# Optimising Lighting to Enhance Interpersonal Judgements for Pedestrians in Residential Roads

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# ABSTRACT

Lighting in residential roads is designed to enhance the visual ability to make interpersonal judgements, which is considered to be a critical task for pedestrians. There appears to be little empirical evidence supporting current standards and consistent conclusions cannot be derived from past studies based solely on facial recognition. This work extends investigation of the relationship between lighting and interpersonal judgements beyond the analysis of facial recognition. The results were used to explore how such data might be used to better estimate appropriate light levels for outdoor lighting.

Analysis of gaze behaviour using eye-tracking suggested that the effect of lighting on interpersonal judgements should be examined using the 'desirable' distance at 15 m and a duration of 500 ms: in past studies these have been arbitrary. Two pilot studies carried out to inform the experimental design suggested that (i) recognition of facial features is of particular interest, and (ii) standard facial expressions and body postures did not lead to consistent judgements of intent.

The first experiment collected forced choice judgements of emotion (from facial expression and body posture) and gaze direction after 1000ms exposure under 18 combinations of three luminances, two lamp types and three distances. Better performance was found with higher luminance and closer distance, but with diminishing returns according to a plateau-escarpment relationship. Effect of lamp type was not found in judgements of facial expression, but was found in judgements of body posture and gaze direction for some of the conditions lying on an apparent escarpment.

The second experiment provided further examination of facial expressions under 72 combinations of test conditions: six luminances, three lamp types, two distances and two durations. Luminance and distance were found having significant effect on expression recognition. The effect of lamp spectral power distribution (SPD) was not significant and the effect of duration was suggested to be significant only within the escarpment region of the performance versus luminance.

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# ABBREVIATIONS

| | |
|---|---|
| **3D** | Three Dimension(al) |
| **4PLE** | Four Parameter Logistic Equation |
| **BEAST** | Bodily Expressive Action Stimulus Test |
| **BS** | British Standard |
| **CCT** | Correlated Colour Temperature |
| **CIE** | Commission Internationale de l'Eclairage (French) |
| | International Commission on Illumination (English) |
| **CPO** | CosmoPolis$^{TM}$ (Lamp) |
| **CRI** | Colour Rendering Index |
| **EPSRC** | Engineering and Physical Sciences Research Council |
| **FACES** | Database of Adult Emotional Facial Stimuli developed by Max Planck Institute for Human Development |
| **HPS** | High Pressure Sodium (Lamp) |
| **IQR** | Inter-quartile Range |
| **LED** | Light Emitting Diode |
| **LPS** | Low Pressure Sodium (Lamp) |
| **MERLIN** | Mesopically Enhanced Road Lighting: Improving Night-vision |
| **MH** | Metal Halide (Lamp) |
| **PAMELA** | Pedestrian Accessibility and Movement Environment Laboratory |
| **Ra** | CIE General Colour Rendering Index (CRI) |
| **SD** | Standard Deviation |
| **SPD** | Spectral Power Distribution |
| **S/P** | Scotopic to Photopic Ratio |
| **uulmHPG** | University of Ulm Head Pose and Gaze Database |

# CHAPTER 1 INTRODUCTION

## 1.1 Aims of Lighting for Pedestrians

Lighting in residential roads is provided to meet the needs of road users such as motorists, cyclists, and pedestrians (British Standards Institution, 2003a). At night time, lighting enhances visual capabilities and thus has an influence on the visual information that is gathered. The main purpose of lighting in residential roads and areas, as stated in British Standard (BS) 5489-1:2003, is to “enable pedestrians and cyclists to orientate themselves and detect vehicular and other hazards, and to discourage crime against people and property” (British Standards Institution, 2003a).

Pedestrians are regarded as one of the most vulnerable user groups of roads in residential areas (World Health Organization, 2009), and thus lighting in residential road is designed primarily to provide good visibility, safety and security for them. As a pedestrian walks along a road, visual information contributes to decisions as to how confident they feel about continuing with the journey. In order to make the roads accessible for pedestrians, proper lighting is necessary to lit both environment and other people along the road with a certain level of visibility.

The need of lighting in residential roads may be understood in terms of critical visual tasks of pedestrians. These critical pedestrian tasks have been identified as: (1) detection of objects or obstacles that pedestrians may trip over, especially for older people; (2) visual orientation directed by the layout of building and road, house numbers or signs; and (3) identification of persons (Caminada and van Bommel, 1980; Raynham, 2004; Cheal, 2007). Identification of persons is the focus of the current study. Being able to identify features of other persons, such as gender, appearance, attitude, intention, clothing etc., in sufficient time to take avoiding action if necessary, may improve perceived safety.

## 1.2 Potential Energy Saving of Road Lighting

Road lighting in the UK consumes 2.5TWh electricity in 2007, approximately one third of which is associated with residential streets (the remainder being trunk route lighting, signs and bollards) and this amount of energy represents an annual cost of over £80 million assuming a typical unit cost of 0.10/kWh (Department of the Environment, 2008). Lighting researchers such as Boyce et al (2009) suggest that road lighting could be changed to reduce energy consumption while maintaining the original benefits it brings to the road users. In their paper, Boyce et al (2009) demonstrate the significant difference on criteria used for average luminance and horizontal illuminance in road lighting recommendations and standards used in UK, USA, Japan, Australia and New Zealand. This implies that the changes of road lighting deserve further investigation. They also examine the possibility of such changes in four sections: technology, pattern of use, standards and basis of design.

On the one hand, recent advances of lighting technologies in light source (e.g. LEDs), control system (e.g. dimmer and wireless communication), luminaries (e.g. self-cleaning cover) and electricity supply (e.g. photovoltaic) enrich the approaches of road lighting that can be used for reducing energy consumption. On the other hand, basis of design, recommendations and standards, which consist of empirical evidences and international agreement, are in demand to explain the difference in different countries. This thesis focuses mainly on the latter: basis of design as well as guidance lead to recommendations and standards that may cut the unnecessary part of energy consumption caused by road lighting in residential areas.

As lighting can be characterised using various features, two of these features about road lighting are of exceptional significance in determining how much lighting to provide without causing needless energy consumption: light level and spectral power distribution (SPD). Visual functions generally degrade only if the lighting decreases below certain levels (Boyce, 2003). Lighting using lamps of higher

Scotopic to Photopic (S/P) ratio will produce faster off-axis detection (Akashi et al., 2007) and perception of greater brightness (Fotios and Cheal, 2011) than the ones with lower S/P ratios at the same luminance. This means better visual performance may be obtained by manipulating SPD without changing the luminance, thus maintaining the same level of energy consumption.

## 1.3 MERLIN Project

This study is part of the MERLIN (Mesopically Enhanced Road Lighting: Improving Night-vision) project funded by EPSRC (Engineering and Physical Sciences Research Council, UK), which is a collaboration between vision science and lighting engineering. This project will investigate how the lighting of roads in residential areas might be changed so as to preserve the benefits of good vision while minimising energy consumption. It aims to provide a fundamental review of what pedestrians need to see and do in residential streets to be safe and to be felt safe, how lighting affects these tasks, and thus what optimum design criteria for lighting should be.

Two parallel projects are investigating perceived safety and pedestrians on roads in residential areas. The overall aim is to identify how judgements of perceived safety are made; what kinds of visual information are sought to inform these decisions? This will in turn allow a better understanding of what needs to be lit and thus the characteristics of lighting that might aid perceived safety. The first project places the effect of lighting in context by the consideration of other attributes such as spatial features, familiarity with an area and the presence of other people, thus to give a holistic picture of the pedestrian experience. The second project examines how lighting affects judgements made about other people on the road. This thesis deals mainly with the work related to the second project.

Previous work in the lighting community has focused primarily on whether facial recognition is affected by the spectral power distribution (SPD) of the lighting. Review of the results reveals a mixed opinion, with some studies suggesting lamp SPD affects recognition whilst others do not. Fotios & Raynham (2011) suggest this is due to differences in methodology and that an improved understanding of procedure is required. Furthermore, there is a need to highlight that facial recognition is not the only requirement: lighting needs also to aid judgements of the intent of other people.

## 1.4 Research Questions of this Thesis

The main aim of this study is to investigate interpersonal judgements that pedestrians might make about other people when walking after dark and how these judgements may be affected by characteristics of lighting, primarily lighting level and SPD.

The aim of this study can be interpreted by the following research questions:

1) Does interpersonal judgement matter for pedestrian?
2) What are the desirable distance and duration?
3) What elements of interpersonal judgement are critical?
4) Can interpersonal judgement be quantified?
5) Does lighting affect the performance of interpersonal judgement?
6) What is the optimum lighting condition?

## 1.5 Structure of this Thesis

Chapter 2 presents a literature review on current status and past studies related to the above research questions. Chapter 3 describes an eye tracking experiment carried out by a colleague (James Uttley). The current author carried out part of the analysis on probability of fixation, and the desirable distance and duration of interpersonal judgement made by pedestrians. Two pilot studies are shown in Chapter 4, exploring 1) features perceived at different distances and 2) consistency of judgement of intent based on facial expression and body posture. Chapter 5, 6 and 7 respectively describe the method, results, analysis and discussion of the two main experiments. Finally, conclusions and limitations of this study were made in Chapter 8.

## 1.6 Methodology

The main methodology used in this study is empirical based, with quantitative data collection process, as investigation on relationship between lighting and vision system can be regarded as psychophysics study in visual perception. The implications of results is sought to be applicable to the whole human species sharing similar physiological mechanism, regardless of culture difference.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews the existing evidence for effects of lighting on interpersonal judgements made by pedestrians in residential roads. The first three sections examine current standards considering visual needs of pedestrians in the UK and the critical tasks of pedestrians that can be enhanced by lighting. Then the importance and elements of interpersonal judgement made by pedestrians are assessed. It turns out that only facial recognition was targeted in past studies. The review on the effect of lighting on facial recognition reveals problems with methodologies which are to be improved in this thesis. The distance at which interpersonal judgement might be desirable is also discussed in this chapter.

## 2.2 Current Standards

Lighting of roads for pedestrian traffic in the UK is currently regulated by British Standards BS 5489-1:2013 (supersedes BS 5489-1:2003) *Code of Practice for the Design of Road Lighting - Part 1: Lighting of Roads and Public Amenity Areas* (British Standards Institution, 2012), and BS EN 13201-2:2003 *Road Lighting Part 2-Performance Requirements* (British Standards Institution, 2003b). The S-series lighting classes defined in above two standards are equivalent as the P-series in CIE 115-2010 *Recommendations for the Lighting of Roads for Motor and Pedestrian Traffic* (International Commission on Illumination, 2010). The S- and A- classes in BS EN 13201-2:2003 and the P-classes in CIE 115:2010 are “intended for pedestrians and pedal cyclists on footways, cycleways, emergency lanes and other road areas lying separately or along the carriageway of a traffic route, and for residential roads, pedestrian street, parking places, etc”. For the purposes of reducing crime and suppressing feelings of insecurity, ES- classes of semi-cylindrical illuminance are added for pedestrian areas.

Table 2.1 and Table 2.2 show minimum average illuminance suggested in BS EN 13201-2:2003 and CIE 115:2010, respectively.

**Table 2.1** S- , A- and ES- series of lighting classes in BS EN 13201-2:2003

| Horizontal illuminance | | Hemispherical illuminance | | Semi-cylindrical illuminance | |
|---|---|---|---|---|---|
| **S Class** | $\overline{E}_{h,min}$* | **A Class** | $\overline{E}_{hs,min}$ | **ES Class** | $\overline{E}_{SC,min}$ |
| **S1** | 15 lux | **A1** | 5.0 lux | **ES1** | 10 lux |
| **S2** | 10 lux | **A2** | 3.0 lux | **ES2** | 7.5 lux |
| **S3** | 7.5 lux | **A3** | 2.0 lux | **ES3** | 5.0 lux |
| **S4** | 5.0 lux | **A4** | 1.5 lux | **ES4** | 3.0 lux |
| **S5** | 3.0 lux | **A5** | 1.0 lux | **ES5** | 2.0 lux |
| **S6** | 2.0 lux | **A6** | PND** | **ES6** | 1.5 lux |
| **S7** | PND** | | | **ES7** | 1.0 lux |
| | | | | **ES8** | 0.75 lux |
| | | | | **ES9** | 0.5 lux |

***Note**: To provide uniformity, the actual value of the maintained average illuminance may not exceed 1.5 times the $\overline{E}$ value indicated for the class. ****Note**: PND = Performance Not Determined.

**Table 2.2** P-series of lighting classes in CIE 115:2010

| Lighting Class | Horizontal illuminance | | If facial recognition is necessary** | |
|---|---|---|---|---|
| | **Average $E_{h,av}$ *** | **Minimum $E_{h,min}$** | **Minimum vertical illuminance $E_{v,min}$** | **Minimum semi-cylindrical illuminance $E_{sc,min}$** |
| **P1** | 15 lux | 3.0 lux | 5.0 lux | 3.0 lux |
| **P2** | 10 lux | 2.0 lux | 3.0 lux | 2.0 lux |
| **P3** | 7.5 lux | 1.5 lux | 2.5 lux | 1.5 lux |
| **P4** | 5.0 lux | 1.0 lux | 1.5 lux | 1.0 lux |
| **P5** | 3.0 lux | 0.6 lux | 1.0 lux | 0.6 lux |
| **P6** | 2.0 lux | 0.4 lux | 0.6 lux | 0.4 lux |

***Note**: To provide uniformity, the actual value of the maintained average illuminance may not exceed 1.5 times the value indicated for the class. ****Note**: A higher colour rendering contributes to a better facial recognition

The guidance of selection of lighting class is based on little more than a subjective ranking process: choose from discrete categories on parameters such as traffic speed, traffic volume, traffic composition, ambient luminance, presence of parked vehicles, and necessity of facial recognition. This process is unlikely to be strictly prescriptive in practical lighting applications. There is a risk that in using guidance, users may work backwards to establish the category parameters that give them the light level they want to use.

The illuminance levels, e.g. average horizontal illuminances of 2-15 lux in BS EN 13201-2:2003, were based on the study of Simons et al (1987). The average horizontal illuminances in the field surveys of this study ranged from 1.0 – 12 lux. The results of optimum lighting level (12 lux) may suffer from range bias that the top limit of surveyed illuminances tends to be rated as ‘good’ regardless of what the range is. This point was addressed and discussed by Fotios and Goodman (2012).

There are statements in CIE 115:2010 and BS 5489-1:2013 that “high (or good) colour rendering contributes to a better facial recognition”, which imply benefits of lighting can be maintained while illuminance reduction being trade-off by lamp spectrum. Although such trade-off might be true for brightness perception or obstacle detection, its effect has not been conclusively proved for facial recognition (see section 2.7 for further discussion).

It can be seen that the scientific basis of lighting requirements suggested by current standards have not included consideration on visual needs or visual performance of pedestrians. Empirical evidence from appropriately designed experiments is required for a better understanding.

## 2.3 What are the Critical Visual Tasks of Pedestrians?

For pedestrians, critical visual tasks were suggested by Caminada and van Bommel

(1980) in the early 1980s to be: (1) detection of obstacles, (2) visual orientation, (3) identification of persons and (4) pleasantness and comfort. They further explained the need of identification of persons as “be able to have a ‘good look’ at the other users of street - identification of persons or of intentions”. Simons et al (1987) emphasised the needs of seeing other person and obstacle and put “to see whether other pedestrians represent a threat” as “most important” of the visual tasks, for that the needs of the pedestrians are paramount as regards deterring crime. However, there is again no empirical evidence behind the “identified” visual needs.

The MERLIN project aims to investigate: (1) visual needs of pedestrians using eye-tracker in field (Fotios et al., 2014b; Fotios et al., 2014c); (2) appropriate illuminance regarding detection of pavement obstacle (Fotios and Cheal, 2009; Fotios and Cheal, 2013); (3) how lighting for pedestrians aids reassurance and their confidence when walking alone after dark (Fotios et al., 2014a); (4) lighting and judgements of other persons. This thesis focuses only on the latest aspect: interpersonal judgement.

The term interpersonal judgement is also called interpersonal perception, person perception or impression formation in the area of social psychology. Cook (1971) defines interpersonal perception as the ‘forming of judgements by people about other people, and more especially those judgements that concern people as social animals’, or more precisely ‘the study of the ways people react and respond to others, in thought, feeling and action’. Such judgements do not need to be made consciously.

The ‘interpersonal judgement’ used in this thesis refers to a subset of ‘interpersonal perception’ discussed by Cook (1971). Unlike the process of interpersonal perception in a job interview, the interpersonal judgement made by pedestrian during actual street encounter can be superficial and quick. The main aim of such judgements is to see whether other people represent a threat.

## 2.4 Interpersonal Judgement in Current Standards

The primary aim of lighting in residential roads is to enhance the safety and perceived safety of pedestrians. One basis of personal safety is the ability to make accurate judgements about the intent of other pedestrians, i.e. whether or not they present a threat (Simons et al., 1987). It has been suggested that lighting should enable facial recognition at a distance of 4m (10m), supposedly the minimum (ideal) distance at which an alert person is able to take defensive action if threatened (Caminada and van Bommel, 1980).

