Article:

Lin, Y. and Fotios, S. (2015) Investigating methods for measuring face recognition under lamps of different spectral power distribution. Lighting Research and Technology, 47 (2). 221 - 235. ISSN 1477-1535

https://doi.org/10.1177/1477153513505306

Investigating methods for measuring facial recognition under lamps of different spectral power distribution

Yandan Lin [a*], Steve Fotios [b]

[a] Institute for Electric Light Sources, Fudan University; Engineering Research Center of Advanced Lighting Technology, Ministry of Education; Shanghai 200433, P.R.China

[b] School of Architecture, University of Sheffield, Sheffield, UK

Citation:

Lin Y, Fotios S. Investigating methods for measuring facial recognition under different road lighting conditions. Lighting Research & Technology, 2015; 47(2); 221-235. DOI: 10.1177/1477153513505306

Abstract

Facial recognition is one of the interpersonal judgements carried out by pedestrians and road lighting should enhance the visual component of such judgements after dark. This article presents experiments carried out using two different procedures, identification and perceived recognition, to investigate why earlier studies led to inconsistent conclusions. For the identification procedure two observation durations were employed (1s, 3s). The two procedures led to similar conclusions regarding recognition ability at different distances. Review of these and past results suggests that an effect of lamp SPD will be found when the task is difficult, i.e. small size, brief observation, and correctly naming the target rather than picking from a sample.

1. Introduction

One intention of road lighting in residential roads is to improve the safety and perceived safety of pedestrians.[1] It has been suggested that facial recognition plays a role in the pedestrians' perception of safety,[2,3] in particular that pedestrians would feel more comfortable if they were able to recognise approaching people by a minimum distance of 4 m.[2] Although, 4 m might not be a well-founded nor precise estimate of the minimum distance at which recognition should be expected,[4] improving the distance for facial recognition would contribute to an increase in the perceived of safety and security of pedestrians. This might be especially true for females.[5,6]

Past studies[3, 7-13] have been carried out to investigate facial recognition under different conditions of street lighting, in particular variations in light source spectral power distribution (SPD) and illuminance, as shown in Table 1. Boyce and Rea[7] found that higher illuminances permit recognition at greater distances. Rombauts et al[3] investigated illuminance and facial recognition, and their results suggest a non-linear relationship between semi-cylindrical illuminance (E_{SC}) and identification distance, with 0.4 lx required for identification at 4 m, approximately 3.0 lx for identification at 10 m, and an asymptote of around 20 lx to 25 lx beyond which higher E_{SC} did not lead to better recognition. The current article is concerned with the effect of SPD on facial recognition and for this the results of past studies are mixed, with some studies[8, 9, 11, 13] suggesting a significant difference while others[7, 10, 12] do not.

A common approach to measuring facial recognition under different lighting is to ask a test participant to walk towards a target face and measure the distance at which the target is first correctly identified (the stop-distance method). A greater recognition distance implies better lighting. The four studies[8, 9, 11, 13] suggesting an effect of SPD on facial recognition used a stop distance procedure. For example in the study by Yao et al,[11] test participants were requested to walk slowly towards photographs of well-known people, starting from a distance of 25m. They were asked to stop at three points: when they could just see the photograph clearly enough to identify the gender; to guess the identity of the person; and finally to indicate when they were certain of the identity, and these three distances were recorded. The results suggested ability to identify the faces from a greater distance under lighting from metal halide (MH) lamps than under high pressure sodium (HPS) lamps, as did Knight.[9, 13] Raynham and Saksvikrønning[8] asked their eight test participants to walk towards targets under three light sources (HPS and two types of compact fluorescent - CFL) and recorded the distance at which recognition was indicated. It was found that a lower semi-cylindrical illuminance was needed when using the CFL than the HPS to achieve a given recognition distance. One limitation of these four studies is, however, that they did not use statistical analyses to examine the apparent differences between lamps.

The results from three studies[7, 10, 12] did not suggest a significant effect of SPD. In the study by Rea et al.,[10] a confederate-pedestrian stood at a fixed designated spot and the participant walked toward the confederate-pedestrian, starting from a distance of 25m, and holding a DVD player that showed eight digital colour photographs of possible pedestrians including the confederate. The test participants were asked to stop walking as soon as he or she could 'guess', and then be 'certain' of, who the confederate-pedestrian was from among the eight pictures displayed on the DVD player. The results did not suggest a significant difference in recognition distance between the MH and the HPS lamps for either criteria, the guess or certainty of identification.

Inappropriate aspects of experimental design may be one reason for these mixed results.[14, 15] One issue is the duration of observation: the continuous observation of the target used in some past studies is an unrealistic proxy for real-world interpersonal judgements as there is a common tendency to avoid looking at others in some social situations. A second issue is that different observers walk at different speeds and different observers take different amounts of time to make up their mind, and any delay in deciding that a face has been recognised can have different consequences for the recognition distance recorded. A third issue is the type of target used: four studies[7,8,10,12] used real faces while three studies[9,11,13] used photographs, and the three studies which did not suggest an effect of SPD used real faces.[7,10,12]

While most studies investigating SPD used a stop-distance procedure, the study by Alferdinck et al[12] did not. In this case the participants' task was making an assessment of the recognition of the face of a target person on a scale between 0% (absolutely not recognisable) and 100% (very good). This was done under six different types of lamp and two illuminances (approximately 3.0 lx and 1.0 lx) at a series of eleven set distances (1.0 m to 32.0 m) between the target and the test participant. What we do not know is how the ratings of recognisability recorded by Alferdinck et al compare with the results found in studies using stop-distance.

The aim of this article is to contribute to discussion of methodology for facial recognition under lighting conditions pertinent to pedestrians after dark to investigate why different studies have found different conclusions regarding the effect of lamp SPD. The article presents the findings of experiments carried out using the two different procedures used in past work to determine whether they lead to similar conclusions regarding effects of SPD and predictions of recognition ability. For one procedure, two different durations of target observation were employed to determine if duration matters, and these were chosen to better represent pedestrian experience after dark.

2. Method

2.1 Variables

Two experimental procedures were used in order to investigate methodology for investigating facial recognition under different lighting conditions.

In the first procedure (*Identification*) test participants were asked to observe a series of target faces and attempt to identify the gender and identity whilst standing at seven set distances from the target (4 m, 6 m, 9 m, 12 m, 16 m, 20 m and 25 m). This is essentially a stop-distance procedure, but, rather than walking towards the target and stopping at the point of recognition as has been used in previous work[7-11, 13] this approach sought to remove other confounds from the effect, if any, of changes in lighting.

