screen 2 was set to a low brightness, a luminance of 0.5 cd/m^2. Target images were presented on display screen 1 using Microsoft Office PowerPoint. A bespoke order of presentation was prepared for every test participant, thus to balance the presentation order of luminance, duration, and target face.

38 test participants were recruited from staff and students of Fudan University: 20 were female and 18 were male, and of approximate mean age 22 years. All test participants had normal (or corrected to normal) visual acuity as tested using a Snellen E chart. Normal colour vision was confirmed using the Ishihara Pseudoisochromatic Plates.

At the start of each test session, 20 minutes was allowed for adaptation to the low light level. Test participants were seated with their eye's positioned 4.5 m perpendicularly in front of display screen 1 and instructed to look at display screen 1. A target image was presented, following which they were required to identify the target from among the reference images presented on display screen 2. The experimenter recorded this response. Prior to presentation of the next target image, the experimenter instructed the participant to observe again display screen 1, which presented a blank (black) screen between successive target images. Every participant carried out 15 trials, one trial per combination of the five exposure durations and three luminances, and hence each of the eight target images was observed approximately twice. In total there were 570 (i.e. 38 x 15) responses.

2.2 Results: Matching faces

Table 1 shows the frequency of correct responses (test participants who correctly identified the target from the reference images) and Figure 3 shows these as a proportion of the sample size for each case. These data are those from trials with the seven targets displayed on screen 1 for which there was a match within the reference set presented on screen 2. In these trials test participants were asked to identify the target from amongst 10 reference images, and therefore there was a 0.10 chance of correct identification by chance: performance was above chance in all conditions. Note that the eight target faces were used at random, and for one of these (the no-match face) the data are not shown in Table 1, leading to the slight differences in sample size.

Table 1. Results of experiment 1: Matching. Frequency (and sample size) of target faces correctly matched with the reference face.

Luminance (cd/m^2)	**Frequency of correct identification**				
	Observation duration (s)				
	0.1	**0.3**	**1**	**3**	**10**
0.1	14 (33)	18 (33)	23 (34)	28 (33)	32 (34)
1.0	28 (34)	31 (34)	34 (34)	33 (33)	34 (34)
10	24 (33)	32 (34)	35 (35)	33 (33)	33 (33)

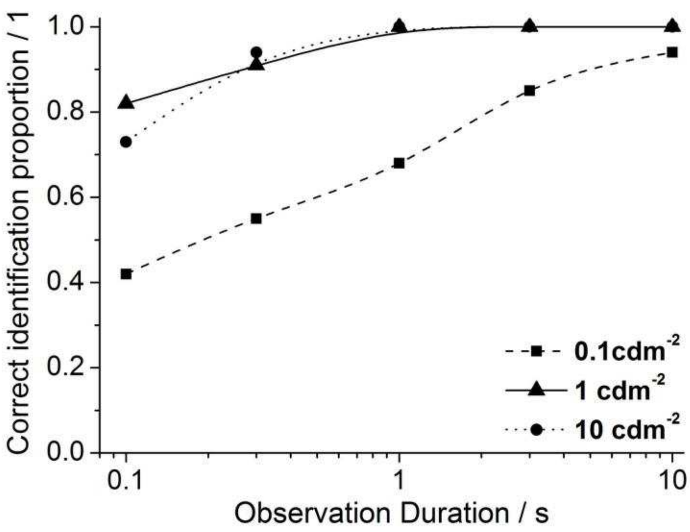

Figure 3. Results of experiment 1: Matching. Proportion of correctly matching a target face with its match in the reference set plotted against the observation duration for three target luminances.

The proportions of correct identification are similar for the two higher luminances (1.0 and 10 cd/m^2) at all durations, and these are higher than for the lower luminance (0.1 cd/m^2). Correct identification approaches 1.0 for the longest duration (10 s) at all three luminances, and reduces at shorter durations.