In fact, the need to make judgements about other people is recognised in road lighting design standards and guidance. Table 2.3 summarise the content related to this issue from both British road lighting standards and CIE reports.

British Standard BS 5489-3:1992 (British Standards Institution, 1992) stated that to provide a sense of security it should be possible for a pedestrian to recognise whether another person is likely to be friendly, indifferent or aggressive in time to make an appropriate response. To ensure a high possibility of recognition it was recommended that the illuminance on vertical surfaces at the average height of the human face should be ‘adequate’. This ‘adequate’ condition is stated to be generally satisfied by fulfilling the lighting requirements for maintained average horizontal illuminances of 10 lux for category ‘3/1’ roads and 6 lux for ‘3/2’ roads.

Similar guidance appeared in the next version of this document, BS 5489-1:2003 (British Standards Institution, 2003a), with one additional suggestion that good colour rendering should be provided for that ‘recognition of the behaviour and intentions of other pedestrians is important’. Following the latest revision, the need to judge the intent and/or identity of other people at a distance sufficient to take avoiding action if necessary, is identified in the commentary of clause 4.2.2 in BS 5489-1: 2013 (British Standards Institution, 2012). As stated also in BS 5489-1:

2013, good colour rendering is expected to contributes to better facial recognition.

**Table 2.3** Statements on the need of making judgement on other people in British road lighting standards and CIE reports

| Document number | Statement in related clause |
|---|---|
| **BS 5489-3:1992** | In 3.2: To provide a sense of security it should be possible to recognize, in time to make an appropriate response, whether another person is likely to be friendly, indifferent or aggressive. To ensure a high possibility of recognition the illuminance on vertical surfaces at the average height of the human face should be adequate. |
| **BS 5489-1:2003** | In 10.4.1: To provide a sense of security sufficient vertical illuminance should be provided at face level so that it is possible to recognize whether a person is likely to be friendly, indifferent or aggressive, in time to make an appropriate response. |
| **BS 5489-1:2013** | In 5.2.2.1: The road lighting should enable pedestrians and cyclists to discern obstacles or other hazards in their path, and to be aware of the movements and/or intent of other pedestrians and cyclists in the proximity. |
| **CIE 115-1995** | In 9.3: The road lighting should enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity.<br>In 9.3.2: Adequate lighting of vertical surfaces is a requirement for facial recognition and for enabling an act of aggression to be anticipated. |
| **CIE 115-2010** | In 3: Three main purposes of road lighting … 2) allow pedestrians to see hazards, orientate themselves, recognize other pedestrians, and give them a sense of security, … |

The 1995 issue of CIE report 115 (International Commission on Illumination, 1995) noted that the adequate lighting of vertical surfaces is required for both facial recognition and enabling an act of aggression to be anticipated. The recent revision of this document CIE 115-2010 (International Commission on Illumination, 2010) states that the purpose of road lighting includes to allow pedestrians to see and recognise other pedestrians, and offers additional requirements for vertical and semi-cylindrical illuminance that apply if facial recognition is necessary.

Guidance for lighting in residential roads tends to prescribe horizontal illuminances on the ground. However, other pedestrians' behaviour and intention tend to comprise vertical surfaces and thus it might be more appropriate to involve vertical or semi-cylindrical illuminance in the measurements of lighting. Vertical illuminance has been considered in standards.

In BS 5489-1:1992 (British Standards Institution, 1992), adequate illuminance on vertical surface at the average height of the human face is suggested to ensure a high possibility of facial recognition. Two statements in BS 5489-1: 2003 (British Standards Institution, 2003a) also address this point: (1) the provision of lighting designed to meet the requirements of the appropriate horizontal illuminance class normally provides adequate vertical illuminance when using mounting heights of between 4 m and 12 m; (2) it was permitted to specify a semi-cylindrical illuminance in addition to the general lighting class when there were particular problems of crime and personal safety. However, the second was only recommended in exceptional circumstances due to the difficulty in defining the appropriate observer position.

The minimum semi-cylindrical illuminances in range of 0.5-10 lux given in ES-series of lighting classes in BS EN 13201-2:2003 (British Standards Institution, 2003b) are intended as additional classes for pedestrian areas for the purpose of reducing crime and suppressing feelings of insecurity. The horizontal illuminance given in S-series as main class (British Standards Institution, 2003b) are intended for pedestrians and pedal cyclists on footways, cycleways, emergency lanes and other road areas lying separately or along the carriage way of a traffic route, and for residential roads, pedestrian streets, parking places, schoolyards etc.

## 2.5 Importance of Seeing Others Pedestrians

This section reviews the available evidence on why it is important to include interpersonal judgement when examining lighting requirements for pedestrians.

Since the study by Caminada and van Bommel (1980) was published, the key visual needs are typically suggested to be perceived safety, obstacle detection, recognition of the identity and/or intent of others, and also with lighting of an acceptable appearance (Fotios and Goodman, 2012). However, there is no empirical evidence to support these assumptions. Questions on whether these visual needs are the most appropriate factors to characterise road lighting, whether there are other essential visual tasks that need to be included, and the relative importance have yet been answered. Prior to checking any effect of lighting on the ability of making interpersonal judgement, it is necessary to check the importance of seeing other pedestrians using evidence other than anecdote.

The relation between lighting and perceived safety, fear of crime or reassurance in a general sense is beyond the scope of this thesis, and the topic has been well discussed in past studies (Boyce and Gutkowski, 1995; Boyce et al., 2000; Fotios et al., 2014a; Painter, 1996).

With the advances in eye-tracker technology, analysis of fixation and visual patterns with acceptable confidence becomes available. To investigate the spatial extent within which objects are regarded as potential obstacles for each pedestrian when considering where to move at the next moment, Kitazawa and Fujiyama (2010) conducted experiment in laboratory settings using eye-tracker. They asked participants to walk repeatedly forward and back on a 15.6 m long × 3.6 m wide platform in PAMELA (Pedestrian Accessibility Movement Environment Laboratory) and found that pedestrians fixated more on static obstacles than on approaching pedestrians. However, the participants in this study were exposed to the same target pedestrians and this is unrepresentative of the natural outdoor situation, where the need to see approaching people might be reduced.

Two eye-tracking studies investigating visual behaviour during walking as natural activity were carried out. Foulsham et al (2011) instructed participants to have a 10 minute walk outdoor to a cafe as a destination in daytime. Fixations were classified as on pavement, objects or people at far or near distance. The results show that the path was fixated most frequently (56%), while people were fixated 7% when near and 14% when far. Davoudian and Raynham (2012) did the field experiment at both daylight and after dark. Fixation on the path again was found dominant, while only 3% were on other people.

However, the proportion of fixation may not be the most effective parameter to show the significance of visual target for three reasons: (1) visual fixation does not always reflect cognitive attention (Triesch et al., 2003); (2) other social factors such as politeness or civil inattention (Goffman, 2008; Zuckerman et al., 1983) may lead to less direct gaze within certain distance; and (3) proportion of fixation is largely affected by the frequency of event occurrence. Therefore, more approaches are needed to better reveal the importance of fixation pattern.

Fotios et al (2014c) used three different approaches to interpret eye-tracker video records of 40 pedestrians walking outdoors both in the day and after dark to determine the apparent importance of fixation (defined as gaze position remained on the same target area for more than 80 ms) on other pedestrians and how this is influenced by the frequency of occurrence. The three approaches they used were: (1) the proportion of time that fixations were on pedestrians (14%), as used in previous studies; (2) the proportion of fixations at critical moments that were on pedestrians (23%), critical moments being defined by delayed response to a dual task; and (3) the probability of an approaching pedestrian being fixated at least once (86%). Of these three estimates of the relative importance of fixating on other pedestrians, with the former estimate one might be less inclined to consider it is important but with the latter one would be more inclined to suggest it is important. The high probability of fixation suggests that fixating on other people is important, and this is better captured by the critical-fixations than all-fixations. Comparison of the proportion and probability of fixations against the number of other pedestrians encountered suggests that the critical-fixations approach is less effected than are the all-fixations and probability approaches.

## 2.6 Elements of Interpersonal Judgement

This thesis investigates judgement of intent, whether or not an approaching person is considered to present a threat, as extension of facial recognition. Recognition of facial identity may play a part but it is not the whole task. Therefore it may be more appropriate to explore the elements of interpersonal judgement for pedestrians after dark.

Cook (1971) summarised non-verbal information available to make interpersonal judgements in the Chapter 4 of his book *Interpersonal Perception*. He classified non-verbal cues in two general groups: static ones, including face, physique, voice, make-up, hair style, clothes and other man-made adornments (e.g. spectacles); and dynamic ones like orientation, distance, posture, gesture, diffuse body movement, facial expression, gaze direction, tone of voice, features of speech and etc. Among them, the visual cues are of particular interest to investigations of the effect of lighting on interpersonal judgement.

Wittgenstein quoted Augustine's *Confessions I.8.* (Augustine, 1961), in describing and explaining the natural progress of how language is learned in the first Aphorism of his *Philosophical Investigations* (Wittgenstein, 2009) as follow:

> "When they (my elders) named some object, and accordingly moved

> towards something, I saw this and I grasped that the thing was called by the sound they uttered when they meant to point it out. Their intention was shown by their bodily movements, as it were the natural language of all peoples; the expression of the face, the play of the eyes, the movement of other parts of the body, and the tone of the voice which expresses our state of mind in seeking, having, rejecting, or avoiding something. Thus, as I heard words repeatedly used in their proper places in various sentences, I gradually learnt to understand what objects they signified; and after I had trained my mouth to form these signs, I used them to express my own desires." (p. 2)

Expression, the dynamic non-verbal cues which form the 'natural language' of man and animals, evoked the interest of Darwinians and Darwin himself, and through it they saw universality. According to Paul Ekman's preface of *The Expression of the Emotions in Man and Animals* (Darwin et al., 2009), some emotions conveyed by either facial or bodily expressions have signals and 'provide important information to others who observe them'. There are six universally recognised facial expressions (Etcoff and Magee, 1992): neutrality, sadness, disgust, fear, anger, and happiness. Similarly for body posture four recognisable emotions have been proposed: anger, fear, happiness, and sadness (de Gelder and van den Stock, 2011).

There is evidence that facial expression and body posture contribute to social judgements that are related to evaluation of threat (Porter et al., 2007; Willis et al., 2011a; Willis et al., 2011b). Willis et al (2011a) found that faces exhibiting angry expressions were less approachable than those with happy expressions: a similar conclusion was drawn for emotions conveyed by body posture. Approachability here was defined as the willingness to *approach* a stranger in a crowded street to ask for directions, which might be considered the polar opposite of a judgement of threat intent and the resulting motivation to *avoid*. The direction of gaze is also a social signal, with direct gaze associated with approach motivation and averted gaze with avoid motivation (Ellsworth et al., 1972; 2011b). Willis et al (2011b) also found that angry faces were considered less approachable when displaying direct eye gaze than averted eye gaze.

Gao and Maurer (2011) suggested that more details are needed to recognise facial expression than to recognize facial identity and as a result, identity may be easier to recognise than expression under conditions that degrade the transmission of higher spatial frequencies in a face image such as large distances and poor lighting.

It can be seen that though many features may contribute to an interpersonal judgement, researchers within the lighting community have tended to target only on facial recognition. Thus the determinants of interpersonal judgment for pedestrians need to be investigated prior to any conclusions from evidence of facial recognition only.

## 2.7 Effects of Lighting on Facial Recognition

While the need to make judgements about possible threatening behaviour was recognised by those who proposed the basis for design criteria (Simons et al., 1987), and is an assumption of design guidance, research within the lighting community has tended to target only facial recognition, and in particular whether it is affected by the spectral power distribution (SPD) of lighting. See Table 2.4 for a summary of past studies on the effect of lighting on facial recognition.

In the facial recognition experiments carried out by Caminada and van Bommel (1980), recognition distances were recorded under different lighting conditions. It was concluded that a semi-cylindrical illuminance of 0.8 lux and 2.7 lux is required to achieve facial recognition at a distance of 4m and 10m respectively.

Rombauts et al (1989) recorded 9 degrees of facial recognition in their experiment.

The results show that 0.4 lux and 3.0 lux are required for facial recognition at 4m and 10m with absence of glare (a shift of 15% extra illuminance is suggested when glare exist), which is somehow consonant with Caminada and van Bommel's. Although the primary form of basis of lighting level on facial recognition has been set, current researchers (Fotios and Raynham, 2011) suggest the methodologies used in the two studies more than twenty years ago have defects in seeing facial recognition only as critical task as well as in stop-distance approach.

**Table 2.4** Summary of past studies on the effect of lighting on facial recognition

| Study | Method | | | Effect of | |
|---|---|---|---|---|---|
| | Target | Procedure | Task | Lighting level | SPD |
| **Alferdinck et al., 2010** | Real person | Evaluate recognisability | Rating | Yes | No |
| **Boyce & Rea, 1990** | Real person | Stop-distance* | Matching | Yes | No |
| **Caminada and van Bommel, 1980** | Real person | Stop-distance | Identification (self-report) | Yes | Not tested |
| **Dong et al., 2014** | Photograph | Observe at fixed distance | 1) Identification 2) Matching | Yes | Not tested |
| **Knight, 2010 Knight et al., 2007** | Photograph | Stop-distance | Identification | Not tested | Yes |
| **Lin & Fotios, 2013** | Photograph | Observe at seven set distances | 1) Identification 2) Rating | Not tested | Yes, when task is difficult |
| **Okuda & Satoh, 2002** | Real person | Rate visibility of component | Rating | Yes | Not tested |
| **Raynham and Saksvikrønning, 2003** | Real person | Stop-distance | Identification (self-report) | Yes | Yes |
| **Rea et al, 2009** | Real person | Stop-distance | Matching | Not tested | No |
| **Rombauts et al, 1989** | Real person | Evaluate recognisability | Rating | Yes | Not tested |
| **Romnée & Bodart, 2014** | Photograph | Stop-distance | 1) Identification 2) Matching | No | No |
| **Yao et al, 2009** | Photograph | Stop-distance | Identification | Not tested | Yes |

***Note**: Stop-distance: participants asked to walk towards the target or the other way round.

Boyce and Rea found that 'intruder' can be detected and recognised at greater distance with presence of higher lighting level, and SPD (LPS versus HPS) has no effect on either intruder detection or facial recognition (Boyce and Rea, 1990). Okuda and Satoh (2000) explore the evaluation method on the visibility of human face using verbal descriptions under various lighting conditions and found the contrast between the cheek and eye was one of the important factors.

For SPD, published studies do not enable a definitive conclusion as to whether light source SPD affects the ability to recognise faces. Among the seven studies in the lighting research, three suggest a significant effect of lamp SPD on facial recognition tasks (Knight et al., 2007; Raynham and Saksvikrønning, 2003; Yao et al., 2009; Knight, 2010), while other four does not suggest a significant effect (Alferdinck et al., 2010; Boyce and Rea, 1990; Rea et al., 2009; Romnée and Bodart, 2014).

Lin and Fotios (2013) suggested that an effect of SPD on facial recognition is expected when the duration of observation is brief or when the target is small, i.e. the task is relatively difficult. Additional evidence is available from two studies. First, investigation of visual acuity at photopic levels suggest that foveal acuity is affected by lamp SPD when the task is small and test participants are encouraged to guess the smaller sizes not otherwise clearly visible (Berman et al., 2006). Second, better recognition of celebrities were found when using colour photographs than grey scale versions, if facial information was made less visible by blurring (Yip and Sinha, 2002). This may suggest that colour information can enhance facial recognition performance when the detail of a target is reduced.

There are several possible reasons why the methodologies used in the past studies of facial recognition have led to mixed results.

First, these studies tended to measure recognition of well-known faces or recognition of a target face from a set of reference faces. Both approaches may be inappropriate because either of them may not be a sufficiently demanding task to discriminate between light sources (Fotios and Goodman, 2012). Either recognising celebrities or picking from sample faces is different from the real interpersonal judgements that need to be performed naturally under lighting in residential roads. The identity of a person may not convey the most important pieces of information on threat judgement.

Second, past studies have not addressed the interpersonal distance at which it might be desirable to make judgements about other pedestrians. The recognition distances recorded as a test variable to reflect the ability of facial recognition reported in past studies are somewhat arbitrary. Image that in one study, test participant walking toward the target participant from 30 m away using stop-distance method with unlimited duration and the participant stopped at 10m, hence the average observation distance is 20 m. It is possible that at nearer distances (e.g. 10 m) any effect of SPD is not significant because the face is of a large size, whilst at further distances (e.g. 30 m), where the face is small, then an improvement due to SPD may be of benefit (Lin and Fotios, 2013).

Third, during the stop-distance process, both the lighting condition on observers' eyes and a target face are changing - probably also the distance and duration. This may increase the error of experiment. What would be better is to control the variable more strictly: e.g. test the ability of facial recognition under different lighting conditions but at consistent sizes and consistent durations.