Previous studies have tended to allow continuous observation of the target; the current work employed two fixed observation times, these being 1 second and 3 seconds, considered to be more appropriate for real situations. The test participants were asked two questions regarding the target face: what is the gender of the target (male or female), and what is the identity of the target (their name)? If they were not able to make either of these judgments, they were encouraged to guess; this follows the approach used by Berman et al[16] during visual acuity trials. Responses at each distance were recorded as either correct or incorrect.

The second procedure (*Perceived Recognition*) was similar to that used by Alferdinck et al[12] and Rombauts et al.[3] At the seven set distances test participants were asked to report the recognisability of the target face using an 11-point rating scale with end points labelled *absolutely not recognizable* (0) and *very good* (10). The 11-point scale was used, being similar to the 9-point scale used by Rombauts et al[3] rather than the 100-point scale (0-100%) used by Alferdinck et al[12] as larger response ranges do not necessarily lead to more precise data recovery[17] and may encourage greater bias.[18]

Figure 1 shows a plan view of the experimental setup. In trials, the seven distances were experienced in order, always beginning with the largest distance (25 m) and progressing toward the shortest distance (4 m), and thus target faces became progressively larger and perhaps easier to identify. This procedure was adopted following a desire to replicate past studies.[3,12] The progressive reduction in observation distance, rather than randomisation of distances, may have led to a range bias in the perceived recognition task (but less so for the identification task where targets were chosen randomly at each distance) and this is being investigated in further work.

The same set of target faces were used in both procedures. These were eight colour photographs of the faces of well-known stars in China, and included four males and four females of similar apparent age[†]. The photos were digitally manipulated so that each was of approximately the same size and background colour (grey). In all photographs the target wore a neutral (grey or black) shirt and they had similar hair styles, and thus the main difference between these photographs was the face. The pictures were printed on non-glossy paper of size A4, the size of which was 297 mm height and 210 mm width, giving a face height of approximately 250 mm so that these were life-sized.

The trials were carried out after dark in three roads, each lit with a different type of light source (Figure 2). The lighting characteristics are shown in Table 2 and Figure 3. The SPD were measured using a Konica-Minolta CS2000 spectrometer aimed at a reference white surface placed in the position of the target faces. The spectral characteristics were determined from the measured SPD. Parallel measurements using a second spectrometer (Everfine STC3000) confirmed the accuracy of these SPD. Vertical illumination on the location of the pictures was measured at the top, middle and bottom of each target. Under a particular lamp, variation in vertical illuminance was small with maximum (and minimum) values of 6.77 lux (6.57 lux) for the HPS, 6.61 lux (6.32 lux) for the LED, and 5.68 lux (5.98 lux) for the MH.

2.2 Observation duration

Previous studies of facial recognition have tended to allow continuous observation of the target face.[7-13] It has been questioned whether this is realistic for pedestrians.[14, 15] The findings of a study using eye tracking to record pedestrians' visual fixations suggests this observation may be of a short duration, typically less than one second [19] - these were distant pedestrians whose identity was unknown. As a first estimate of whether observation duration matters for facial recognition two exposure times were used in the *Identification* trials, 1 s and 3 s. The *perceived recognition* test used continuous exposure.

In trials, the 1 s and 3 s observation durations were achieved by manual removal and

[†] The target faces were Chi Hsu, Jackie Chan, Cecilia Cheung, Jay Chou, Li Gong, Ming Yao, Ziyi Zhang and Andy Lau. In China these people are well-known actors or sports stars.

replacement of a board covering the target face. Precision in this action was gained by practice before the trials with the experimenter setting exposure durations of 1 s or 3 s several times. Twenty trials each for 1 s and 3 s were then recorded using a stopwatch monitored by a colleague. The mean exposure times were 0.98s (std. dev. 0.11) for the nominally 1 s duration and 2.96s (std. dev. 0.18) for the nominally 3 s durations. This suggests the manual control was satisfactory. In future work using manually-controlled target exposure it would be useful to video record trials such that exposure duration could be monitored.

2.3 Procedure

Between arrival of a test participant at the experiment location and the start of the first trial was approximately 20 minutes, this allowing for chromatic adaptation to the stimulus, during which time the test procedure was explained.

1. The test participant stood at a distance of 25m (the furthest distance) from the target face, this target being covered by a board. The board was removed for 1 second by the experimenter and then replaced. The test participant was asked to state the gender and identity of the target. Participants were not given feedback as to whether their judgements of identity or gender were correct.
2. The target face was changed, and the test participant was asked to state the gender and identify of the target, but this time the exposure duration was 3 s.
3. The target face was changed and, following an unlimited observation time, the test participant rated the recognisability of the face using the 0-10 scale.
4. Steps 1-3 were repeated for the remaining six observation distances, these being performed in order of largest to shortest distance between the test participant and the target.

The experiment was carried out by 42 test participants in an independent samples approach. There were three test conditions (light source and road) and each was experienced by 14 test participants who carried out the trial individually, a sample similar to that used in past studies,[7, 8] and these were randomly allocated to a particular lamp. When it became clear that a test participant could accurately recognize targets at a certain distance, he/she was not asked to continue with judgements at a shorter distance and their test session ended. This led in total to 336 evaluations each of identity and gender and 243 evaluations of perceived recognition. The test participants were students (20-26 years old) who purposefully visited the sites for these trials and all had normal colour vision (self-reported) and normal visual acuity or were corrected to normal using their prescribed lenses. All tests were carried out in one night for each street.

For steps 1 and 2 the target faces were chosen at random from the set of eight. For step 3 a test participant saw the same photograph at all distances, following the procedure used by Alferdinck et al.[12] The eight target faces were used randomly in these trials. For the identification trials, participants carried out eight identification trials on average, and hence some faces may have been observed more than once by a participant. Therefore there may have been a learning effect in the identification process if a particular photograph was seen more than once.

3. Results

3.1 Identification task

Figures 4 and 5 show the percentage of participants who were able to correctly identify the gender or identity of the target faces at each of the seven distances, for the exposure times of 1 s and 3 s respectively. The curves for each lamp type were fitted using the Boltzmann model.[20] A first inspection of Figures 4 and 5 suggests that at larger distances it is possible to correctly identify target gender with much higher probability than it is possible to identify target identity. It must be noted of course that there is a 50% probability of guessing gender by chance, and the average rates of correct gender identification are around 50% at the greatest test distance (25 m). For identification of identity, the probability of correct identification appears to be higher under the MH lighting than under the LED and HPS lighting, despite the MH having slightly lower vertical illuminance than did the LED or HPS. For identification of gender, the differences between lamps appear to be small.