Two data in Table 1 and Figure 3 appear to be irregular. These are the correct identification results for 0.1 s duration at 1.0 and 10.0 cd/m^2; the expected trend is that the proportion correct at 10 cd/m^2 (0.73) would be higher than at 1.0 cd/m^2 (0.82) but it is not. We expect that this is a chance result.

The results were recorded as a correct response (1) or an incorrect response (0) and each test participant carried out one trial for each combination of luminance and duration. Statistical analyses of these results were carried out with the frequencies of correct responses from the 38 participants (Table 1) using the Chi-square test.

Table 2 summarises the luminance differences suggested to give significantly different facial recognition ability in the matching experiment. The Chi-square test suggests that effects of target luminance were significant (p<0.01) for four of the five durations (0.1 s, 0.3 s, 1 s and 3 s), with higher luminance leading to a higher frequency of correct identification. The differences between 0.1 cd/m^2 and 1.0 cd/m^2 and between 0.1 cd/m^2 and 10 cd/m^2 are suggested to be different with a stronger difference (p<0.001) at the shorter durations (0.1, 0.3, 1.0 s) than at 3.0 s (p<0.05), but the difference between 1.0 cd/m^2 and 10 cd/m^2 is not suggested to be significant. When the duration was 10 s, the difference between any of the three luminances was not suggested to be significant.

Table 2. Summary of luminances differences suggested using the Chi-square test to give significantly different facial recognition in the matching procedure (experiment 1) according to duration of observation.

Duration (s)	**Luminance pairs** 0.1 cd/m^2 vs 1.0 cd/m^2	**0.1 cd/m^2 vs 10 cd/m^2**	**1.0 cd/m^2 vs 10 cd/m^2**
0.1	p<0.001	p<0.01	n.s.
0.3	p<0.001	p<0.001	n.s.
1.0	p<0.001	p<0.001	n.s.
3.0	p<0.05	p<0.05	n.s.
10.0	n.s.	n.s.	n.s.

As to the effect of duration on recognition, the Chi-square test suggests this was significant (p<0.01) for all the three luminances, with longer duration leading to a higher frequency of correct identification.

2.3 Results: Non-Matching faces

For one target face displayed on screen 1 there was no match in the reference set displayed on screen 2. In this situation test participants responded by stating either that the reference set did not include a matching face (no match: a correct response) or by identifying a matching face (match indicated), this clearly being an incorrect response. The results, shown in Table 3, suggest a general trend for the proportion of correct responses for the no-match target face to increase with luminance and duration. This matches the trend found for responses to the set of faces with a match (Table 1).

Table 3. Frequencies of correct and incorrect response for the no-match target face.

Luminance (cd/m^2)	**Duration (s)**	**Frequency of incorrect response (*match indicated*)**	**Correct response (*no match*)**	
			Frequency	**Proportion**
0.1	0.1	5	0	0
	0.3	5	0	0
	1.0	3	1	0.25
	3.0	4	1	0.2
	10.0	0	4	1.0
1.0	0.1	3	1	0.25
	0.3	2	2	0.5
	1.0	1	3	0.75
	3.0	0	5	1.0
	10.0	0	4	1.0
10.0	0.1	5	0	0
	0.3	3	1	0.25
	1.0	0	3	1.0
	3.0	0	5	1.0
	10.0	0	5	1.0

2.4 Further work

In this experiment, the ten images in the reference set were located at the same position throughout a participant's test session. It would be useful to examine the impact of relocating images within the array, of using different sets of reference images for each trial, and of using a different expression and/or direction of view from that shown on the test screen. These variations might be a step towards the behaviour of pedestrians in real settings, and towards ensuring test participants were recognising faces rather than patterns.