In addition, the duration of observation, which is also one of the determinants for interpersonal judgement, is not mentioned in the past studies. It is unrealistic for people to gaze or look directly at unfamiliar others for more than several seconds (Goffman, 2008; Zuckerman et al., 1983). Looking at others when eye-contact is engaged can be perceived as uncomfortable or a signal of dislike and/or threat (Argyle et al., 1974).

## 2.8 Interpersonal Distance

Past studies have tended to identify the distance at which a correct judgement of facial recognition was achieved, but not the distance at which this judgement might be desirable in a real setting. In this section, desirable distance was examined from theory and experiments of comfort.

Interpersonal space, also called personal space, means the area surrounding a person into which it is preferred that intruders do not come; maintaining this space allows people to operate at acceptable levels of stress (Evans and Howard, 1973). It is also suggested that the interpersonal distance is the distance we tend to keep between ourselves and those we do not expect to interact with (Sundstrom and Altman, 1976).

Gibson (1950) used the hypothetical example of an ancestor *genus homo* in order to illustrate the meaning conveyed by interpersonal distance:

> For example, one conceivable object to which he must have been sensitive was a sabre-toothed tiger or some beast of equal ferocity. His conduct must have been rather nicely adjusted to distance when he encountered one in open country, varying as the retinal image varied in a precise way. To the tiger at a mile he could react by going about his business. To the tiger at 400 yards he should have reacted by going in another direction. To the tiger at 10 yards he must have reacted (if he was one of our ancestors) by running like the wind. His behaviour was graded in relation to a variation of his retinal images. *(Gibson, 1950, p. 197)*.

Past studies of facial recognition have not addressed the interpersonal distance at which it might be desirable to make judgements about other pedestrians, and this is important because it affects the visual size of the task. Caminada and van Bommel

(1980) proposed a requirement to recognise the face of an approaching pedestrian at 4 m at least. This is rounded from the minimum public distance by Hall (1969): a distance of 12 feet (3.7 m) being suggested as the minimum distance at which an alert subject would be able to take evasive or defensive action if threatened. An ideal facial recognition distance was suggested to be 10 m, which is the transition point between close and far phases of public zone defined in Hall's system of interpersonal space (Hall, 1969).

However, others consider these distances to be too short. In the discussion of Luymes and Tamminga (1995) about public safety and urban planning, they suggest that where pathways are intended for night use, lighting should be provided to a level which will allow a user to recognise another person's face at a distance of 25 m. The original source of this is an unpublished report from the Metropolitan Toronto Action Committee (METRAC) on Violence against Women and Children: Women's Safety Audit Guide (1989). However, the original document is not available from METRAC or elsewhere. In some later adopted safety audit checklists drawn and adapted from sources including METRAC *Womens' Safety Audit Guide (1989)* or METRAC *Women's' Safety Audit Kit Guidebook (1989)*, this issue is stated in checklists as: "Is lighting adequate for someone to see another person 20 metres (60 feet) away?" (Cowichan Women Against Violence Society, 1998). It seems that the purpose of safety audit guides does not require the distinguishing between 'identify someone' and 'facial identification' or '20-25 metres' and an ambiguous 'distance'. It should be noted that though different groups of users, such as women or the elderly, might have different levels of visual need hence different lighting requirements, this thesis is sought to address on general population.

Dravitzki et al (2003) concluded "*the literature indicates that lighting for pedestrians should be high enough for facial recognition at 15 metres, because this is considered a reasonable distance at which to make eye contact with someone you are about to pass*." They refer to two sources for this. One is a book *Safer City*

*Centres: Reviving the Public Realm* edited by Oc and Tiesdell. The book contains a chapter by Townshend (1997) who suggested that once interpersonal distance is 'reduced below 15 m, the space in which we have time to react to avoid trouble, or simply an undesirable situation, becomes reduced beyond comfortable levels'. The second source which is a 2002 guide from the government of South Australia does not appear to be available. In addition, Colquhoun (2004) suggests that lighting in public spaces should be adequate to have a good look at another person at a reasonable distance "*not more than 12 to 15 meters*". However, supporting evidence is not provided.

### 2.8.1 Classification of Interpersonal Space

Caminada and van Bommel (1980) established their critical distances for interpersonal judgements referring to Hall (1969). In Hall's discussion of the term proxemics (man's use of space) following observations of animals and people in natural situations, he defined four interpersonal distances: intimate, personal, social and public. For example, the border set between personal and social distance is at 4 feet (1.22 m) with the definition that nobody touches or expects to touch another person: the border between social and public distance was set at 12 feet (3.66 m) - the distance at which Hall alleged an alert subject could take evasive or defensive action if threatened. See upper part of Figure 2.1 for illustration of interpersonal space defined by Hall (1969).

From Hall's book *The Hidden Dimension (1969)*, it can be seen that Hall's apparent aim was to relate the interplay of the senses to interpersonal distances. The phenomenon of regulations on the space around human is revealed from various aspects including behavioural, physiological, psychological, cultural, social, art and etc. Definitions of the four distances were compiled from observations and interviews. The evidence appears to be largely anecdotal and Hall himself acknowledges that it provides only a first approximation. It does not appear that he intended for the findings to be interpreted as evidence for marking critical distances which specifically suits the situation of pedestrian. Thus Hall's data alone do not provide convincing evidence that 4m is a critical distance for facial recognition or other interpersonal judgements.

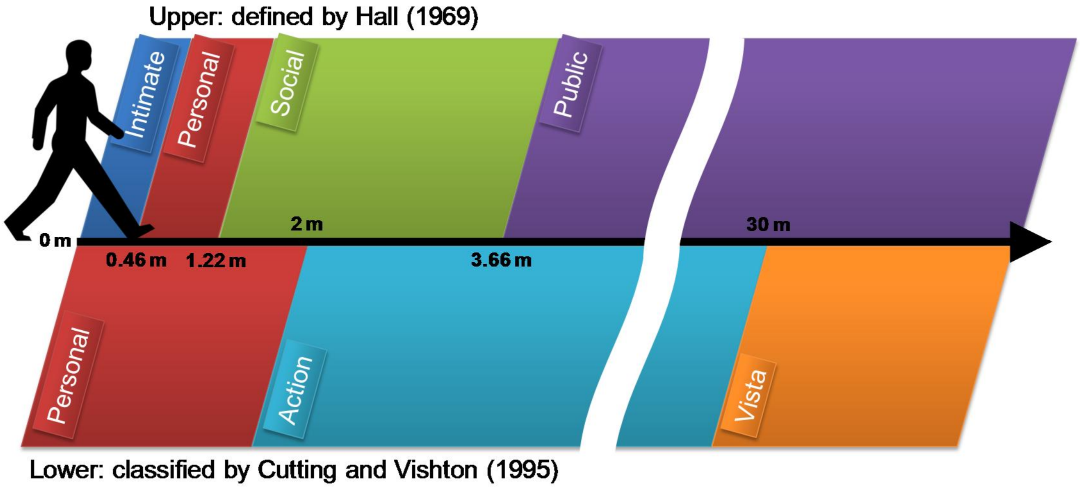



**Figure 2.1** Illustration of interpersonal space defined by Hall (1969) and classified by Cutting and Vishton (1995)

Interpersonal space was also classified by Cutting and Vishton (1995). They suggest three zones: (1) personal space (< 2 m), space within arm's reach and slightly beyond, within which other people are allowed to enter only in situations of intimacy or public necessity; (2) action space (2 m - 30 m), circular region just beyond personal space and is a space of an individual's public action: we can talk within it without too much difficulty and if need be we could toss something to a compatriot or throw a projectile at an object or animal; and (3) vista space (> 30 m), the border between personal space and vista space was set at 30 m because "*the utility of disparity and motion perspective decline to our effective threshold value of 10% at about 30m*". See lower part of Figure 2.1 for illustration of interpersonal space classified by Cutting and Vishton (1995).

The two approaches to categorising personal space are not consistent. It is also unlikely that there is a universal optimum distance: past studies suggesting distances between strangers to be random (Burgess, 1983) and there are differences between cultures, for example it is known that people from North America and Northern Europe have larger zones of personal space than those from the Mediterranean (Evans and Howard, 1973). Caminada and van Bommel (1980) adopted the minimum public distance (4m) defined by Hall in setting lighting requirements, to be the distance at which facial recognition should be performed. If the definition of Cutting and Vishton (1995) had been adopted by Caminada and van Bommel (1980), then maybe the critical distance of facial recognition would be set at 30 m: the border between their action and vista spaces, rather than the border between Hall's (1969) social and public zones. Therefore, further evidence was sought from studies attempting to directly measure interpersonal distance in the situation of pedestrians in residential areas.

### 2.8.2 Effect of Lighting on Interpersonal Distance

Though Hall was aware that the measured distances may change somewhat with personality and environmental factors, e.g. 'a high noise level or low illumination will ordinarily bring people closer together' (p116), his work did not specifically address interpersonal judgements at low light levels and this raises a further question as to whether it is a suitable basis for road lighting.

One criterion to identify critical interpersonal distance may be the ability to perceive details about others. Early in 1877, German architect Maertens introduced the human scale into urban design (Moughtin, 2003). He suggested that the nasal bone is a critical feature for the perception of the individual and considered a visual angle of one minute as the smallest size of detail discernible. He then proposed critical distances from this, including 12 m (at which people can be distinguished), 35 m (at which the face becomes featureless) and 135m (body gesture can be discerned).

There are two lab-based studies on lighting and interpersonal distance. Adams and Zuckerman (1991) examined interpersonal distance for comfort at low (1.5 lux) and high (600 lux) light levels using a stop-distance procedure. The mean comfortable distance was greater under low illuminance (1.17 m) than under high illuminance (0.53 m), indicating a preference for greater separation from unknown people at night-time than at daytime. Fujiyama et al (2005) also used a stop-distance procedure to investigate comfortable distances under five illuminances, ranging from 0.67 lux to 627 lux. Ten stationary participants were asked to say "stop" when they felt uncomfortable about an unfamiliar person walking towards them. The results are reported only graphically and without error bars or similar to indicate variance. Mean comfort distances lie in the region of 4.0 to 5.2 m, with a slight trend to decrease at higher light level. Comfort distances at 0.67, 2.8 and 5.5 lux were significantly longer ($p<0.05$) than that at 627 lux, but they did not find a significant difference between comfort distances at 12.3 and 627 lux.

The results from Fujiyama et al suggest comfortable interpersonal distances that are longer (4.0 to 5.2 m) than do the results from Adams and Zuckerman (0.53 to 1.2 m). Both studies were carried out in interior spaces. One difference between them is the size of the test environment: Adams and Zuckerman used the smaller room, of approximate area 30 $m^2$ (dimensions: 5.18 m x 6.1 m) while Fujiyama et al used the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) which is larger (80 $m^2$). Thus there may be a range bias: Adams and Zuckerman used a smaller room which resulted in their estimate of comfort distance being shorter.

Both studies (Adams and Zuckerman, 1991; Fujiyama et al., 2005) on interpersonal distance used stop-distance procedures for measuring comfort: the test participant and/or the experimenter walk towards one another and the test participant stops walking (or otherwise indicates) at the point where the presence of the other person becomes uncomfortable. The stop-distance procedure has been regarded as an attractive technique for measuring personal space since it places the subjects in a real situation (Hayduk, 1978). It may however provide an unrepresentative level of comfort if carried out in a laboratory where test participants are not subject to the same types of discomfort and fear as they might experience in real streets. Concern of laboratory studies are that test participants know they are being observed which may affect their behaviour (Sundstrom and Altman, 1976) and that the level of reassurance (Fotios et al., 2014a) does not reflect that experienced in outdoor locations – it is unlikely that confederate pedestrians in the experiments will be considered as threatening, and will thus be allowed to come closer for a given level of comfort (Sundstrom and Altman, 1976). These concerns are addressed in field studies.

Apart from comfort distance, collision avoidance distance under different lighting levels was also measured by Fujiyama et al (2005). Test participants were used in pairs, simultaneously walking towards one another, and the distances between the two points at which participants started avoidance manoeuvres were recorded. Mean collision avoidance distances were in the region of 8.0 to 9.0 m for the four lower illuminances (0.67, 2.8, 5.5 and 12.3 lux), reducing to 6.0 m for the higher illuminance (627 lux). These distances are longer than those reported for comfort. Their statistical analyses of differences between illuminances suggests a mixed pattern and may suffer from the small sample size (n=10).

There are two studies investigated interpersonal distance outdoors, but lighting condition is not considered. Sobel and Lillith (1975) observed the movements of unaware members of the public in a shopping street. Colleagues would walk toward approaching members of the public without changing their direction whilst observers noted the distance at which members of the public took collision avoiding action. The average avoidance distance was only 1.18 m, surprisingly short. In this study we do not know how crowded the pavement was and how far ahead of the target it was that the colleague appeared; both would affect the avoidance distance. Townshend's (1997) proposal of a minimum comfort distance of 15 m was determined using an after-dark field study in which he asked members of the public to estimate the distance at which they would be comfortable about an approaching person or group of people. This is a greater distance than reported by others, perhaps because Townshend sought an estimate by perception, not by actual behaviour.

Table 2.5 summarises past studies of desirable interpersonal distances for comfort and collision avoidance. Figure 2.2 shows interpersonal distances plotted against illuminance, from the studies by Adams and Zuckerman (1991) and Fujiyama et al (2005), these having used and reported trials at more than one illuminance.

**Table 2.5** Past studies of interpersonal distances between pedestrians

| Study | Method | Type | Results | |
|---|---|---|---|---|
| | | | Dim lighting | Bright lighting |
| **Adams and Zuckerman, 1991** | Laboratory | Stop-distance | 1.17 m (1.5 lux) | 0.53 m (600 lux) |
| **Fujiyama et al, 2005** | Laboratory | Stop-distance | 5.2 m at 0.67 lux ($p<0.05$)*<br>5.2 m at 2.8 lux ($p<0.01$)<br>4.6 m at 5.5 lux ($p<0.05$)<br>4.3 m at 12.3 lux (n.s.)** | 4.0 m (627 lux) |
| **Fujiyama et al, 2005** | Laboratory | Collision avoidance distance | 9.0 m at 0.67 lux (n.s.)<br>8.3 m at 2.8 lux ($p<0.05$)<br>8.8 m at 5.5 lux (n.s.)<br>8.8 m at 12.3 lux ($p<0.05$) | 5.9 m (627 lux) |
| **Townshend, 1997** | Field interview | Preferred distance | 15.0 m | NA |
| **Sobel and Lillith, 1975** | Field observation | NA | NA | 1.18 m (daylight) |

***Note**: difference between comfort distances at dim light level and 627 lux reported by Fujiyama et al. (2005). ** **Note**: n.s. = not significant ($p>0.05$).

In Figure 2.2, three of the data sets present linear relationship between preferred distance and illuminance. However, the three datasets do not appear to be associated; the collision avoidance distances reported by Fujiyama et al (2005) using stop distance are greater than their comfort distances at all illuminances, and these in turn are greater than the comfort distances reported by Adams and Zuckerman (1991).

Neither Table 2.5 nor Figure 2.2 suggests conclusive evidence of a desirable minimum distance for making interpersonal judgements regarding intent. One reason is that different methods have been used and there is often low correlation between dependent measures of personal space: different techniques measure different aspects of behavioural responses to violation of personal space (Evans and Howard, 1973).

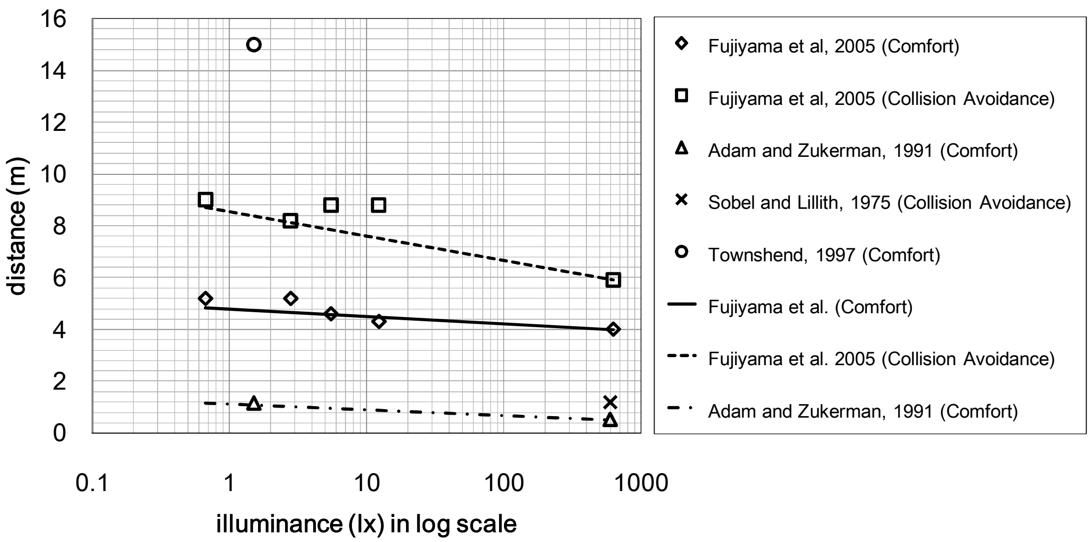



**Figure 2.2** Illuminance plotted against interpersonal distances for comfort or collision avoidance

## 2.9 Summary

This chapter reviewed past studies related to lighting for pedestrians, particularly its effect on interpersonal judgement. Interpersonal judgement is no doubt an important issue as it is mentioned in both British Standards and CIE reports that include requirements of lighting for pedestrians. However, the lighting parameters such luminance, illuminance and spectrum suggested by the current British standards and CIE technical reports are lack of empirical evidence.