Table 3 shows the mean distance (for each lamp) at which identity and gender were first correctly identified. For identification of gender, the mean distances are in the range of 19 m to 22 m and for identity they are in the range of approximately 11 m to 16 m. As to the effect of duration, differences in mean identity identification distance between lamps are slightly larger at 1 s than at 3 s, but the variance at 1 s is smaller than at 3 s. These data were found to be normally distributed.

For identification of gender, differences between lamps are not suggested to be significant, using either ANOVA or any pair-wise comparison of the three lamps. For identity, two-way ANOVA suggests a significant effect of lamp type ($F=6.93$, $p<0.01$) and a near significant effect of duration ($F=3.78$, $p=0.056$) but does not suggest interaction between lamp type and duration to be significant. One-way ANOVA suggests significant differences between the three lamps for first-identification distance with 1 s observation ($F=5.12$, $p< 0.05$) but does not suggest a different at 3 s observation. For the 1 s data, the independent samples t-test does not suggest differences between the HPS and LED to be significant but the MH lamp permitted recognition at significantly greater distances ($p<0.05$) than the HPS or LED.

Table 3 shows that the mean distance (for each lamp) at which correct identification of identity and gender were first found tends to be slightly greater under 3 s observation duration than 1 s indicating that recognition is more difficult with 1 s observation than with 3 s observation. These data are shown in Figure 6. As the recognition distances were normally distributed these differences were compared using the paired samples t-test. For identification of gender, this did not suggest an effect of observation duration ($t=-1.57$, $p>0.05$). For identification of identity this suggested a significant difference between 1 s and 3 s observations ($t=3.04$, $p<0.01$); making this comparison under the three lamp types separately suggests a significant difference under the HPS lamp ($t=-2.28$, $p<0.05$), a near significant effect under the LED lamp ($t=-2.01$, $p=0.065$) but did not suggest an effect under the MH lamp ($t=-1.18$, $p=0.257$).

3.2 Perceived Recognition task

Table 4 shows the median ratings from the 14 test participants for each of the three lamps at the seven test distances. The recognition ratings tend to increase (i.e. to indicate a higher perceived recognition) at shorter distances. For shortest distance (4 m) recognition was rated at 10 for all lamps and by all test participants. For longer test distances (6 m to 25 m) the median ratings under MH are higher than those under HPS or LED, while the difference between HPS and LED are small.

The one-sample Kolmogorov-Smirnov test did not suggest these data were normally distributed and thus analyses of differences between lamps were carried out using non-parametric statistical tests for independent samples (i.e. unrelated data). The Kruskal-Wallis test was used to compare recognition ratings under the three types of lamp and this was done separately for each of the seven distances. The results suggest a significant difference ($p<0.05$) between the three lamps at the three greater differences (25 m, 20 m and 16 m) but does not suggest a difference at the four shorter distances (12 m, 9 m, 6 m and 4 m). The Mann-Whitney U test was used to compare ratings under different lamp pairs. For the MH and HPS lamps this suggests significant differences ($p<0.05$) in perceived recognition at 25 m and 20 m and a near significant difference at 16 m ($p=0.08$). For the MH and LED lamps this suggests significant differences ($p<0.05$) in perceived recognition at 20 m and 16 m and a near significant differences ($p\approx0.08$) at 25 m. Differences between the HPS and LED lamp were not suggested to be significantly different at either of the test distances.

These data suggest that lamp SPD can have a significant effect on ratings of perceived recognition but that there is a floor effect: at the shorter distances (≤12 m) ratings were similar possibly because the large visual size of the task (and possibly also a learning effect) outweighed any potential effect of SPD. We suspect there will also be a ceiling effect: at distances greater than those used in the current study, ratings of recognisability are likely to be near zero regardless of lamp type.

4. Discussion

4.1 Comparing Procedures

Two experimental procedures were employed to examine facial recognition under light sources of different SPD. Results of the identification test suggest that, for 1 s observation there is a significant effect of lamp SPD, with the MH lamp permitting correct identification of identity at greater distances than the HPS and LED lamps, but that at 3 s the data do not suggest a significant effect. Results from the perceived recognition test suggest a similar effect of SPD to that of the 1 s identification test, in that the MH lamp permits better perceived facial recognition than either the LED or HPS lamp and that differences between these two lamps are not significant.

Figure 7 compares the results of the two procedures. For the recognition procedure these data are the probability of correct recognition of identity (Figures 4 & 5): for the perceived recognition procedure these are the ratings recorded using the 0-10 scale (Table 4). The coefficient of linear determination between these data ($r^2=0.95$, $p<0.01$, $n=42$) suggests association between the two procedures. The data in Figure 7 include all three lamps, for both 1 s and 3 s durations of observation, at all seven distances. Separation of these data by lamp type or observation duration does not suggest significant deviation from the trend shown (e.g. HPS, $r^2 = 0.96$; LED, $r^2 = 0.98$; MH, $r^2 = 0.91$). Figure 8 shows the probability of correct identification and rating of perceived recognition at each test distance for the three test lamps.

Figures 7 and 8 indicate that a given probability of correct identity recognition is matched by a similar rating of perceived recognition, and thus similar estimates of facial recognition ability at different distances. This conclusion needs to consider a limitation of the current procedure in that test distances were experienced in fixed order (longest to shortest) following previous work[12] rather than being a random order, which may have induced a range bias in the perceived recognition procedure, and also that the two procedures employed different durations of observation.

Analysis of results gained using perceived recognition (section 3.2) does not suggest differences between the LED and HPS lamps, but that there is a difference between either of these two lamps and the MH lamp at the longer of the test distances: analysis of results gained using the identity identification procedure (section 3.1) suggests similar differences between lamps with 1 s observation but does not suggest a different between lamps at 3 s observation. One reason for this is that at 3 s variances within the identification data are larger than at 1 s.