3. Experiment 2: Identification

3.1 Method

Experiment 1 used a matching procedure in which target faces are matched to those in a reference set. A second procedure widely used in past research is to name the celebrity shown in a photograph[2, 3, 5] and it has been proposed that these procedures present different levels of difficulty.[10] Hence, a second experiment was carried out using the same ranges of luminance and duration as experiment 1, but with the identification procedure used in previous work.[10]

The target faces were colour photographs of the faces of 26 well-known celebrities in China (Jay Chou, Jackie Chan, Chris Lee, Deng Chao, Fan Bingbing, He Jiong, Huang Xiaoming, Jiang Wen, Jet Li, Ruby Lin, Andy Lau, Liu Xiang, Crystal Liu, Tang Wei, Leehom Wang, Wen Zhang, Daniel Wu, Nicholas Tse, Yao Ming, Cecilia Cheung, Zhang Ziyi, Zhao Benshan, Vicki Zhao, Chiu Man-Cheuk, Donnie Yen, Zhou Xun), of which eight were used in the previous study.[10] The photographs were downloaded from the internet and digitally manipulated so that each was of approximately the same size and background colour (grey), whilst the faces retained their original colour. In all photographs the targets wore a neutral (grey or black) shirt and had similar hair styles, and thus the main difference between these photographs was the face. When presented on display screen 1, the target images were approximately 90 mm in height, and this was observed at a distance of 4.5 m with the test participant's eye position fixed using a chin rest, simulating an equivalent distance of approximately 10 m. For each participant, 15 target faces were picked at random from the set of 26 photographs, thus allowing a different image for each of the 15 experimental conditions experienced in trials.

The apparatus for the experiment 2 was same as that for experiment 1 other than display screen 2 was not required and was thus removed.

Twenty test participants were recruited from the students and staffs of the Fudan

University: 10 were female and 10 were male, and of approximate mean age 21 years. All test participants had normal (or corrected to normal) visual acuity as tested using a Snellen E chart. Normal colour vision was confirmed using the Ishihara Pseudoisochromatic Plates.

Before trials commenced, a period of 20 minutes was allowed for adaptation to the low light level. Test participants were instructed to look at the display screen: a target image was presented for a limited duration, following which the participant was asked to state the identity of the target. The experimenter recorded the response as correct or incorrect. The screen was blank between successive target images. Prior to the onset of the next target image the experimenter alerted participants to focus on the display screen.

Each participant carried out 15 trials, one for each combination of target luminance and duration in a random order, and hence each of the 15 target images was observed only once. In total there were 300 (i.e. 20 x 15) responses. Even though the target faces were carefully selected to be well-known people, there were some cases where a test participant did not know the name of the target person. This was ascertained following the experiment by asking test participants to identify the same set of faces under unrestrained conditions (1 cd/m^2, no restraint over duration or distance). The 14 cases where the test participant did not know who the celebrity was (4.7% of the complete set of 300) were removed from the results, i.e. ignored during analysis.

3.2 Results

Table 4 shows the results recorded during experiment 2, the frequency of correct responses, and these are presented as proportions in Figure 4. The trends exhibited by these data are similar to those found for results of the matching test of experiment 1 (Table 1, Figure 3): higher luminances and longer durations lead to higher proportions of correctly identifying the target.

Table 4. Results of experiment 2: identification. Frequency (and sample size) of target images correctly identified. Note that these data exclude the 14 cases where the target celebrity was unknown to the test participant.

Luminance (cd/m^2)	**Frequency of correct identification**				
	Observation duration (s)				
	0.1	**0.3**	**1**	**3**	**10**
0.1	1 (20)	3 (20)	6 (19)	9 (19)	10 (18)
1	7 (19)	13 (20)	17 (18)	19 (20)	19 (19)
10	9 (20)	16 (19)	17 (18)	19 (19)	18 (18)