Reviews of the importance of making interpersonal judgement of other person have been empirically verified by the results of eye-tracker studies: other pedestrians are fixated at high probability. Interpersonal judgements comprise elements including physique, facial identity, emotion, body posture, gait, clothes, decoration and etc., but lighting research has focused only on facial recognition. Nevertheless, the results of lighting studies solely based on facial recognition (the ability to recognise identity) do not lead to consistent conclusions, primarily because of problems of methodology. For example, unlimited observation duration was used but it is not the case in real street encounters. The distance at which interpersonal judgements are desirable also lacks conclusive evidence. Empirical evidence of typical distance and duration are therefore required to develop further experiments with rigid methodologies about the effect of lighting on interpersonal judgements of pedestrians.

# CHAPTER 3 DESIRABLE DISTANCE AND DURATION

## 3.1 Introduction

This chapter aims to explore the evidence for the desirable distance and duration at/within which pedestrians tend to make their interpersonal judgements. Better understanding on comfort distance and typical duration will facilitate with interpretation of the significance of lighting characteristics like illuminance and spectrum, though studies directly addressing on such distance or duration have not been found. Results and methodologies of past eye-tracker studies will be briefly reviewed while new analyses will be performed on eye-tracker records run by a colleague (James Uttley) within the MERLIN project.

## 3.2 Why Bother?

Past studies associated with interpersonal judgements have tended to target primarily facial recognition and review of these reveals mixed results regarding the effects of SPD (see Table 2.4). Mean recognition distances in the two studies ranged from 12 metres (Rea et al., 2009) to 24.9 metres (Boyce and Rea, 1990). Statistical analysis did not suggest SPD to be a significant factor in these two studies. In three studies reporting an effect of SPD, mean recognition distances were in the range of 5.4 metres to 8.45 metres (Knight, 2010; Knight et al., 2007; Yao et al., 2009). As to investigate whether design should account for SPD, these data suggest that distance matters in the experiments, although there are other differences in experimental settings: the former group of studies used a matching task, the latter group used an identification task.

Duration of facial recognition was not considered in the past studies. Recent investigation (Lin and Fotios, 2013) suggested that SPD matters when the task is difficult, and this difficulty is a factor of the procedure (e.g. whether the target face is familiar) and the observation duration in addition to the target distance.

As to the distance, there is evidence that interpersonal distance (and hence apparent size) affects illuminances required for recognition of identity (Caminada and van Bommel, 1980; Rombauts et al., 1989); higher illuminances enable recognition when the approaching pedestrian is further away but recognition reaches a plateau where further increase in illuminance has negligible effect.

As to the duration, interpersonal judgements are usually being made at a brief glance therefore allow unlimited observation time in the methods of past studies is inappropriate.

There are at least two possible reasons that can explain why it is unnatural to ‘keep eyes’ on another person. One reason is that interpersonal judgement is a brief process. Description of this reason can be found in *Intimate Behaviour* (Morris, 1971), that “our brain are so beautifully tuned in to the delicate business of assessing social signals that we can often sum up a social situation in a split second” (p.35). The other reason is that it is unrealistic for people to gaze or look directly at the unfamiliar others for more than several seconds, because of c*ivil inattention*: transient street encounters give visual notice to each other and then withdraw their attention (Goffman, 2008; Zuckerman et al., 1983). This is perhaps because looking at others when eye-contact is engaged can be perceived as uncomfortable or a signal of dislike/threat (Argyle et al., 1974).

Evaluation of optimum lighting characteristics for interpersonal judgements would be aided by better understanding of the desirable distance and duration of such judgement. The data from eye-tracker would be used to benefit the design of experimental settings investigating lighting and interpersonal judgement.

## 3.3 Evidence from Past Eye-tracker Studies

Three past studies have been identified as providing evidence of desirable distance and duration of interpersonal judgement made by pedestrians.

Jovancevic-Misic and Hayhoe (Jovancevic-Misic and Hayhoe, 2009) found in their laboratory experiment that observers handle the uncertainty of a visual scene by proactively allocating gaze on the basis of learned experience. The target pedestrians were asked to perform one of the three behaviours in the 48 laps around an oval track: no collision (safe), act to have collision with test participants (rogue) or equally safe and rogue (risky). A learning effect can be seen from the duration data acquired by Jovancevic-Misic and Hayhoe (Jovancevic-Misic and Hayhoe, 2009). In the first 12 laps, durations of all three were approximately 500ms, but differentiated as laps continued: duration of fixation on safe pedestrians gradually reduced to 200 ms while on rogue pedestrians increased to 900 ms.

Foulsham et al (Foulsham et al., 2011) reported visual fixations based on data from 14 test participants walked a 5-10 minute outdoor walk to a café in daytime. Gazes toward the 133 pedestrians encountered during these trials tended to occur when they first appeared in the field of view; typically while they were still "*several metres away*" (precise distances are not reported). As shown in Figure 3.1, at approximately 4s after first appearing in the field of view, the cumulative probability reaches a plateau of being fixated of ≥70%. Of discrete gazes toward an approaching pedestrian, 26% were in the first three seconds in which they appeared and only 4% were in the last three seconds prior to passing. 75% of pedestrians were fixated within 8 seconds of appearing. These data suggest a tendency to look at people soon after they appear in the field of view and hence when they are further away.

Davoudian and Raynham (Davoudian and Raynham, 2012) used eye-tracker to record fixations of 15 pedestrians after dark whilst walking along three different residential routes. In these trials 55 pedestrians were encountered. Distances at which first fixation occurred were estimated from the video record using the number of parked cars as a guide, these being residential roads, and this was possible for 54 of the 55 pedestrians. Distances at which fixations occurred ranged from 10m to over 50m, with a median of 20 m).

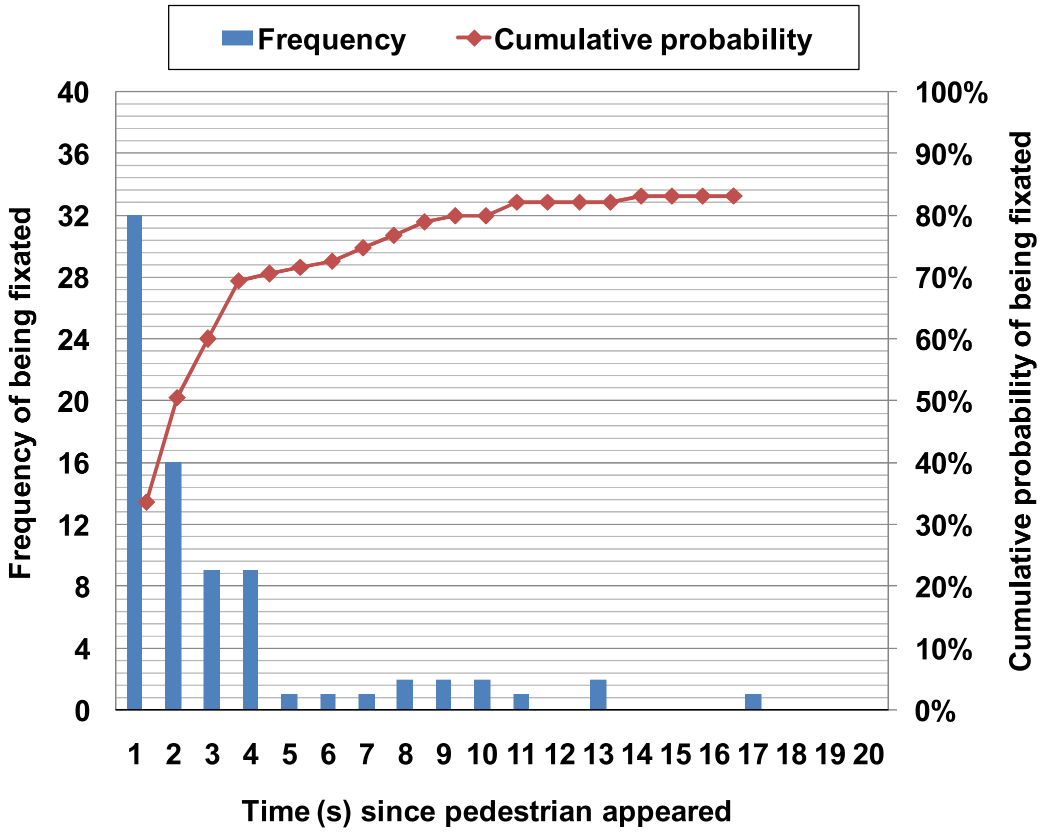



**Figure 3.1** The cumulative probability of a pedestrian being fixated at least once since that pedestrian first entered the field of view (Foulsham et al., 2011, their Figure 8). **Note**: graph redrawn using data supplied by Foulsham.

Results of these three studies show the rough nature on fixation of pedestrian as well as estimations on its ranges of distance and duration. Nevertheless, further data is needed in order to draw typical or critical distance and duration that can be used to guide experiments setting on lighting.

## 3.4 Estimating the Desirable Distance and Duration

### 3.4.1 Method

Further data were sought by new analysis of the eye tracking study reported by Fotios et al (Fotios et al., 2014b; Fotios et al., 2014c). These data are of interest because of the larger sample of test participants (n=40), each of whom carried out the experiment in daytime and after dark, where a much larger number (1538) of target pedestrians were encountered than in past field studies, and where test participants were occupied with a simultaneous dual task (responding to an acoustic signal) whilst walking to occupy resources of attention.

Participants were asked to walk a route of approximately 900m circumnavigating the University of Sheffield campus whilst wearing the iView X™ HED eye-tracking apparatus (SensoMotoric Instruments) for which gaze position accuracy is reported by the manufacturer to be typically between 0.5° - 1.0°. The forward-view and pupil-view cameras were calibrated by observation of standard targets immediately before the experiment began, thus to ensure an accurate eye-tracking was achieved, and eye track position was checked at the end of the trial before the participant removed the equipment to verify it was still accurate.

Each participant carried out the walk twice, once in daylight and once after dark. Tests were taking place between 08:00 and 16:00, and between 17:00 and 20:00 respectively. Orders of the light condition (daylight or after dark) and route direction (clockwise or anti-clockwise) were counterbalanced. Forty participants took part in the experiment (53% male; 58% in the 18-29 age group, 35% in the 30-49 age group and 7% in the 50+ age group). Participants were screened for having normal or corrected-to-normal vision using a Landolt ring acuity test. 40% of participants wore their normal glasses or contact lenses.

The video record of eye tracking shows the scene facing the test participants with a cross-hair superimposed to show the point of fixation. Review of these videos was carried out to determine two characteristics of fixation upon other pedestrians, the distance at which they were fixated and the duration of fixation. Distances were estimated according to the relative size of reference objects in the field of view, for example the length of paving slabs. The duration of observation was established by counting the number of frames for which the fixation cursor remained on a specific target: each frame of the video is 40ms.

Video records were reviewed for all 40 test participants, for both daytime and after dark trials, and for two of the four sections (difficult and unfamiliar) of the route used by Fotios et al (Fotios et al., 2014b). The *difficult* section was a route of approximately 270 m, characterised as such due to a relatively high number of obstacles on the pavement, such as litter bins and lampposts, relatively uneven and poor pavement surfaces, features that required greater attention such as steps and a road crossing, and a high number of other pedestrians. The *unfamiliar* section was a route of approximately 320 m situated in a residential neighbourhood outside the University campus. It was anticipated most participants would be unfamiliar with this area and this was confirmed by ratings of familiarity taken at the end of the experiment. The pathway surface was generally good but included changing gradients, there were some parts without road lighting, and the number of other pedestrians is low. In both sections the road lighting comprised a mix of low pressure sodium (LPS) and high pressure sodium (HPS) lamps.

Within these records, 1538 pedestrians were available in the video, of whom 1128 (73.3%) were fixated at least once. The mean number of fixations (per target pedestrian) was 1.75 (standard deviation SD = 0.895: median = 2, inter-quartile range IQR = 1 to 2) meaning that there was a tendency to look at other pedestrians more than once. The current analysis includes all fixations on other pedestrians: with further resource it would be interesting to separate the first and subsequent fixations.

In some cases, target pedestrians were fixated upon for a relatively long time, e.g. >1000 ms, in which time the distance between the observer and target may have changed if one or other was moving. In the current analysis we measured distance as that of the first fixation. Fixation was assumed if the gaze position remained on the same location of the target person for at least 80 ms (two video frames), also a standard assumption used by others (Marigold and Patla, 2007). Gazes positioned on target pedestrians for only one fixation were ignored and assumed to be saccades, i.e. fast movement of eyes.

### 3.4.2 Results of Distance

Figure 3.2 shows the distances at which the 1128 pedestrians were fixated, these being the median distances across the 40 test participants for each of the four combinations of route section in the day and after dark (i.e. a distribution of n=160). For those pedestrians fixated more than once by a test participant, each fixation distance was recorded, this being a total of 1683 fixations. Note that in 25 of the 160 cases, the data do not exhibit any encounters with pedestrians due to either incomplete fixation records or that the test participant did not encounter any other pedestrians. Note also that these data are collated in 2 m bins and labels for these bins along the x-axis are the maximum distance for that bin. For example, the bin labelled '8' represents the upper limit of the bin collating fixations occurring at distances greater than 6 m but equal to or less than 8 m.

Figure 3.2 suggests a tendency to fixate upon other pedestrians in the range of approximately 4 to 18 m, with a mode of 8 to 12 m. Extreme values of up to 52 m were found in the unfamiliar route section at daytime where only very few people were fixated.

Analysis of the data using the Kolmogorov-Smirnov test, the Shapiro-Wilks test and measures of dispersion did not suggest these data were drawn from a normally distributed population. Hence Table 3.1 summarises the median fixation distances and inter-quartile ranges. Note that removal of apparently extreme fixation distances (as can be observed in Figure 3.2) only slightly reduces these median distances. Overall, the median fixation distance was 10.3 m (inter-quartile range 8.3 to 12.3 m).

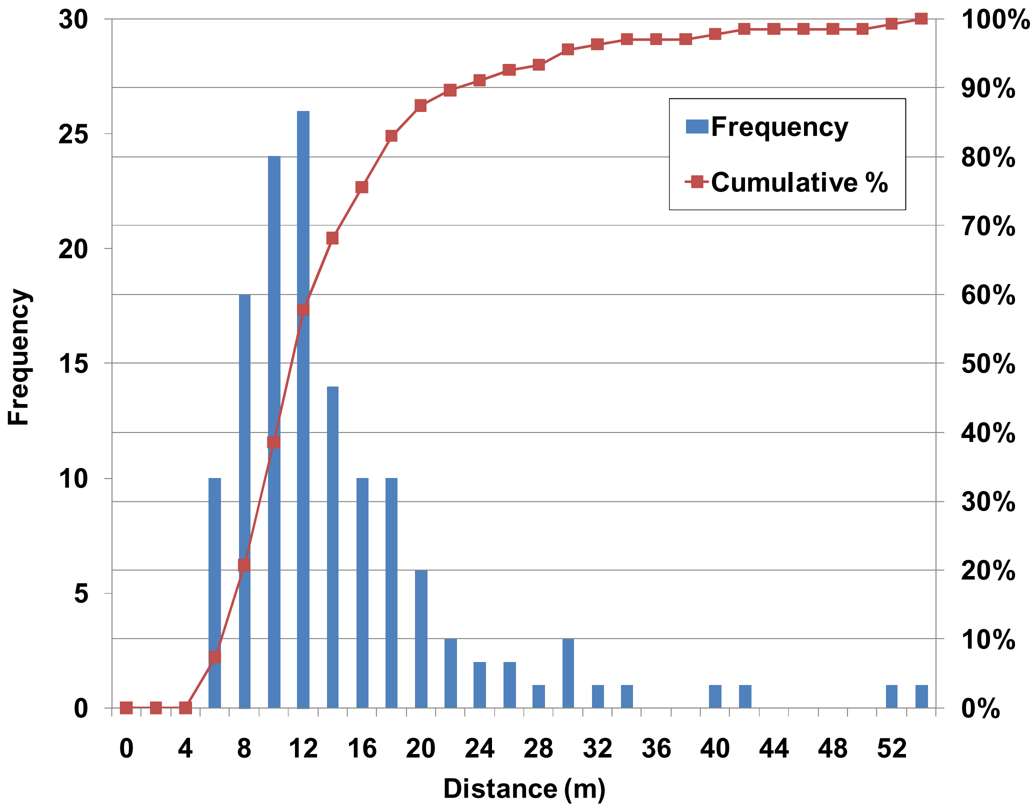



**Figure 3.2** Median frequencies of distances at which each visible person was fixated, as averaged across 40 test participants for daytime and after-dark trials in two route sections. **Note**: the x-axis label of '8' (for example) represents the upper limit of distance, i.e. a bin 6<x≤8 m.