4.2 Effect of SPD

Results of the identification procedure (at 1 s observation) and the perceived recognition procedure suggest that the MH lamps enables facial recognition to be obtained at significantly greater distances than do the LED or HPS lamp, but the difference between the LED and HPS lamps is not significant. This agrees with the findings of previous studies suggesting that SPD can affect facial recognition but were lacking confirmation that the differences were real.[8, 9, 11, 13]

Neither of the metrics presented in Table 2 characterise this effect. The LED lamp has a higher CCT, gamut area and S/P ratio than the MH lamp in contrast to weaker facial recognition under the LED lamp. The MH lamp has a higher CRI (81) than does the LED (71) and HPS (20) but if CRI were to correlate with facial recognition then the LED lamp would be expected to enable better facial recognition than the HPS lamp: a similar conclusion can be drawn using the Colour Quality Scale (CQS).[21] (Note that Davis and Ohno[14] report CQS version 7.5; a later version of the model, version 9.0, was used in the current work and this was obtained from Ohno). Further analysis is needed to determine a metric that best characterises facial recognition under lighting of different SPD. Note also that repeating these procedures using test distances in a randomised order may lead to different conclusions regarding SPD. That is being investigated in further work.

The principle of prominence in qualitative judgements is that "the most prominent attribute looms larger".[22] There is a possible effect of prominence in facial recognition judgements, which might indicate why past studies of facial recognition did or did not reveal an effect of SPD. A prominence effect suggests that when SPD is considered alone it will be revealed to have a significant effect, but when both illuminance and SPD are independent variables then SPD will not be revealed as a significant effect because the influence of illuminance is larger than that of SPD. Of the seven studies in Table 1 investigating SPD and facial recognition, this proposal is correct for five studies [7, 9, 11, 12,13] but not for two.[8,10] A similar effect was noted in review of spatial brightness evaluated using the category rating method: lamp SPD was revealed as a significant factor when examined alone but not when both SPD and illuminance were independent variables.[23]

The perceived recognition test revealed a significant effect of SPD in contrast to Alferdinck et al[12] who did not suggest such an effect. One possible reason for this difference is the type of targets used. In the current study the targets were photographs of people's faces, these being manipulated to ensure that faces were the critical difference. Alferdinck et al used three real people as the targets and it is apparent (from Figure 21 of Alferdinck et al) that their clothing was of different style and colour, and that they were different in age, gender, hair style and hair colour. Although test participants were asked to ignore the clothing, hairstyle, length and posture of the targets, these differences may have contributed to judgements. It may be that the current work provided a better measure of facial recognition while Alferdinck et al examined recognition based on the whole body. Further discussion is needed to determine which of these is more pertinent to pedestrians after dark.

4.3 Task difficulty

These data suggest an influence of task difficulty on the influence of SPD. In the perceived recognition task, the difference between lamps is significant only at the larger distances where the task size is smaller. In the identification task, differences between lamps are significant at the shorter observation duration (1 s) but not at the longer duration (3 s). This suggests that if the recognition task is difficult (small visual size and brief observation) it is more likely that lamp SPD will have effect. Further data are required to confirm this proposal. Supporting evidence is available from two studies. Firstly, colour photographs were found to provide significantly better recognition of celebrities than grey scale versions when facial information was made less visible by blurring.[24] Secondly, investigation of visual acuity at photopic levels of adaptation found that lamp SPD affects foveal acuity when the task is small and test participants are encouraged to guess the smaller sizes not otherwise clearly visible.[16]

If task difficulty is a determinant of the effect of SPD then there is a need to establish the visual task relevant to pedestrians after dark, i.e. the minimum distance at which evaluation of identity is desirable, and the typical duration of observation. Glare may also be an issue as there is some evidence that face luminance required for pedestrian visibility increases as equivalent veiling luminance increases.[25]

A further way in which the results of facial recognition experiments might be explained is the choice of target faces and hence the precise task of observers.

The three studies in which an effect of SPD was not suggested to be significant [7, 10, 12] used real, unknown people as targets. Identification by name is not possible with these targets. Instead, in the two studies using an identification procedure the task was to pick the target from a set of either four [7] or eight [10] photographs of possible targets – an identity parade. In these studies, mean recognition distances ranged from 12 metres [10] to 24.9 metres [7].

However, in the three studies suggesting an effect of SPD on facial recognition [9, 11, 13] the targets were photographs of well-known people (alleged celebrities). In these studies the task was to correctly name the person and mean recognition distances were in the range of 5.4 metres to 8.45 metres[9, 11, 13] – the target needs to be closer (i.e. a larger visual size) to permit correct naming of a celebrity than does picking an unknown target from an identity parade. In other words, naming a celebrity appears to be a more difficult task than does picking the target from a small set of possible options. Persike et al [26] found that familiar faces were found more quickly than unfamiliar faces in a search task, and having the identity parade of faces may have increased familiarity, thus leading to an easier task. It may also be the case that 3D faces are more easily recognised than are 2D photographs, and indeed the three studies which did not suggest an effect of SPD used real faces.[7,10,12] Again, an effect of SPD is revealed when the task is more difficult.

In the current study which used photographs of well-known people, mean distances at which identity was first correctly identified ranged from 10.9 m to 16.6 m, a greater distance than other studies using celebrity photos, and hence an apparently easier task. One reason for this difference is that the current study sought identification at a series of set distances whereas past studies used the stop-distance procedure where the participant stopped walking when identification was possible: the former did not allow assessment of recognition at intermediate distances, the latter introduces a possible delay between recognition and stopping walking, a motor delay that may have led to shorter distances.

In the remaining study [8] real people were used as targets but the degree of familiarity between observers and targets is not known.

5. Conclusion

Facial recognition was investigated using two different procedures, correct identification and perceived recognition, under three different types of lamp. Both procedures lead to similar estimates of facial recognition ability; at a given distance, recognition probability and perceived recognition were found to be similar.

For identification of identity, the perceived recognition procedure and identity procedure at 1 s lead to the same conclusion regarding effects of SPD, with the MH lamp tending to permit better facial recognition than did the LED and HPS lamps, and with little difference between the LED and HPS. For 3 s observation, the identification procedure did not suggest a significant effect of SPD. Neither CCT, S/P ratio nor gamut area correctly predict that the MH lamp would permit better facial recognition than LED and HPS. While both CRI and CQS do predict the better performance under the MH, these also suggest a difference between the LED and HPS lamps that was not found in the test results. For identification of gender, the results do not suggest an effect of SPD at either observation duration.

The identification procedure was repeated using two durations of observation, 1 s and 3 s. The mean distances at which correct identification of identity was first found was slightly longer under 3 s observing duration than 1 s, suggesting the identification task was easier with the longer exposure time.