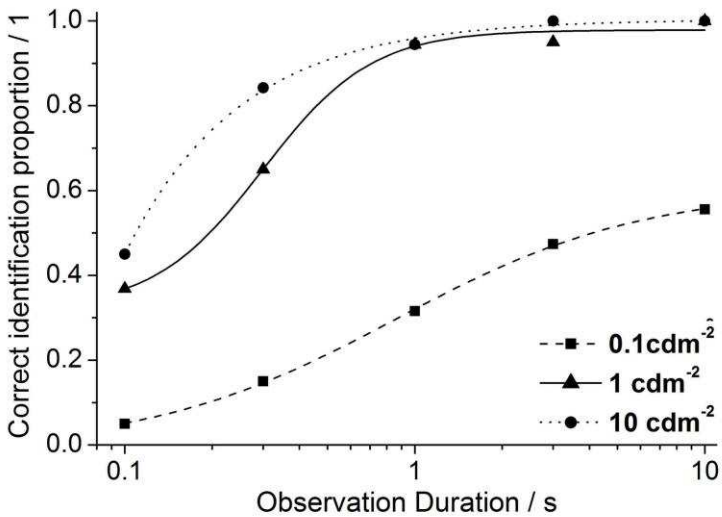

Figure 4. Results of experiment 2: identification. Proportion of correctly identified target faces plotted against the observation duration for three target luminances.

For the target luminance of 0.1 cd/m^2, the proportions of correct identification are clearly lower than those of two higher luminances (1.0 and 10 cd/m^2). The difference between two higher luminances is quite small, and the correct identification proportions at 10 cd/m^2 are only slightly higher than those of 1 cd/m^2 for the 0.1 s, 0.3 s and 3 s durations. At 1.0 and 10.0 cd/m^2, the data exhibit a plateau-escarpment relationship between observation duration and performance (Figure 4) while at the target luminance of 0.1 cd/m^2 there is a near-linear relationship between correct identification proportion and log duration suggesting the plateau has yet to be reached.

As with experiment 1, statistical analyses were carried out for the frequency of correct responses from the 20 participants (Table 4) using the Chi-square test. This suggests that effects of luminance were significant ($p<0.01$) for all five durations and that effects of duration were significant ($p<0.01$) for all three luminances. For all five durations, the Chi-square suggests luminance to be significant between 0.1 cd/m^2 and 1.0 cd/m^2 ($p<0.001$) and between 0.1 cd/m^2 and 10 cd/m^2 ($p<0.001$): the difference between 1.0 cd/m^2 and 10 cd/m^2 was not suggested to be significant at any duration (Table 5).

Tables 2 and 5 suggest similar trends as to the effect of luminance on the matching and identification procedures at different durations, except for the results at 10 s duration: for matching the difference is not suggested to be significant while for identification there is a significant difference. This supports the proposal that the identification task is more difficult than the matching task.

Table 5. Summary of luminances differences suggested to give significantly different facial recognition in the **identification** task using the Chi-square test according to duration of observation.

Duration (s)	**Luminance pairs**		
	0.1 cd/m^2 vs 1.0 cd/m^2	**0.1 cd/m^2 vs 10 cd/m^2**	**1.0 cd/m^2 vs 10 cd/m^2**
0.1	p<0.05	p<0.01	n.s.
0.3	p<0.001	p<0.001	n.s.
1.0	p<0.001	p<0.001	n.s.
3.0	p<0.001	p<0.001	n.s.
10.0	p<0.001	p<0.001	n.s.

4. Discussion

4.1 Task Difficulty

The results (Figures 3 and 4) indicate that luminance and duration exhibit a plateau-escarpment relationship with facial recognition performance. With long durations and high luminances, performance reaches a maximum and variation in either have little effect on performance. At short durations and low luminance performance tended towards a minimum and variation of duration and luminance have little effect on performance. At the intermediate region, however, variation in luminance or duration can have significant effect on recognition.

Since both duration and luminance appear to matter, consider that task difficulty for targets at a given distance is represented by the product of luminance and duration (L*D). Figure 5 shows the relationship between the proportion of correct identification and the logarithmic scale of L*D for the matching and identification tests. The best fit lines were determined using a logistic fit: Identification, $y=1-1/(1+(x/0.273)^{0.72})$, $R^2=0.87$; Matching, $y=1-1/(1+(x/0.018)^{0.62})$, $R^2=0.86$. These trend lines indicate that the product of luminance and duration provides a good model for task performance.