**Table 3.1** Fixation distances averaged across test participants

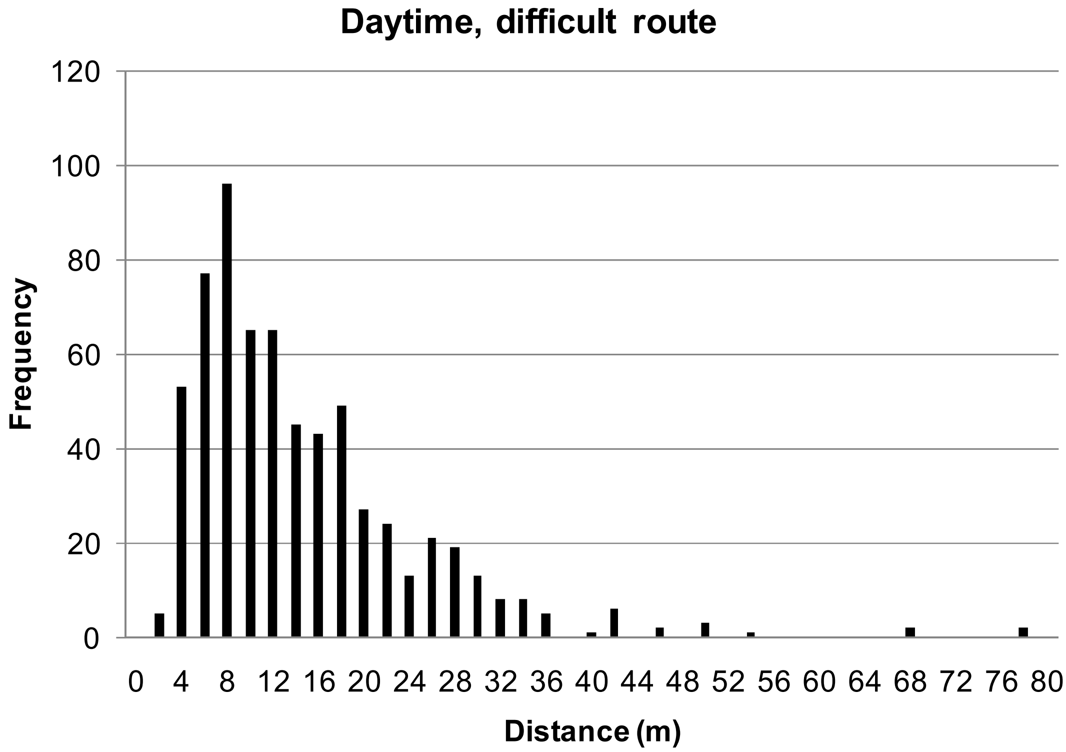
| | **Day** | | **After Dark** | |
|---|---|---|---|---|
| | Median | Inter-quartile range | Median | Inter-quartile range |
| **Difficult** | 11.6 | 8.6 to 13.7 | 8.9 | 7.4 to 10.2 |
| **Unfamiliar** | 19.1 | 14.1 to 27.4 | 11.1 | 8.9 to 14.3 |
| **Both routes** | 13.0 | 9.0 to 15.3 | 8.9 | 7.5 to 10.3 |

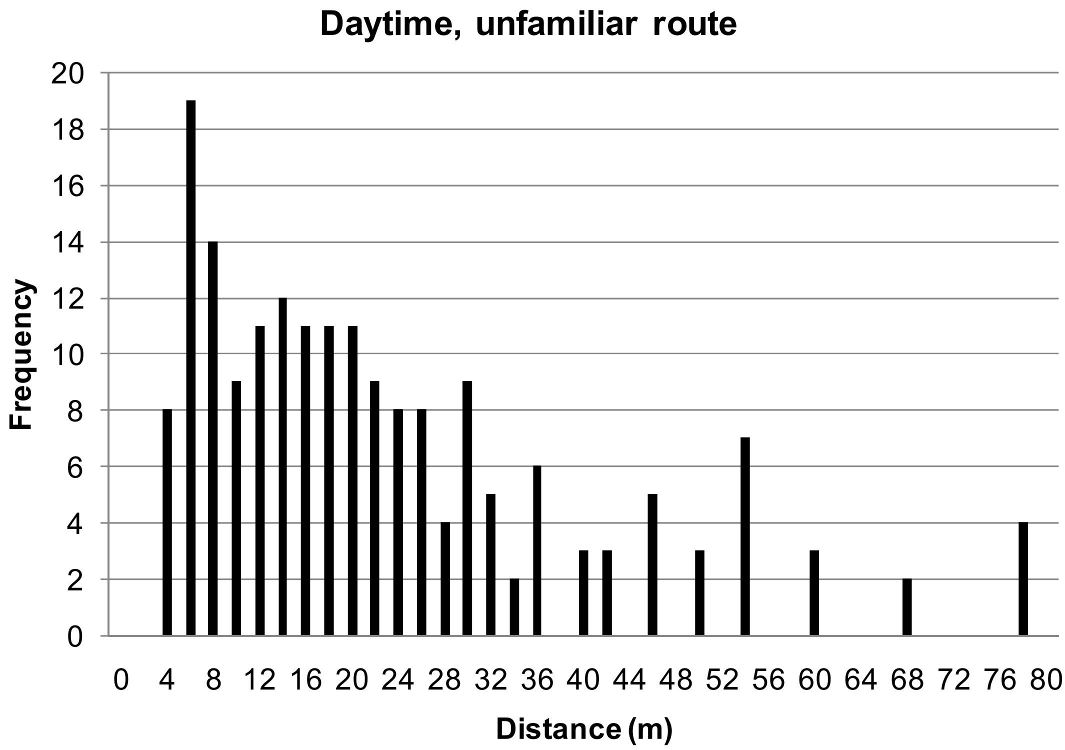
Median fixation distances were shorter after dark (8.9 m) than during daytime (13.0

m). This may reflect a desire to fixate upon others at shorter distances after dark, or alternatively it may be that this is because the lower light level after dark, and hence lower visibility of a pedestrian's features, does not make fixation at greater distances worthwhile. It is also possible that after dark pedestrians at distances above 11.0 m were not sufficiently visible, either for detection with peripheral vision or inspection with foveal vision.

These data comprise two routes (difficult and unfamiliar), each walked in daytime and after dark by 40 test participants. According to the Friedman test the difference between these four conditions is significant ($\chi^2$=23.5, $p<0.001$). Comparison of individual route pairs using the Wilcoxon test suggests significant differences between day and after dark, and between the two route sections ($p<0.01$).

While the data in Figure 3.2 show the typical distances at which test participants fixated on other pedestrians for all four conditions, Figure 3.3 shows the distances at which each of the target pedestrians were fixated for two conditions, the unfamiliar route in daytime and the difficult route after dark. Note that in daytime and after dark, fewer pedestrians were encountered in the unfamiliar section than in the difficult section. As noted above, fixation distance is also a function of the local geography and approaching pedestrians may have entered the field of view at a shorter distance than desirable, contributing to the skew towards shorter distances exhibited in Figure 3.3.

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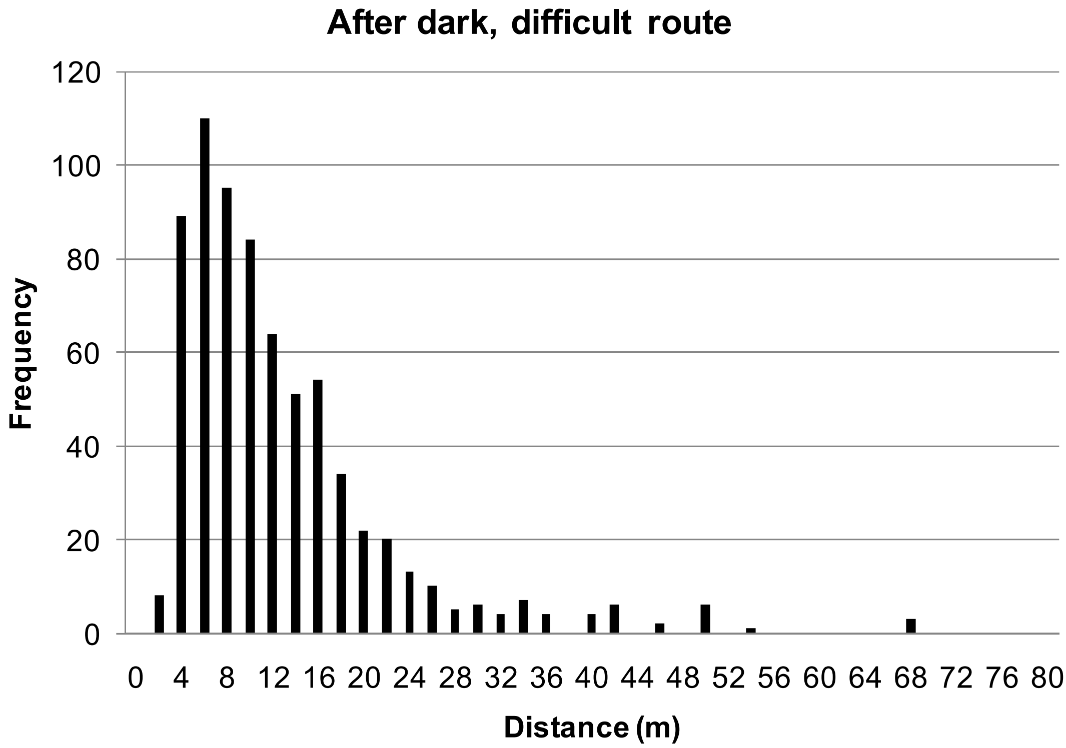


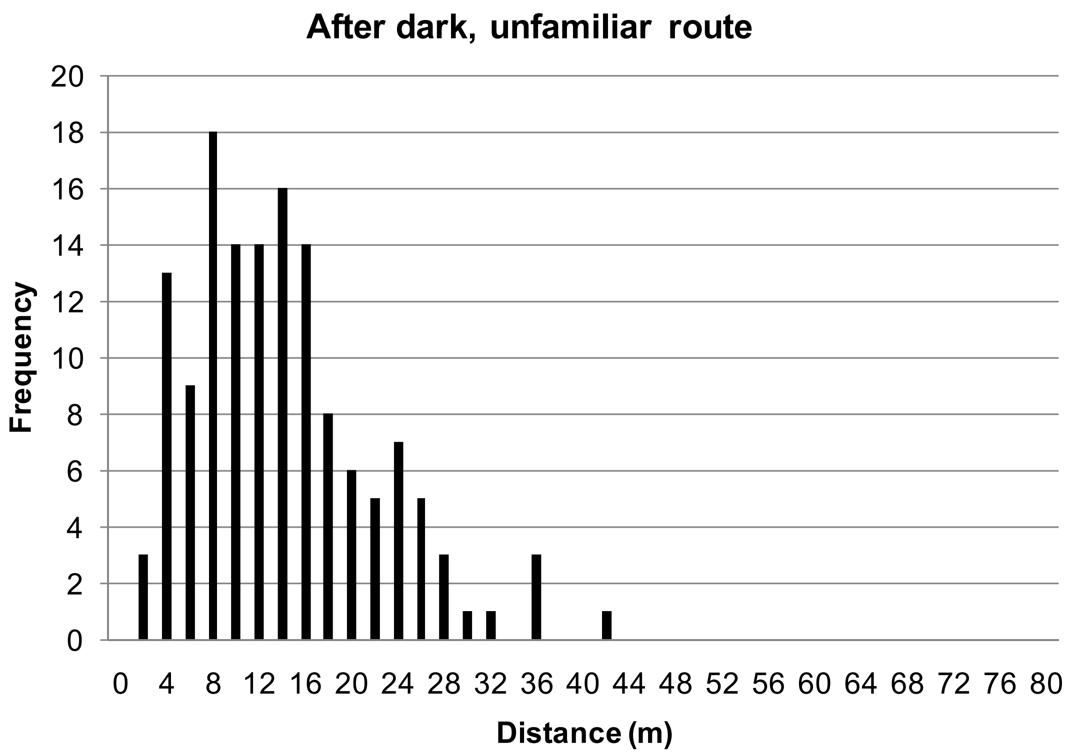




**Figure 3.3** Frequency of the distances at which each of the target pedestrians were fixated in the difficult and unfamiliar route, in daytime and after dark. **Note**: the x-axis label of '8' (e.g.) represents the upper limit of distance, i.e. a bin $6<x\leqslant 8$ m.

### 3.4.3 Results of Duration

For five of the 40 test participants, these being chosen at random, the durations of their fixations on other pedestrians were measured from the video records, for the unfamiliar and difficult route sections. When an approaching pedestrian was fixated more than once, the durations of observation were averaged. The five test participants fixated on a total of 177 pedestrians (100 at daytime, 77 after dark) (Figure 3.4). The observation durations tend to be found in the range of 160 to 720 ms with extreme values of up to 4000 ms.

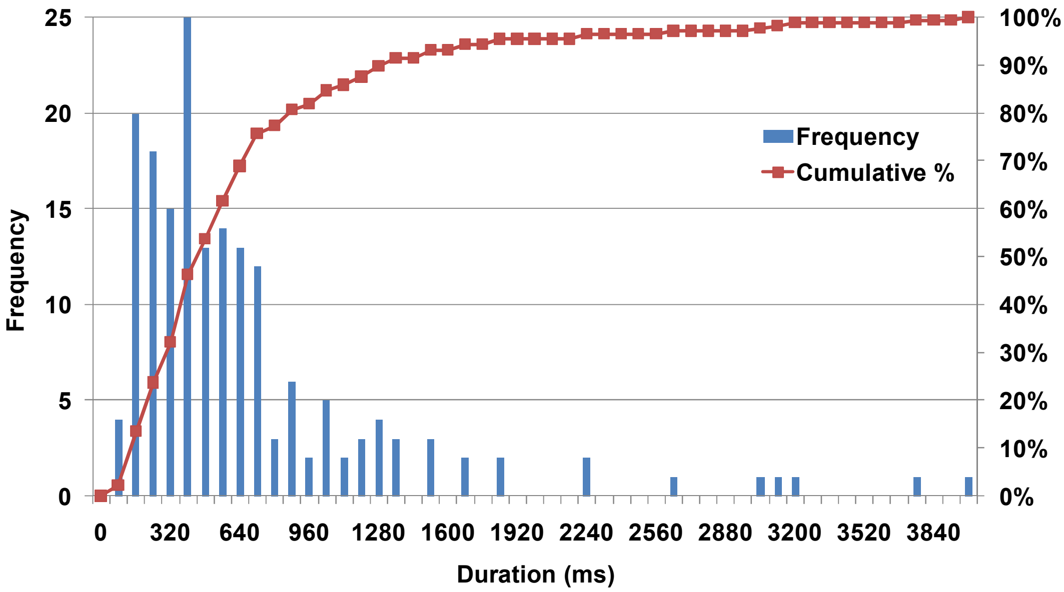



**Figure 3.4** Distribution of durations of fixations on pedestrians. **Note**: the x-axis uses bin intervals of 80 ms. Thus the '320' bin (for example) represents the upper limit of the duration bin 240<x≤320 ms.

In the eye-tracking study (Fotios et al., 2014b) the test participants had unlimited time to fixate on target pedestrians but only did so for brief periods. In past studies of interpersonal judgements permitting unlimited observation duration it may be that they also fixated the targets for a brief portion of the overall period; the data available do not report the overall duration nor the proportion for which fixation actually occurred. The obedience of test participants to follow instructions is well known (Milgram, 1963) and it is suspected this would lead to continuous fixation on the target, in particular in a stop-distance procedure where the task is to keep looking at the target to the point of recognition certainty and then stop. In further studies of interpersonal judgements it would be interesting to record the duration and pattern of visual fixations.

It is clear that the unlimited observation allowed in many studies (Alferdinck et al., 2010; Boyce and Rea, 1990; Knight, 2010; Knight et al., 2007; Rea et al., 2009; Yao et al., 2009) does not match the durations found in natural conditions. The overall median duration of observation was 480 ms (inter-quartile range 400 to 640 ms). Table 3.2 shows that the median duration of fixations after dark was shorter than that during daytime. These data were not found to be normally distributed. The Wilcoxon Signed Ranks Test did not suggest differences between daytime and after-dark, or between the two route sections, to be significant.