These findings give some insight as to the effect of task difficulty. When the task is relatively easy (large visual size, longer observation) then lamp SPD does not have an effect, but when the task is made more difficult (smaller visual size, shorter observation) then SPD does have a significant effect. The precise recognition task may also have an effect: picking the target (a real face) from an identity parade appears to be an easy task and does not reveal an effect of lamp SPD whereas naming the identity of a celebrity presented on a photograph is a more difficult task and does reveal an effect of lamp SPD.

One associated issue is that the ability to recognise identity may not be the whole nor primary interpersonal evaluation that matters to pedestrians after dark: what does matter is the ability to interpret the intent of people approaching and this is the focus of work being carried out in parallel.[4]

Acknowledgement

This work was carried out through funding from the National High Technology Research and Development Program of China (863 Project, Grant No. 2011AA03A113). We wish to thank Dong Mengdi who helped carrying out the experiment and assisted in the data analysis.

References

1. International Commission On Illumination, CIE115-2010 Technical Report, Recommendations for the lighting of roads for motor and pedestrian traffic. 2010.

2. van Bommel W, and Caminada E. Considerations for the lighting of residential areas for non-motorised traffic. In: *CIBS National Lighting Conference.* 1982.

3. Rombauts P, Vandewyngaerde H and Maggetto G. Minimum semicylindrical illuminance and modelling in residential area lighting. *Lighting Research and Technology* 1989; 21: 49-56.

4. Fotios SA and Yang, B. Measuring the impact of lighting on interpersonal judgements of pedestrians at night-time. In: *CIE Mid-term conference: Towards A New Century of Light* 2013: Paris. 990-998.

5. Keana C. Evaluating the influence of fear of crime as an environmental mobility restrictor on women's routine activities. *Environment and Behavior* 1998; 30(1): 60-74.

6. Haans A and de Kort Y. Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology* 2012; 32(4): 342-352.

7. Boyce P.R. and Rea MS. Security lighting: Effects of illuminance and light source on the capabilities of guards and intruders? *Lighting Research and Technology* 1990; 22: 57-80.

8. Raynham P and Saksvikrønning T. White light and facial recognition. *The Lighting Journal* 2003; 68(1); 29-33.

9. Knight C and van Kemenade J. Effect of outdoor lighting on perception and appreciation of end-users. *Licht* 2006.

10. Rea M.S, Bullough J.D and Akashi Y. Several views of metal halide and high-pressure sodium lighting for outdoor applications. *Lighting Research and Technology* 2009; 41(4): 297-320.

11. Yao Q, Sun Y and Lin Y. Research on Facial Recognition and Color Identification under CMH and HPS Lamps for Road Lighting. *LEUKOS* 2009; 6(2): 169-178.

12. Alferdinck J.W.A.M, Hogervorst M A, van Eijk A M J and Kusmierczyk J T. Mesopic vision and public lighting - A literature review and a face recognition experiment. Report, 2010.

13. Knight C. Field surveys of the effect of lamp spectrum on the perception of safety and comfort at night. *Lighting Research and Technology* 2010; 42(3): 313 -329.

14. Fotios SA and Raynham P. Correspondence: Lighting for pedestrians: Is facial recognition what matters? *Lighting Research and Technology* 2011; 43(1): 129 -130.

15. Fotios SA and Goodman T. Proposed UK guidance for lighting in residential roads. *Lighting Research and Technology* 2012; 44(1): 69 -83.

16. Berman S.M, Navvab M, Martin M J, Sheedy J and Tithof W. A comparison of traditional and high colour temperature lighting on the near acuity of elementary school children. *Lighting Research and Technology* 2006; 38(1): 41-52.

17. Green P and Rao V. Rating scales and information recovery- how many scales and response categories to use? *Journal of Marketing* 1970; 3(34): 33-39.

18. Alwin D. Information transmission in the survey interview: Number of response categories and the reliability of attitude measurements. *Sociol Methodo* 1992; (22): 83-118.

19. Fotios S, Uttley J, Cheal C, Hara N. Road lighting for pedestrians: Identifying critical visual tasks. Lighting Research & Technology, <u>submitted for publication August 2013</u>.

20. Palmer S. *Vision science: photons to phenomenology.* A Bradford book 1999: Massachusetts Institute of Technology.

21. Davis W and Y Ohno. Color quality scale. *Optical Engineering* 2010; 49(3): pp.033602 – 1 to 16.

22. Hsee CK, Loewenstein GF, Blount S, Bazerman MH. Preference reversals between joint and separate evaluations of options: A review and theoretical analysis. *Psychological Bulletin* 1999; 125(5): 576-590.

23. Fotios SA and Houser KW. Research Methods to Avoid Bias in Categorical Ratings of Brightness. *Leukos* 2009; 5(3): 167-181.

24. Yip AW and Sinha P. Contribution of color to face recognition. *Perception* 2002; (31): 995-1003.

25. Kohko S, Kawakami K, Nakamura Y. A study on effects of veiling luminance on pedestrian visibility. *Journal of Light and the Visual Environment* 2008; 32(3): 315-321.

26. Persike M, Meinhardt-Injac B, Meinhard G. The preview benefit for familiar and unfamiliar faces. *Vision Research* 2013; 87: 1-9.

Table 1 Summary of past research of facial recognition, SPD and illuminance.

Study	Method			Effect of illuminance	Effect of lamp SPD
	Procedure	Identification task	Type of target face		
Alferdinck et al., 2010[12]	Ratings of recognisability at set distances	Evaluate the recognisability	Real person	Yes	No
Boyce and Rea, 1990[7]	Stop-distance ***	Pick from a sample	Real person	Yes	No
Knight and van Kemenade, 2006[9]	Stop-distance	State name of person	Photograph	Not tested	Yes*
Knight, 2010[13]	Stop-distance	State name of person	Photograph	Not tested	Yes*
Raynham and Saksvikrønning, 2003[8]	Stop-distance	"*Walk towards a person until their face could be recognised*"	Real person	Yes	Yes *
Rea, Bullough and Akashi, 2009[10]	Stop-distance	Pick from a sample	Real person	Not tested	No**
Rombauts et al, 1989[3]	Ratings of recognisability at set distances	Evaluate the recognisability	Real person	Yes	Not tested
Yao, Sun and Lin, 2009[11]	Stop-distance	State name of person	Photograph	Not tested	Yes*

Note:

* In these studies there was a trend for SPD to affect recognition distance but there is no statistical analysis of differences.