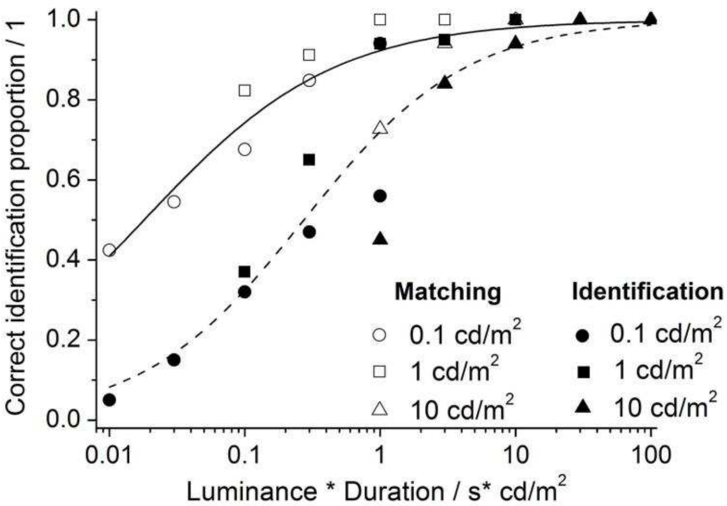

Figure 5. Relationship between the proportion of correct responses and the product of target luminance and observation duration (L*D) for the matching (solid line) and identification (dashed line) procedures.

Comparison of the curves in Figure 5 again confirms a difference in performance between the matching and identification tasks in that the correct identification proportion (experiment 2) is smaller than the correct matching proportion (experiment 1) for targets of identical size. This may explain why past studies using the identification task[2,3,5] found facial recognition required a larger target size (i.e. shorter distance) than studies using a matching task.[7,8]

One reason why matching may exhibit better performance than identification in the current study is that each of the eight target faces was seen approximately twice in the 15 trials, leading to a potential benefit from familiarity. To investigate this the results for the first presentation of the eight target faces per test participant (these being the first eight trials) were isolated, as these should avoid any learning effect associated with repeated observation of the same face. Figure 6 compares recognition performances for the two procedures at the three luminances, with matching data for the full test and for the first eight trials. It can be seen that while results from the first eight matching trials do suggest lower recognition performance than for the results of all 15 trials, this difference is small compared with the difference in recognition performance between the matching and identification procedures. It was therefore concluded that any learning effect in the matching procedure was negligible.