**Table 3.2** Duration of fixation upon other pedestrians estimated from the eye-tracking records of five test participants

| | **Number of pedestrians encountered** | **Duration of fixation (ms)** | |
|---|---|---|---|
| | | **Median** | **Inter-quartile range** |
| Daytime | 100 | 480 | 400-620 |
| After dark | 77 | 400 | 280-640 |
| **Overall** | **177** | **480** | **400-640** |

## 3.5 Discussion

Before discussion of the distance at which people choose to observe others, consider the distance at which it should be possible to correctly identify a person, this giving an upper limit as to the distance at which an effect of lighting on interpersonal judgements is of matter. Detail about a target is discerned using foveal fixation, and for this part of the retina the smallest detail that can be resolved with normal vision is that which subtends one minute of arc at the eye. Using this as a basis, and assuming the nose (typical width 10 mm) to be a critical feature for perception of the individual, Maertens (Moughtin, 2003) noted that the face becomes featureless as 35 m. Similarly he suggested the threshold distance for discerning body gesture to be 135 m. Loftus and Harley (Loftus and Harley, 2005) carried out experiments to investigate ability to recognise celebrities, using size and blurring of photographs to simulate variations in interpersonal distance. Their data suggest that recognition performance remains at a plateau of maximum performance (approximately 90%) for distances up to approximately 8 m, reducing to 75% at 10 m (34 ft) and 25% at 23.5 m (77 ft).

The difference between *ability* to see and *desirability* to see was expressed by Townshend (Townshend, 1997) who suggested that while we can normally identify people in daylight at distances of up to 22 m, once this distance is reduced below 15 m the space in which pedestrians have time to react to avoid an undesirable situation becomes reduced beyond comfortable levels. The former distance (22 m) was apparently derived again from Maertens' visual acuity approach; the latter distance (15 m) was as determined by Townshend (Townshend, 1997) in the field study carried out after dark in which test participants were asked to estimate the distance at which they would be comfortable about an approaching person or group of people.

While laboratory studies (Adams and Zuckerman, 1991; Fujiyama et al., 2005) have attempted to measure interpersonal distance for comfort or to avoid collision it appears that these may suffer from range bias, with smaller laboratory spaces leading to smaller estimates of desirable interpersonal distance, and thus we suggest such data are not suitable for establishing the minimum interpersonal distance for outdoor lighting. Laboratory studies of fixation may induce an incorrect estimate of distance due to familiarity with the target pedestrians' identity and behaviour.

To interpret data from eye tracking there is possibility that these data underestimate the desirable distance due to people appearing in the field of view at distances shorter than desirable, that the median measure of fixation is shorter than desired for approximately half of the cases, and also the evidence from Foulsham et al (Foulsham et al., 2011) for the desire to fixate on people soon after they appear in the field of view. Therefore, the upper quartile may be a better measure of desirable interpersonal distance. It should also be noted that we do not know if the tendency for shorter fixation distances after dark indicates a desire for shorter distance or a limitation of vision not to permit fixation at longer distances. In the current data, the upper quartiles were 15.3 m for daytime trials and 10.3 m for after dark trials. These estimates are lower than the median after-dark fixation distance of 20 m determined from an independent eye-tracking study (Davoudian and Raynham, 2012).

One issue associated with using a fixed distance to examine lighting effects is that it precludes use of the stop-distance procedure as used in many past studies of facial recognition with inconclusive results (Boyce and Rea, 1990; Knight, 2010; Knight et al., 2007; Lin and Fotios, 2013; Rea et al., 2009; Yao et al., 2009).

In this chapter, it can be proposed that 15 m is an interpersonal distance at which it would be appropriate to investigate the effects of lighting on interpersonal judgements. It is a shorter distance than that at which recognition judgements are no longer possible and falls within the zone of *action space* (2 m to 30 m) of Cutting and Vishton (Cutting and Vishton, 1995). It is longer than the distances (4 m and 10 m) adopted by Caminada & van Bommel (Caminada and van Bommel, 1980) but agrees better with opinion from design guidance texts which propose there should be ability to have a good look at other people at distances from 12 m to 25 m (Colquhoun, 2004; Dravitzki et al., 2003; Luymes and Tamminga, 1995), and agrees with Townshend's (Townshend, 1997) finding of preferred comfort distance after dark.

It is not suggested that 15 m is an accurate estimate of interpersonal distance for making interpersonal judgements. Analyses of the current data suggest that fixation distance varies with different routes. In this thesis, 15 m is proposed as a better-founded estimate than that used by Caminada and van Bommel.

As to the duration of continuous fixations, the eye-tracking records suggest median fixation duration on other pedestrians of approximately 480 ms, which can be rounded to 500 ms for simplicity. Further evidence that 500 ms is a typical duration of observation is found in the study by Jovancevic-Misic and Hayhoe (2009). The first of their 48 laps of the oval laboratory path best simulated real situations, i.e. before learning of the behaviour patterns of target pedestrians had been gained, and for these laps the fixation duration was also approximately 500 ms.

This chapter has focused on the distance and duration of interpersonal judgements but has not discriminated between fixations on different parts of the body, in particular between face and body. Both are associated with judgements of approachability (Willis et al., 2011a) and intention (Baldwin and Baird, 2001; Meeren and van Heijnsbergen, 2005), but fixations on these elements may be to extract different sorts of information and may be desirable at different distances and require different durations. Further work is required to investigate which parts of body are fixated (e.g. face or arm) and the reasons for such fixation upon others.

It is clear what point gaze is directed to, but the inference about what is being processed is not so easily accessible: gaze location does not uniquely specify the information being extracted (Rothkopf et al., 2007). Though eye pattern of fixation captured by eye-tracker is generally considered to be closely attached to the orienting of attention under natural viewing, the potential dissociation between attention and fixation raise a problem for eye-tracking studies. Another problem is that evidence on visual perception of human face suggests that we may look at other people’s faces more than we need: attention may be preferentially directed to faces rather than to other objects in a scene (Davoodian and Raynham, in press). The dual task method that limits part of the cognitive recourse used in gaining the current eye-tracking data is an attempt to reduce such biases and thus better understand the visual need of pedestrians. Further improvement on interpreting eye-tracking data is still in demand.

The current eye-tracking data suggest a tendency to fixate on other pedestrians more than once and information for different evaluations may have been sought on these separate fixations (Jovancevic et al., 2006). It may be that, following detection with peripheral vision, the first fixation seeks mainly to confirm the location and travel direction of a person and the second, closer, observation is used to gain finer detail to aid judgement of intent. Further data are required to determine what data are drawn during these successive observations. For example, if the first fixation is used to note the location and movement of a person, then the location of fixation on the body may not be critical, but that subsequent fixations in order to interpret likely behaviour may tend to be on the face. Further analyses of why we look when we do would enable the estimates of distance and duration to be improved.

## 3.6 Summary

Desirable interpersonal distances and durations of fixations on other pedestrians after dark were investigated in the chapter. Recognition ability varies with size and significance of the effect of SPD is dependent on task difficulty (Lin and Fotios, 2013), then this knowledge better informs interpretation of data to establish optimum design criteria.

Caminada and van Bommel proposed a requirement to recognise the face of an approaching pedestrian at a minimum distance of 4 m and past studies have tended to examine facial recognition using unlimited duration of observation. It is proposed that experiments seeking to examine the effect of lighting on interpersonal judgements should instead use an interpersonal distance of 15 m and restrict observation duration to 500 ms, these values better representing pedestrian behaviour in natural situations after dark.

# CHAPTER 4 PILOT STUDY

## 4.1 Introduction

Before investigating how lighting can be optimised to enhance interpersonal judgements, there is a need for preparatory studies in order to evaluate the experimental design. Two pilot studies were carried out. The first pilot study is to identify what elements of visual feature are used to guide such judgements, and at what distances we might be able or desire to see them. Fotios and Raynham (2011) suggested that intent might be judged from facial expression: hence the second pilot study is to check whether judgements of threat based on facial expression yield consistent responses. Discussions on the validation of proposed methodologies are also presented.

## 4.2 Information Perceived at Different Distances

This section presents a pilot study carried out to explore the elements of visual features in interpersonal judgements. A test was carried out to identify what features of target pedestrians at different distances would be mentioned in an open response task. This was an open response task in which test participants were instructed to report all the information they could about a target pedestrian, these being photographs of unknown people printed at different sizes to represent different interpersonal distances.

### 4.2.1 Method

Test participants were asked to describe features of target people, these being presented at different sizes to represent different distances, and the task was carried out without time restriction. Four target images shown in Figure 4.1 were used. These were photographs of four different people on a neutral background; they were standing upright and were asked to hold particular objects. One target was female, three were male; all were aged approximately 20 years old; one male was Chinese, the other three were European. Each target person was asked to wear and/or hold specific items and these are described in Table 4.1.

**Figure 4.1** The four target images used in trials (Target 1 to 4 from left to right)

**Table 4.1** Specific objects worn and/or held by the four target people

| Target | Number of objects | Objects held in hands | Objects worn |
|---|---|---|---|
| **No. 1** | 5 | book in right hand, metal bottle in left hand | scarf, hair ornament, black earphone |
| **No. 2** | 2 | a pair of scissors in right hand | headphone set |
| **No. 3** | 6 | fruit knife in right hand, beer bottle in left hand | headphone, glasses, bracelet on right wrist, watch on left wrist |
| **No. 4** | 4 | tripod held horizontally in both hands | shoulder bag, glasses; watch on left wrist |

The aim of the experiment was to determine what features of the targets would be reported at different distances from the test participant. The four distances were 15 m, 35 m, 66 m, and 135 m. The shortest distance, 15m, was derived from

Townshend (1997) who suggested that an interpersonal distance of 15m was required for comfort at night time. This is subsequently found in Chapter 3 to be the desirable distance at which pedestrians tend to fixate on other people. According to Maertens' 35 m is the distance at which human faces become featureless and 135 m is the maximum distance at which we are able to distinguish gender and body gesture under daylight (Moughtin, 2003). The 66 m distance was included to provide an intermediate point between 35m and 135 m. These distances and reasons why they were selected are summarised in Table 4.2.

**Table 4.2** Distance used and reason(s) why they were selected

| Distance | Reason(s) being selected |
|---|---|
| **15 m** | Comfort distance at night time, in Townshend (1997);<br>Desirable distance to make interpersonal judgement found in Chapter 3. |
| **35 m** | Human faces become featureless, in Moughtin (2003). |
| **66 m** | To provide an intermediate point between 35 m and 135 m. |
| **135 m** | Maximum distance at which gender and body gesture can be distinguished under daylight. |

Using these distances in an experiment would be impractical and therefore the targets were observed at constant distance (3.5m) with real distance simulated by target size (Figure 4.2). Each of the four targets was presented at all four distances, thus giving 16 target images, and these were printed on A3 size paper.

The tests were carried out in a laboratory. During trials the laboratory was lit using indirect lighting (6500K fluorescent), with the luminaire placed behind the test participant and aimed toward the ceiling. The wall surrounding the target images was painted white and this had a mean luminance of 1.0 cd/m$^2$. The luminance of the neutral surround on each image was approximately 0.5 cd/m$^2$.

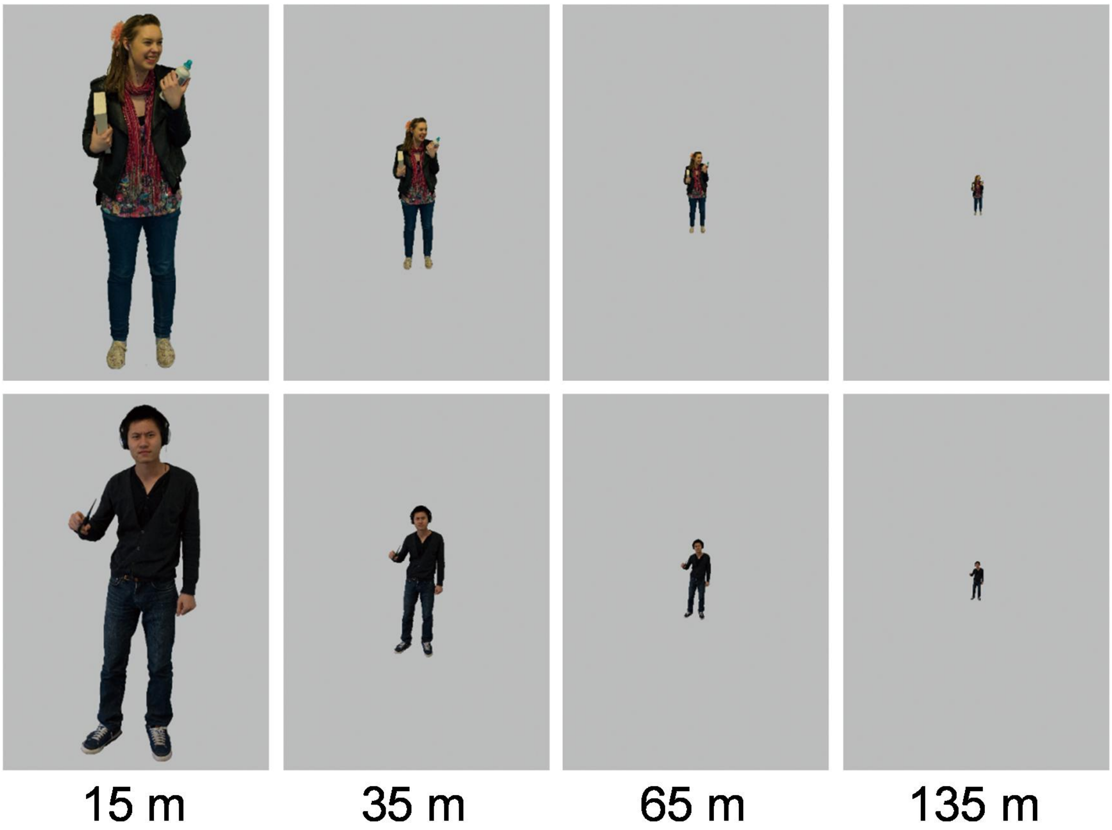



**Figure 4.2** Examples of target people at the four different sizes representing four observation distances. At full size these were printed on A3 paper.

### 4.2.2 Procedure

The experiment was carried out by individual test participants who were seated facing the target images (Figure 4.3). Each trial started with 15 minutes for adaptation to the low light level. A practise image was presented during the adaptation time before any trials: this was a photograph of a target person at 15m, but was a different target to those used in trials. The practice trial was carried out to inform participants of the type of information that was sought and so that they were familiar with the response format.

Test participants observed four images in sequence: each of the four target images was seen at one of the four target distances, and these were presented in a counter-balanced order, balanced so that each target image was the first to be presented for an equal number of trials. The test participants were instructed to report all the information they were able to provide about the target person on the poster. This was done without a time limit. The experimenter recorded which items were correctly reported. For example, stating (correctly) that the target wore a white shirt if this is true would be recorded as a correct response for type and colour of upper clothing, but stating (incorrectly) that the target wore black trainers when they wore yellow trainers would be recorded as a correct response for type of shoes but an incorrect response for colour of shoes.

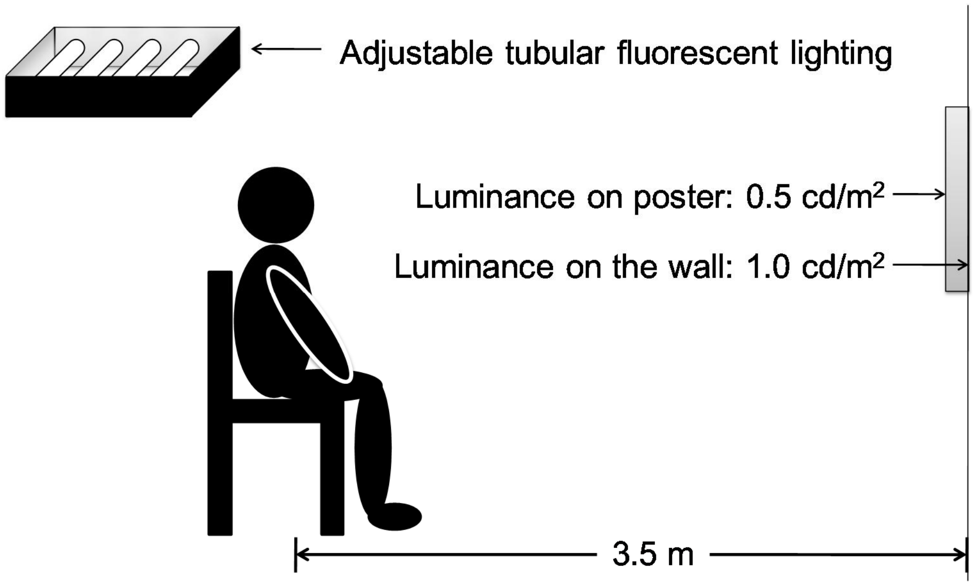



**Figure 4.3** Schematic diagram of test procedure

Twenty test participants carried out the test. These were recruited from staff and students at the University of Sheffield and were paid a small fee for their contribution. Nine were male and 11 were female; they were drawn from European, Middle East and Asian populations; 15 were young (aged 18-34 years old) and five were in the 35-54 age group.