** It is reported that there was no significant difference between the MH and HPS but the article does not provide any numeric results for this test nor the method of statistical analysis.

*** Stop-distance procedure: this required the test participant to walk toward the target except for Boyce & Rea 1990 where the target walked towards the test participant.

Table 2 Characteristics of lighting conditions used in the facial recognition experiment.

Road	Lamp type	CCT(K)	CRI	S/P	Gamut area	CQS	Vertical illuminance on target (lx)
1	HPS	1930	20	0.563	0.0009	37	6.7
2	LED	5298	70	1.88	0.0059	74	6.5
3	MH	2726	81	1.29	0.0038	81	5.8

Table 3 Mean distances at which identity and gender were first correctly identified.

	1 second			3 seconds		
	HPS	**LED**	**MH**	**HPS**	**LED**	**MH**
Gender identification						
Mean identification distance (m)	19.2	20.0	22.6	21.9	21.4	22.1
Standard Deviation	5.44	4.04	3.84	4.91	4.05	4.79
n	14	14	14	14	14	14
Identity identification						
Mean identification distance (m)	11.0	10.9	15.1	12.9	13.1	16.6
Standard Deviation	3.37	4.26	4.08	3.77	5.39	5.21
n	14	14	14	14	14	14

Table 4 Median ratings and inter-quartile range of the ratings of recognisability under HPS, MH and LED lamps at seven set distances.

Distance to target face (m)	Recognition ratings					
	HPS		LED		MH	
	median rating	inter-quartile range	median rating	inter-quartile range	median rating	inter-quartile range
4	10.00	0.00	10.00	0.00	10.00	0.00
6	10.00	1.00	10.00	2.00	10.00	0.00
9	8.00	2.25	8.50	2.50	10.00	2.00
12	6.00	1.00	6.00	2.50	7.50	3.50
16	4.00	1.00	4.00	3.25	5.50	4.00
20	3.00	1.25	3.00	2.75	4.00	4.00
25	1.00	1.00	1.00	1.25	3.00	2.25

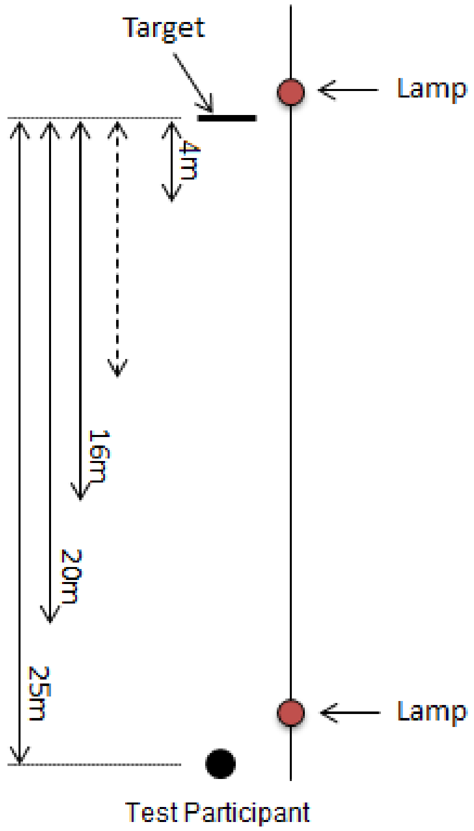

Figure 1 Plan view of the facial recognition experiment. Target faces (photographs) were suspended from a bracket of height 1.7m.

Figure 2 The three scenes used in facial recognition trials. These were illuminated by HPS, LED and MH lamps (left to right).

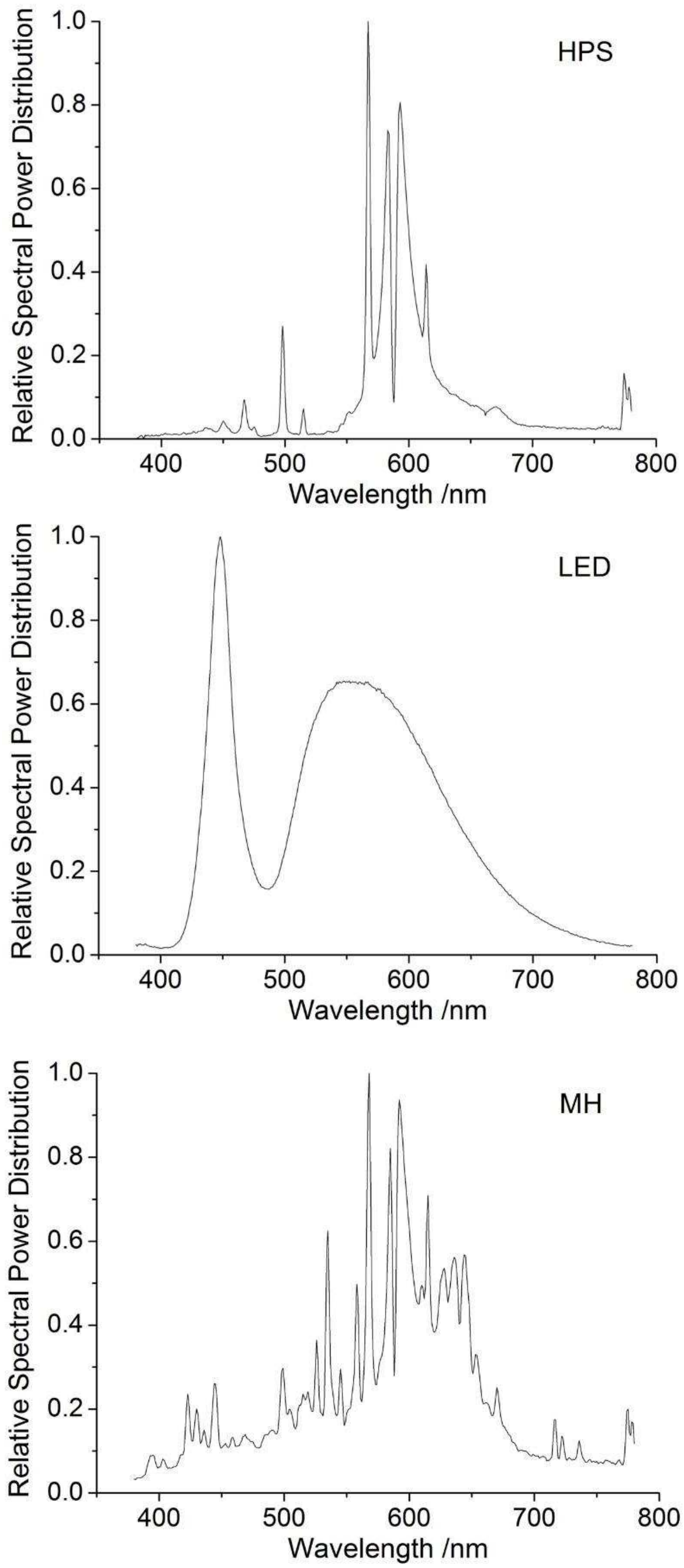

Figure 3 SPD of the test lamps measured with the spectrometer aimed at a reference white surface placed in the position of the target faces.