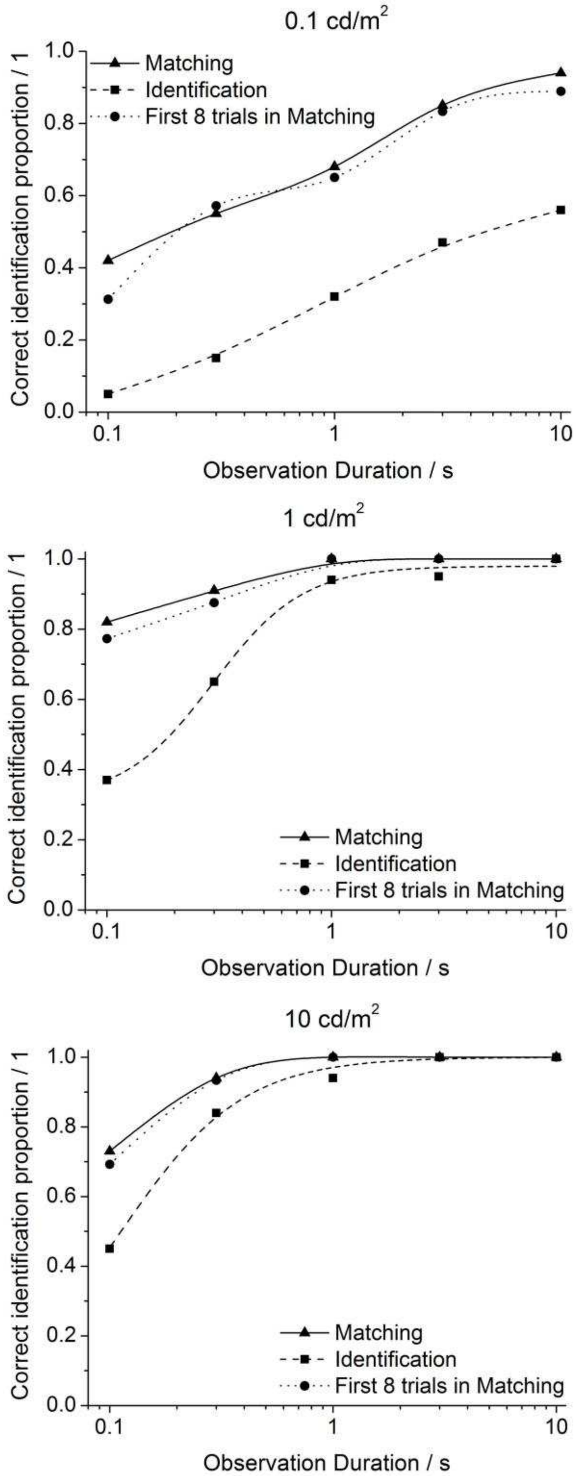

Figure 6. Comparison of correct identification performance for the matching and identification tasks and for the first eight trials of the matching experiment.

A further difference between the two procedures is that the matching task (experiment 1) used achromatic images of sculpted faces while the identification task (experiment 2) used colour images of real faces. Note that Yip and Sinha[1] did not find the difference in recognition between grey scale and colour images of faces to be significant when these were of high resolution (their better quality images), but became significant when using lower resolution images. In the current data, any effect of colour would have had a conservative influence, since the colour images were used with the more difficult procedure (identification) which would reduce the apparent difference between the two procedures.

4.2 Optimum Luminance

Figure 5 allows the optimum luminance to be established for a given duration of observation and probability of correct recognition, with these data being suitable for a target at a distance of 10 m. As to the appropriate duration, there is evidence from studies using eye-tracking to investigate pedestrian behaviour that a typical fixation is in the region of 500 ms[16]. Interpolation first requires discussion of the appropriate task (whether matching or identification, or some other procedure, best represents that employed by pedestrians when evaluating others) and the ideal probability of correct recognition.

4.3 Further Work

Target faces in the current study were 2-dimensional images of faces, these being achromatic in experiment 1 and colour in experiment 2. In natural settings the targets (i.e. other people) are likely to include colour, are 3-dimensional, and allow evaluation in parallel from body posture, gaze direction, clothing, gait and acoustic signals. Further research is required to determine the significance of these differences on conclusions regarding optimum luminance and the effect of SPD.

The targets in experiment 1 were photographs of faces sculpted from clay.
Harries et al[14] also used faces sculpted from clay, in their case using the model directly as a target rather than a photograph. Using 3-dimensonal targets would enable variations in spatial distribution of lighting to be considered, again a step toward real road lighting conditions, but that first requires better understanding of a

procedure that enables repeatable presentation of the target.

5. Conclusion

This article reports investigation of facial recognition using two procedures, matching and identification, and five observation durations ranging from 0.1 to 10 s. The results conformed two proposals regarding task difficulty[10]: (1) the identification procedure was more difficult than the matching procedure, as seen in the lower proportion of correct recognition; (2) for both procedures, shorter durations lead to a lower proportion of correct recognition. These differences became smaller at higher luminances and longer durations. The data were interpolated to indicate the luminance required for a given level of performance and duration. Note that these are presented as an examples of method and should not be considered as proposals pending further clarification of the task that is carried out by pedestrians.

Acknowledgement

This work was carried out as part of the National High Technology Research and Development Program of China (No. 2011AA03A113) and the National Basic Research Program of China (973) (Project NO. 2010CB734102).

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