### 4.2.3 Results of Common Features

Common features are defined as the feature that can be reported from any of the target person, normally excluding specific objects worn and/or held by the four target people. Reported features were placed into 14 categories. Table 4.3 shows the frequency by which each feature was correctly identified during trials, summated across targets for each distance and summated across distances for each target. The data in Table 4.3 excludes the specific objects identified in Table 4.1 and which are analysed separately below because these were not consistent between Targets.

**Table 4.3** Frequency of correctly reported features summated across targets

| Feature | Total | Frequency at each distance | | | | Frequency for different targets | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 15m | 35m | 66m | 135m | Target 1 | Target 2 | Target 3 | Target 4 |
| Gender | 67 | 20 | 19 | 19 | 9 | 14 | 18 | 18 | 17 |
| Hair Length | 58 | 19 | 19 | 16 | 4 | 15 | 13 | 15 | 15 |
| Type of clothing: lower body | 56 | 20 | 16 | 13 | 7 | 13 | 16 | 16 | 11 |
| Build | 55 | 19 | 16 | 15 | 5 | 15 | 14 | 13 | 13 |
| Colour of clothing: lower body | 49 | 19 | 15 | 9 | 6 | 9 | 15 | 13 | 12 |
| Type of clothing: upper body | 47 | 20 | 16 | 10 | 1 | 11 | 9 | 16 | 11 |
| Colour of clothing: upper body | 38 | 16 | 11 | 8 | 3 | 10 | 9 | 16 | 3 |
| Age Group | 32 | 19 | 8 | 5 | 0 | 8 | 9 | 9 | 6 |
| Shoe Colour | 27 | 14 | 8 | 4 | 1 | 8 | 9 | 3 | 7 |
| Ethnic Group | 18 | 11 | 3 | 4 | 0 | 5 | 7 | 5 | 1 |
| Shoe Type | 13 | 10 | 3 | 0 | 0 | 2 | 5 | 4 | 2 |
| Hair Colour | 12 | 5 | 5 | 2 | 0 | 3 | 6 | 2 | 1 |
| Facial Expression | 9 | 9 | 0 | 0 | 0 | 5 | 4 | 0 | 0 |
| Facial Feature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 481 | 201 | 139 | 105 | 36 | 118 | 134 | 130 | 99 |

Table 4.3 does not suggest a significant difference between the four target people and the feature frequencies within each Target tend to follow the same trend as with the total frequency. Subsequent analyses therefore do not distinguish between the Targets. Table 4.3 shows that the frequency by which features were reported

decreased as distance increased.

Figure 4.4 suggests a better linear relationship with distance in log scale. At 15 m most features (except for hair colour, facial expression and facial feature) were mentioned correctly in at least 50% of trials. Facial expression was mentioned at 15 m but not at greater distances. At 35 m only half of the features were correctly reported in more than 50% of trials, and at 66 m, only gender, hair length, type of lower clothing and build were correctly reported in more than 50% of trials. At 135 m no features were correctly reported more than 50%.

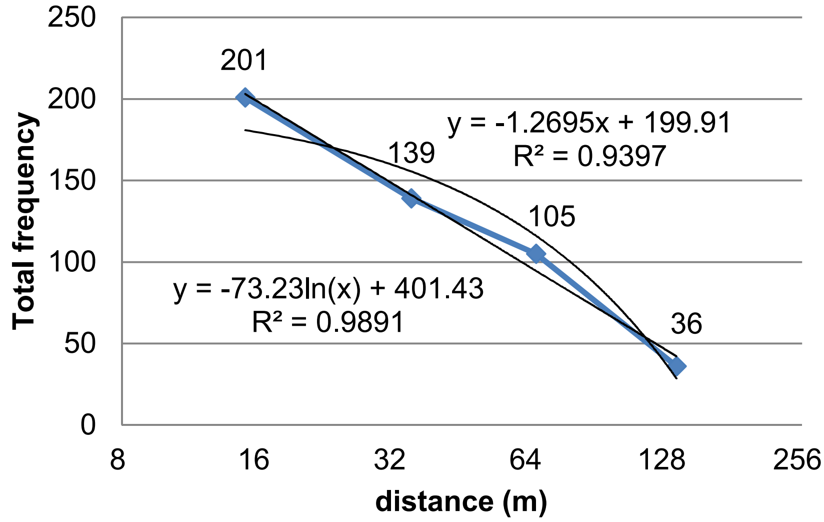
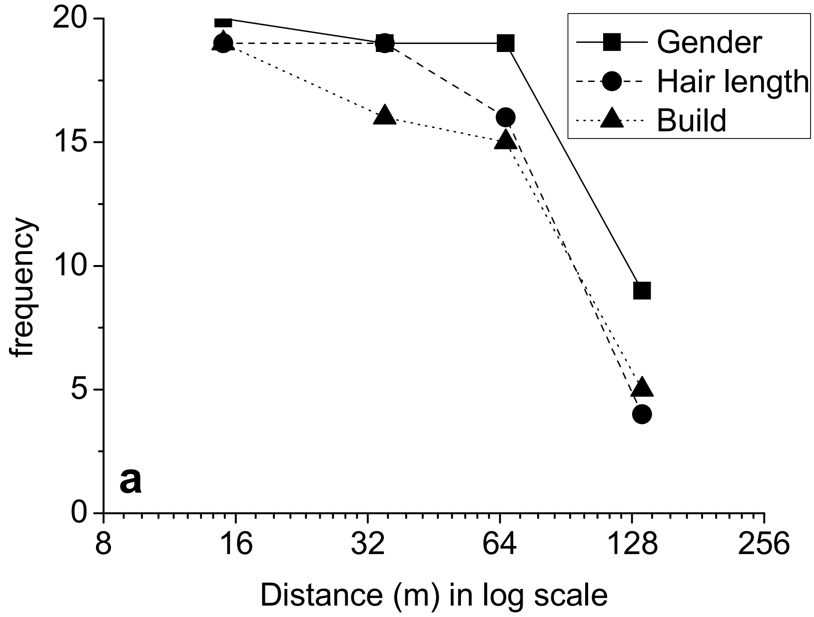
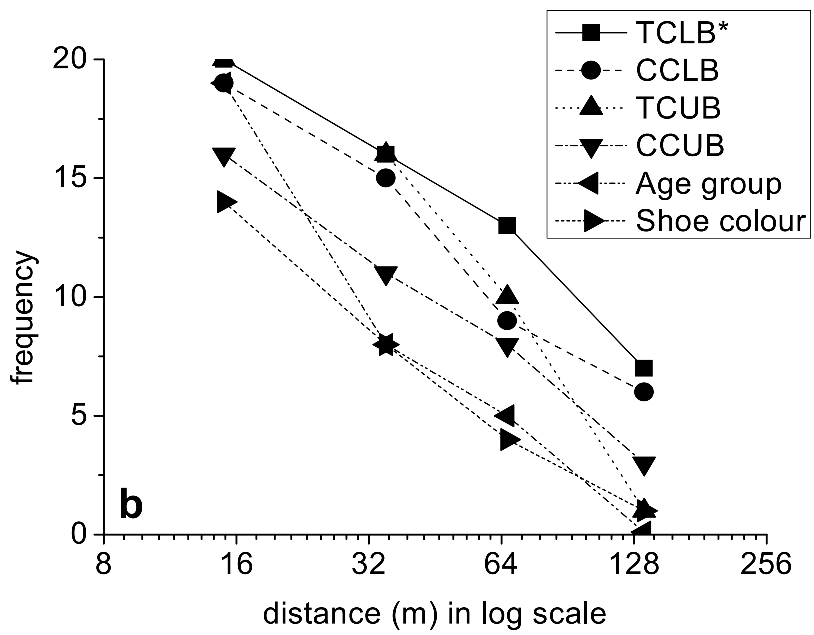



**Figure 4.4** Frequency of correctly mentioned features at different distances, summated across the four targets

Figure 4.5 shows the relationship between distance (log units) and frequencies by which individual features were mentioned, and these have been grouped according to the apparent trend. For three features (gender, hair length, and build) correct responses were gained at an approximately consistent level of between 75% and 100% for the nearer three distances. It was only at the longest distance, 135 m, that a large reduction was found. For six features (type and colour of clothing on upper and lower body, age group, and shoe colour) there is an approximate linear relationship between distance in log scale and frequency of being correctly mentioned, and for all six items there is a high frequency of correct identification at the nearest distance. For three features (ethnic group, show type, and facial expression) correct mention at the nearest distance is only approximately 50%, and subsequently decreases to less than 25%. For the final two features (hair colour and facial feature) there was a poor frequency of correct mention at all distances.

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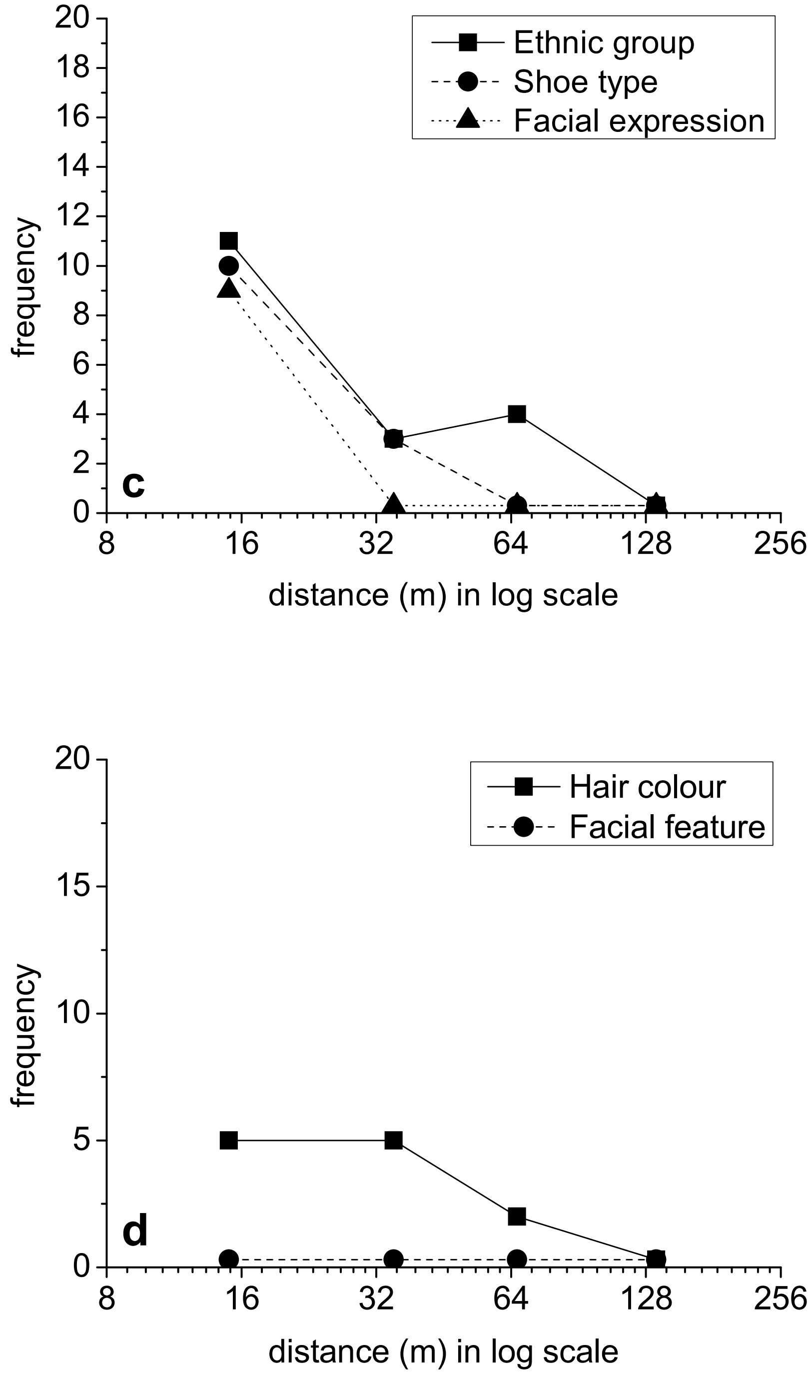


**Figure 4.5** Four groups of frequencies of individual features at different distances. (**Note**: *TCLB = type of clothing: lower body; CCLB = colour of clothing: lower body; TCUB = type of clothing: upper body; CCUB = colour of clothing: upper body)

### 4.2.4 Results of Individual Objects

The results of the target-specific objects are presented in Table 4.4. The numbers and types of objects worn and held by the four target people were not identical and are thus incomparable with other features. To enable comparison between Targets these are reported in Table 4.4 as the mean percentage of the total objects associated with each Target. Thus the score of 56% for Target 1 at 15 m indicates that each test participant mentioned approximately 2.5 of the five objects that were held or worn.

**Table 4.4** Percentage of correctly reported specific objects

| **Target person** | **No. 1** | **No. 2** | **No. 3** | **No. 4** | |
|---|---|---|---|---|---|
| Number of objects held/worn | 5 | 3 | 6 | 4 | **Mean** |
| Number of trials per distance | 5 | 5 | 5 | 5 | |
| **Distance** | **Percentage of correctly identified individual objects, %** | | | | |
| 15 m | 56 | 27 | 30 | 50 | 41 |
| 35 m | 20 | 0 | 7 | 20 | 12 |
| 66 m | 0 | 7 | 0 | 5 | 2 |
| 135 m | 4 | 0 | 0 | 0 | 1 |
| **Average** | *20* | *9* | *9* | *19* | |

Table 4.4 shows that the objects were rarely reported at distances beyond 15 m. The relationship with distance follows a similar trend to that of ethnic group, show type and facial expression (Figure 4.5c) as is shown in Figure 4.6. Target 3 held a knife, an object which would likely be interpreted as threatening. Target 3 was seen by five test participants at each test distance, of whom only one participant reported the knife at 15 m and 35 m and no participants reported the knife at 66 m or 135 m.

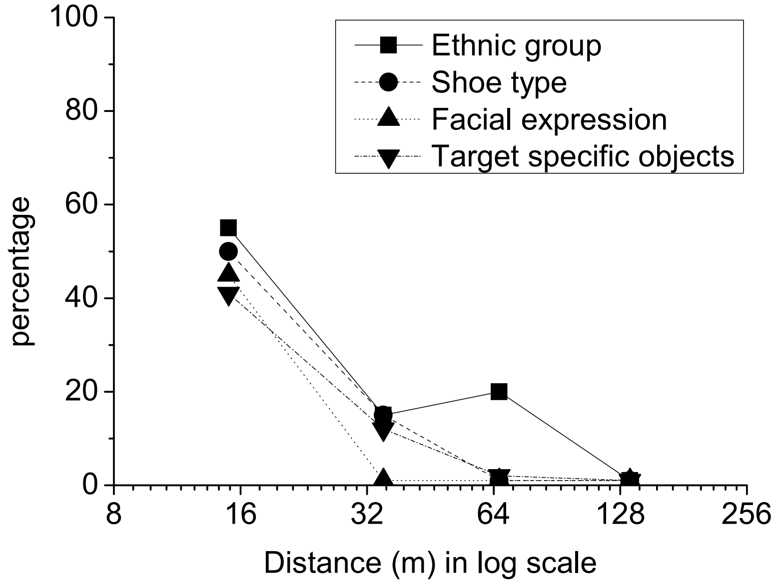


**Figure 4.6** Percentage of correct identification of the target-specific objects at different distances presents a similar trend to that found for ethnic group, shoe type and facial expression

Boyce and Bruno (1999) carried out an object identification task in which their15 test participants were asked to identify the object held by an experimenter walking back and forth at a distance of approximately 10.5 m. This was repeated using five different objects, chosen at random from a set of ten. At the lower light levels (2-5 lux), Boyce and Bruno (1999) found mean correct identification of approximately two of the five objects (40%), increasing to approximately 3 (60%) at the higher illuminances (22-50 lux). It is interesting that the identification rate (40%) reported by Boyce and Bruno (1999) at their lower illuminance is similar to the average across targets found in the current study (41%) at a similar distance (15m).

### 4.2.5 Discussion

One possible way to interpret the results is that if some feature is both important and difficult to see, then this feature is the critical feature which should be given attention in the main experiment. This is based on an assumption that a feature should be recognisable if another more difficult feature can be identified at the same distance.

Among the five visual features that were most difficult to identify (ethnic group, shoe type, hair colour, facial expression and facial feature), features of the head and/or face are somewhat prominent, which implies that facial recognition investigated in past studies and facial expression that is proposed to be explored in this study is of priority with other features.

## 4.3 Consistency of Judgements on Threat

Past work suggests that visual cues as to intent include facial expression (Etcoff and Magee, 1992) and body posture (Ekman and Friesen, 1969), but the performance of these tasks under low light levels and different SPD is yet to be examined. A problem with evaluation is that judgements may vary within and/or between subjects, and such inconsistency may confound interpretation of the effect of lighting, if any. Thus a study was carried out to determine the repeatability of judgements of intent based on facial expression or body posture.