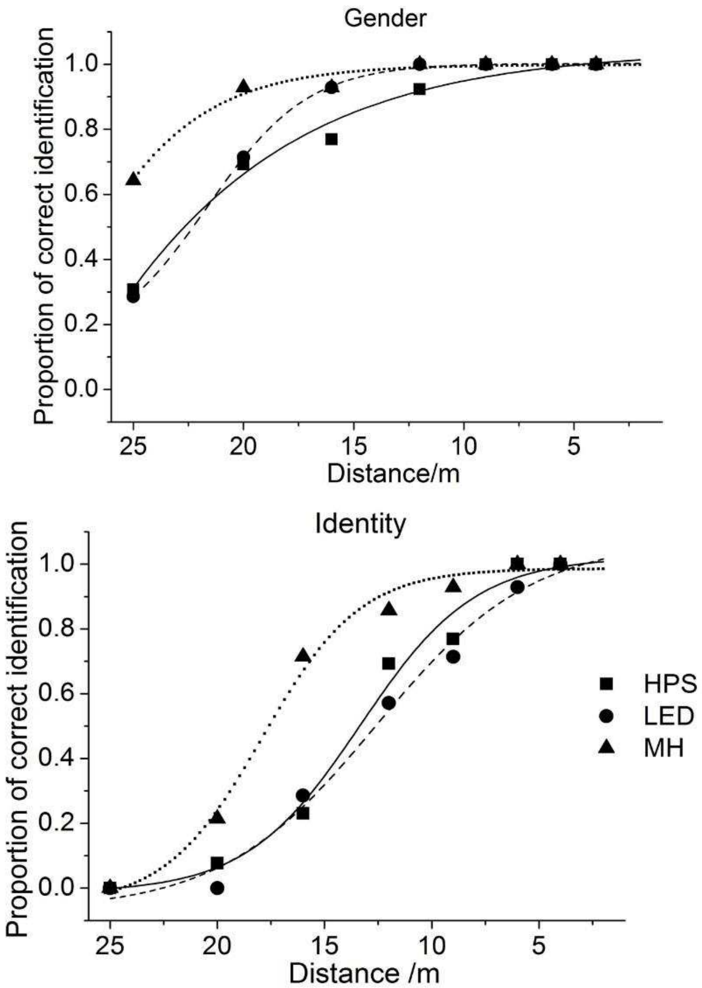

Figure 4 Probability of correct identification of the gender or identity of the target face according to observation distance for an exposure time of 1 second.

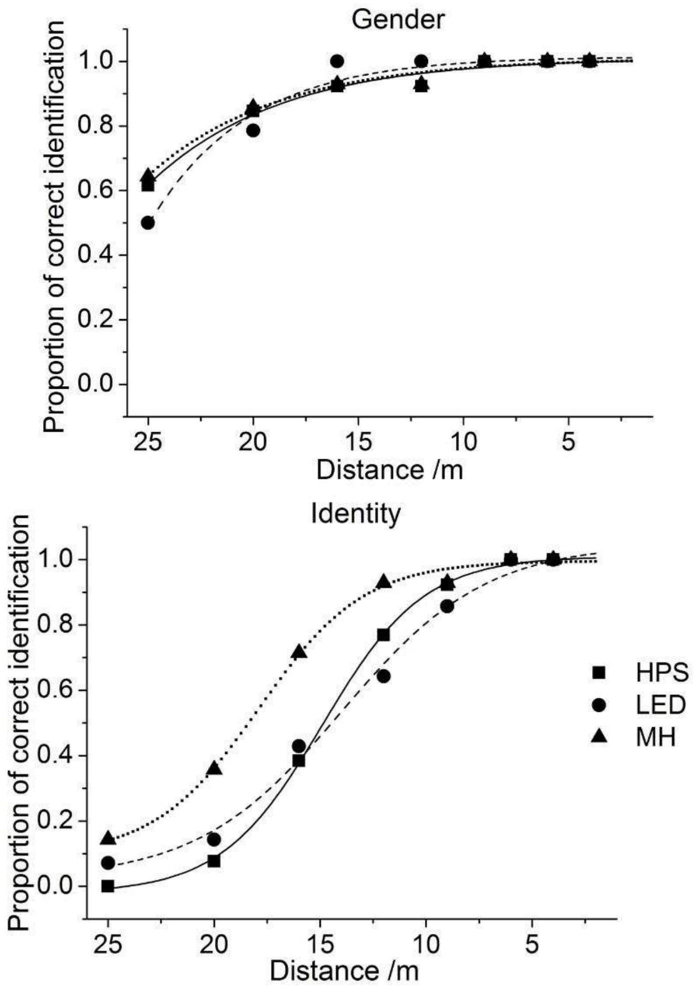

Figure 5 Probability of correct identification of the gender or identity of the target face according to observation distance for an exposure time of 3 seconds.

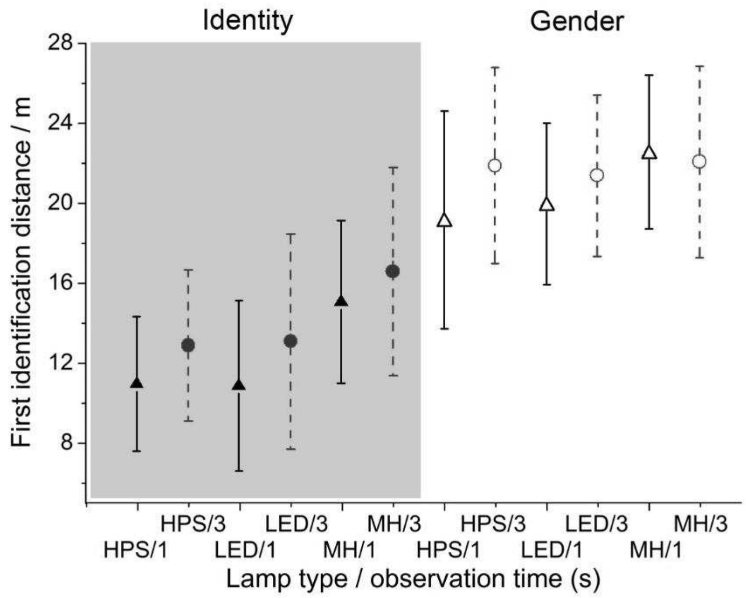

Figure 6. Distance (m) at which the gender/identity was first correctly identified for 1 s and 3 s observation durations using the identification procedure. The data points show the mean recognition distance. Error bars show standard deviation: 1 s (solid line) and 3 s (dashed line) durations.

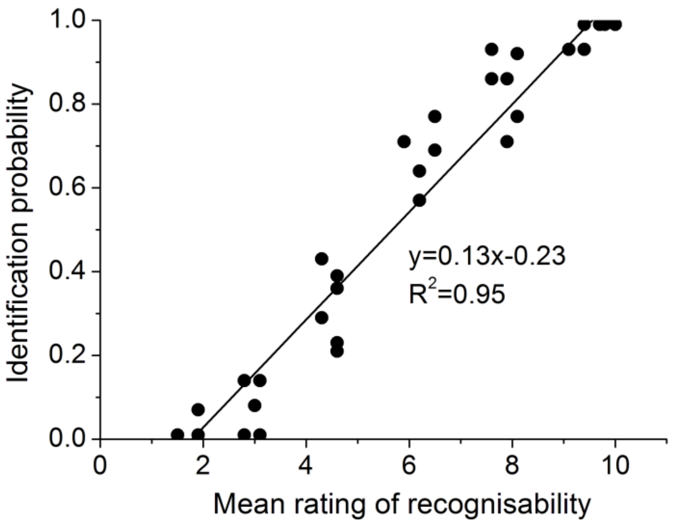

Figure 7 Regression of probability of correct identification (from Figures 4 and 5) plotted against ratings of recognisability (from Table 4) for each combination of lamp type, distance, and observation duration.

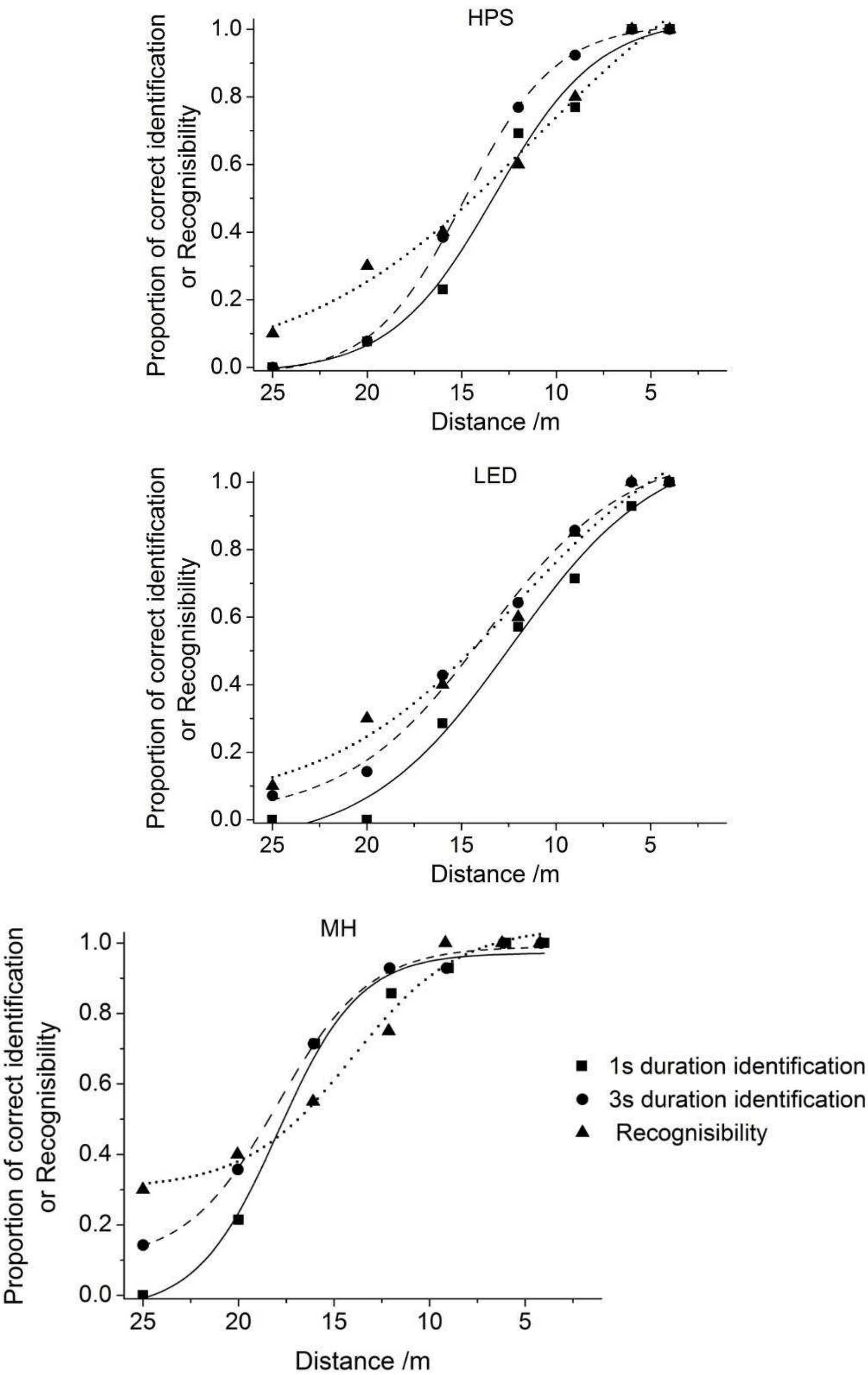

Figure 8. Comparison of probability of correct identification and rating of perceived recognition at each test distance. Note that for the perceived identification task the results were gained using a 0-10 scale and are redrawn here using a 0-1.0 scale.