There are six universally recognised facial expressions: neutrality, sadness, disgust, fear, anger, and happiness (Ebner et al., 2010). For body posture there are four recognized postures: anger, fear, happiness, and sadness (de Gelder and van den Stock, 2011).

Target images were drawn from established databases, these being validated photographs of actors, the FACES database (Ebner et al., 2010) and for body posture the Bodily Expressive Action Stimulus Test (BEAST) (de Gelder and van den Stock, 2011) database. Copyrights are acquired from the developers of the databases. Figures 4.7 to 4.8 show examples of these images from FACES and BEAST respectively.

The FACES database is a set of images of naturalistic faces of 171 younger, middle-aged and older women and men, displaying each of six facial expressions described as anger, disgust, fear, happiness, neutrality and sadness (Ebner et al., 2010). The database comprises two sets of pictures per person and per facial expression, resulting in a total of 2,052 images. It was developed between 2005 and 2007 by Ulman Lindenberger, Natalie Ebner, and Michaela Riediger at the Center for Lifespan Psychology, Max Planck Institute for Human Development, Berlin, Germany. All of the target faces were of an apparent white Caucasian origin. The models were asked to remove their jewellery, glasses, makeup and any clothing that covered the neck, and to put on a standard grey shirt.

**Figure 4.7** Sample of facial expressions from FACES database (Ebner et al., 2010). These are a younger female with expressions (from left to right) of angry, disgust, fear, happy, neutral and sadness.Website of database: http://faces.mpdl.mpg.de/faces/

**Figure 4.8** Sample of body postures from BEAST database (de Gelder and van den Stock, 2011). These are a male with postures (from left to right) of angry, fear, happy and sadness. Website of database: http://www.beatricedegelder.com/beast.html

The BEAST database (de Gelder and van den Stock, 2011) comprises 254 whole body postures from 46 actors conveying four emotions: anger, fear, happiness and sadness, from which 16 images were selected, these being four postures from four target people, two males and two females. Note that in these images the target faces are covered by neutral shading, therefore information of identification or expression are obscured.

### 4.3.1 Between-subject

This experiment sought to determine if different people would produce the same response as to whether a particular target was threatening or non-threatening.

#### 4.3.1.1 Method

Test participants were presented with 120 images on 5 A4-sized papers (each contain 24 images) in random order, these being 72 facial expressions and 48 body postures, and asked to state whether or not the target would be considered threatening if encountered alone after dark. For facial expressions there were 12 targets (6 male and 6 female) with two each in the younger, middle and older age groups. For each target there were six expressions, angry, disgust, fear, neutral, happy and sad. Participants were required to make rapid judgements on a set of 12 expressions and 12 postures and this was typically within two seconds per image. Note the two seconds was not controlled but estimated without measurement by the experimenter.

There were 48 participants (27 male and 21 female) including 37 younger (18-34 years) and 11 older (35-59 years). Each facial expression of a particular target person was seen by eight participants while each body posture seen by 12 participants. Trials were carried out under daylight or office lighting.

#### 4.3.1.2 Results

Table 4.5 shows the results of trials for facial expressions. These are the frequency by which a target was considered to be a threat from the 16 trials (two target images in each expression category). A frequency of >12 (>75%) was considered to present a consistent judgement of threat and a frequency of <4 (<25%) was considered to be consistent judgement of non-threatening, following the quartile manner. It can be seen that *happy* and *sad* facial expressions yielded a consistent judgement of not-threat, but none of the other expression lead to consistent judgement of threat. This suggests a low consistency of judgement on threat based on facial expressions (angry was near consistent).

**Table 4.5** Results of between-subject threat judgements: facial expression

| **Target** | | **Facial expressions (/16)** | | | | | |
|---|---|---|---|---|---|---|---|
| **Gender** | **Age** | **Angry** | **Disgust** | **Fear** | **Happy** | **Neutral** | **Sad** |
| Male | Old | 8 | 4 | 1 | 1 | 3 | 0 |
| Male | Middle | 9 | 10 | 6 | 3 | 10 | 1 |
| Male | Young | 14* | 8 | 4 | 1 | 2 | 2 |
| Female | Old | 6 | 3 | 5 | 1 | 1 | 1 |
| Female | Middle | 7 | 3 | 5 | 0 | 7 | 3 |
| Female | Young | 6 | 2 | 4 | 0 | 2 | 0 |
| Total percentage | | 69% | 42% | 35% | 8%* | 35% | 10% |

***Note**: items with grey background denote consistent judgements

Table 4.6 shows the results of trials for body postures. These are the frequency by which a target was considered to be a threat from the 72 trials (two target images in each expression category). A frequency of >54 (>75%) was considered to present a consistent judgement of threat and a frequency of <18 (<25%) was considered to be consistent judgement of non-threatening. It can be seen that *fear* and *happy* body postures yielded a consistent judgement of not-threat, but none of the other expressions led to consistent judgement of threat. This suggests a low consistency of judgement on threat based on body posture.

**Table 4.6** Results of between-subject threat judgements: body posture

| Target | Body posture (/72) | | | |
|---|---|---|---|---|
| | **Angry** | **Fear** | **Happy** | **Sad** |
| Male | 41 | 8 | 10 | 31 |
| Female | 34 | 5 | 8 | 17 |
| Total percentage | 52% | 9%* | 13% | 33% |

*Note: items with grey background denote consistent judgements

### 4.3.2 Within-subject

This experiment sought to determine if different targets would produce the same response for each participant as to whether a particular target was threatening or non-threatening.

#### 4.3.2.1 Method

This experiment sought to determine if a test participant would give the same response as to whether a particular target was threatening or non-threatening when observing the image on separate occasions.

Test participants were presented with a set of 48 images in random order, these being 24 facial expressions and 24 body postures, and asked to state whether or not the target would be considered threatening if encountered alone after dark. Participants were required to make rapid judgements and this was typically within 2s per image. Participants were asked to repeat this task twice for each target, and there was an interval of at least 24 hours between the 1st and 2nd trial for each test participant. All trials were carried out under daylight or office lighting.

For facial expressions there were 12 targets, these being six male and six female, with two each in the young, middle and older age groups. For each target there were two facial expressions angry, happy (or sad for target #008): according to the between-subject study (section 4.3.1) these were the most expected to yield consistent judgements of threatening and non-threatening responses respectively. For body posture there were 12 targets, these being six male and six female but of unknown age since target faces are obscured. According to the results of the between-subject study, happy, fear and sad postures were selected to present non-threatening targets and angry postures to present threatening postures. Figure 4.7 shows examples of the target facial expressions and body postures.

Test participants were shown targets and asked to respond whether or not the target presented a threatening situation. Targets were presented on a series of cards, in a randomised order, with one target per card. Note that images were presented separately (different from within-subject study) to avoid bias such as stereotype or anchoring effect. The size of the targets were chosen to present the images at the visual size at which decisions would be made in real situations, 10 m for facial expression and 30 m for body posture. The twenty test participants included seven females, they were drawn from European, North America and East Asian populations, 18 were young (aged 18-34 years old) and two were in the 35-59 age group.

#### 4.3.2.2 Results

Table 4.7 and 4.8 show the results of trials for facial expressions and body postures respectively. These are the frequency by which a target was considered to be a threat from the 40 trials (20 test participants x 2 trials). A frequency of >30 (>75%) was considered to present a consistent threat and a frequency of <10 (<25%) was considered to be consistently non-threatening.

For facial expressions it can be seen that happy expressions yield a consistent judgement of not-threat for all 11 targets, with the sad expression giving an inconsistent judgement, and nine of the 12 angry expressions leading to consistent judgements of a threat. Note that neither of the two older female targets with angry expressions was consistently regarded as presenting a threat. Note that for target

#008 the not-threat expression was Sad not Happy, as this was predicted by the experimenter more likely to be considered non-threatening.

For body postures it can be seen that 100% (6/6) of the happy postures led to consistent non-threat judgements, but this was not the case for the fear and sad expressions. However, the angry postures led to consistent judgements of threat for only two of the 12 targets.

**Table 4.7** Results of within-subject threat judgements: facial expression

| Target Identity number | Facial expression | | Predicted NOT THREAT from happy expressions | | Predicted THREAT from angry expressions | |
|---|---|---|---|---|---|---|
| | Gender | Age | Judgements of 'threat' (/40) | Assessment | Judgements of 'threat' (/40) | Assessment |
| 140 | F | Y | 0 | NO | 37 | YES |
| 069 | F | Y | 1 | NO | 36 | YES |
| 073 | F | M | 1 | NO | 34 | YES |
| 122 | F | M | 2 | NO | 36 | YES |
| 112 | F | O | 4 | NO | 29 | not consistent |
| 088 | F | O | 6 | NO | 22 | not consistent |
| 066 | M | Y | 1 | NO | 40 | YES |
| 008* | M | Y | 13* | not consistent* | 38 | YES |
| 045 | M | M | 0 | NO | 32 | YES |
| 026 | M | M | 1 | NO | 36 | YES |
| 015 | M | O | 0 | NO | 27 | not consistent |
| 059 | M | O | 3 | NO | 31 | YES |

*Note: for target #008 the not-threat expression was Sad not Happy

### 4.3.3 Discussion

It seems that the interpersonal judgements of threat based on facial expressions are more consistent than are those based on body postures. This might be partly explained as Ekman (1965) suggested that facial expression identifies the emotion while body cues indicate its intensity. Although the simulation distances of facial expression and body posture were not the same in the present tests, they were both clearly presented.

**Table 4.8** Results of within-subject threat judgements: body posture

| Target Identity number | Posture | Predicted NOT THREAT | | Posture | Predicted THREAT | |
|---|---|---|---|---|---|---|
| | | Judgements of 'threat' (/40) | Assessment | | Judgements of 'threat' (/40) | Assessment |
| F15 | Happy | 0 | NO | Angry | 14 | not consistent |
| F11 | Happy | 1 | NO | Angry | 27 | not consistent |
| F26 | Happy | 2 | NO | Angry | 20 | not consistent |
| M9 | Happy | 4 | NO | Angry | 28 | not consistent |
| M14 | Happy | 2 | NO | Angry | 28 | not consistent |
| M08 | Happy | 5 | NO | Angry | 18 | not consistent |
| F23 | Fear | 4 | NO | Angry | 30 | not consistent |
| F04 | Fear | 11 | not consistent | Angry | 22 | not consistent |
| F19 | Fear | 12 | not consistent | Angry | 22 | not consistent |
| M16 | Fear | 11 | not consistent | Angry | 26 | not consistent |
| M11 | Fear | 8 | not consistent | Angry | 20 | not consistent |
| M17 | Sad | 22 | not consistent | Angry | 34 | YES |

Results of between-subject study suggest that judgement of non-threat is consistent for happy and sad facial expressions, and for fear and happy body posture, while no expression leads to consistent judgement of threat. Results from within-subject study only confirm that judgements on happy facial expression and happy body posture to be consistent. The difference between the results of two methods (between-subject and within-subject) could be caused by the different ranges of stimuli given to the participants, which may bring range bias. The low consistency of judgement of threat implies that it is also affected by other factors such as context or individual experience.

While facial expression and body posture are stated to provide visual cues to emotion, and thus intent, it was concluded that universally recognised facial expressions or body postures do not map to judgements of intent with sufficient consistency: only one positive emotion (happy) conveyed by facial expression or body posture led to consistent judgement with percentages of more than 75(%). No opposite expression/posture that is consistently considered as threat is available to couple happy ones. Using such evaluation to investigate the effects of lighting, as suggested by Fotios and Raynham (2011), would therefore be confounded by the inconsistent responses and is unlikely to work. This means that investigation methodologies of lighting effects on interpersonal judgements need to be reconsidered. The use of the original categories of facial expressions and body postures was then proposed, for these are found to be consistent according to the validations of FACES database (Ebner et al., 2010) and BEAST database (de Gelder and van den Stock, 2011).

## 4.4 Justification of New Methodologies

This work investigates judgement of intent, whether or not an approaching person is considered to present a threat, rather than facial recognition. This may be the more appropriate task for pedestrians after dark; identity recognition may play a part but it is not the whole task.

Identification of emotion conveyed by facial expression are different from that of identity conveyed by faces only. More details are needed to recognise facial expression than to recognize facial identity and as a result, identity may be easier to recognise than expression under conditions that degrade the transmission of higher spatial frequencies in a face image such as large distances and poor lighting (Gao and Maurer, 2011).

There is evidence that facial expression and body posture contribute to social judgements that are related to evaluation of threat (Porter et al., 2007; Willis et al., 2011a; Willis et al., 2011b). There are six universally recognised facial expressions (Etcoff and Magee, 1992): neutrality, sadness, disgust, fear, anger, and happiness. Similarly for body posture four recognisable emotions have been proposed: anger, fear, happiness, and sadness (de Gelder and van den Stock, 2011). Willis et al (2011b) found that faces exhibiting angry expressions were less approachable than those with happy expressions, and similarly for emotions conveyed by body posture. Approachability was defined as the willingness to approach a stranger in a crowded street to ask for directions, which might be considered the opposite of a judgement of threat intent and the resulting motivation to avoid.

The direction of gaze is also a social signal, with direct gaze associated with approach motivation and averted gaze with avoid motivation (Ellsworth et al., 1972; Willis et al., 2011b). Willis et al (2011b) found that angry faces were considered less approachable when displaying direct eye gaze than averted eye gaze.

Past studies (Willis et al., 2011a; Willis et al., 2011b) exploring social evaluations based on facial expression have used as targets photographs rather than real people. The validity of this is confirmed in past studies where accuracy of the response can be evaluated, these demonstrating that static images of faces provides better than chance level assessments of intelligence, sexual orientation, and criminal tendency (Valla et al., 2011).

It was suggested (Fotios and Raynham, 2011) that intent might be investigated using faces exhibiting different expressions and asking people to categorise these as either friendly or non-friendly. Similarly, Valla et al (2011) sought judgements of criminality using photographs of faces and found that test participants were able to distinguish between criminals and non-criminals. This would allow a variety of targets to be presented at a constant visual size, overcoming a limitation of the stop-distance procedure, with controlled duration of observation, lighting, and randomised target order. However, according to the second pilot study, it can be concluded that standard facial expressions and body postures do not lead to consistent judgements of intent, i.e. threatening or not.

There are two reasons why, in contrast, Valla et al (2011) found consistent judgements of criminality; first, longer observation durations (20 s to 30 s) were permitted than in the current study (approximately 2 s); second, that the photographs presented by Valla et al included real criminals while the current study used actors who attempted to portray expressions such as anger.

## 4.5 Summary

A pilot study was carried out to question the interpersonal features that are observed. The 14 types of features were categorised according to the relationship between frequency and distance. This pilot study was done because the literature does not offer any conclusive evidence as to the distance at which making interpersonal judgement is desirable, and these data would be of use in determining where lighting may be of benefit. It was concluded that among element features of interpersonal judgement, facial features are of priority to be investigated.

A second pilot study was carried out to determine the consistency of judgements of intent (threat or not) based on universally recognised facial expressions and body postures. It was concluded that standard facial expressions and body postures did not lead to consistent judgements, therefore any effect of lighting being investigated would be confounded by the inconsistent responses. An alternative to judgements of intent would be to seek the effect of lighting on judgements of the emotion conveyed by facial expressions. This enables the proposal of experiment design presented in the following chapter.

# CHAPTER 5 EXPERIMENTAL DESIGN

## 5.1 Introduction

This chapter describes the method used in two experiments investigating the effects of lighting on interpersonal judgements expression. Performance of forced choice judgements of emotion and gaze direction were recorded under multiple visual conditions with combinations comprising lighting level, lamp spectrum, observation duration, and observation distance as represented by changing target size. These experiments were carried out to investigate two objectives:

- To examine whether elements of interpersonal judgements based on facial expression, body posture and gaze direction are affected by lighting level or spectrum of lamp.
- To obtain the relationship between lighting and the performance of interpersonal judgement. This would provide evidence to identify optimum lighting level.

## 5.2 Stimuli and Apparatus

Target images were photographs of actors expressing a range of facial expressions, body postures and gaze directions, and these were obtained from three databases with permission. Figure 4.7 and 4.8 in Section 4.3 show examples of facial expression and body postures.

Figure 5.1 shows the geometry of the gaze direction targets used in trials. These images were obtained from the head pose and gaze database developed by Institute of Neural Information Processing, University of Ulm (uulmHPG) (Weidenbacher et al., 2007). Note that unfortunately reproduction of the uulmHPG images is not permitted. The website of uulmHPG database is: http://www.uni-ulm.de/in/neuroinformatik/mitarbeiter/g-layher/image-databases.html

Sixteen images of four target people were used, these being two males and two females, with one male and one female each wearing glasses. For each target person there were four combinations of head pose and gaze direction: straight or rotated (30°) head position and direct or averted (30°) gaze. The faces used as gaze direction targets included three of white and one of brown skin colour.

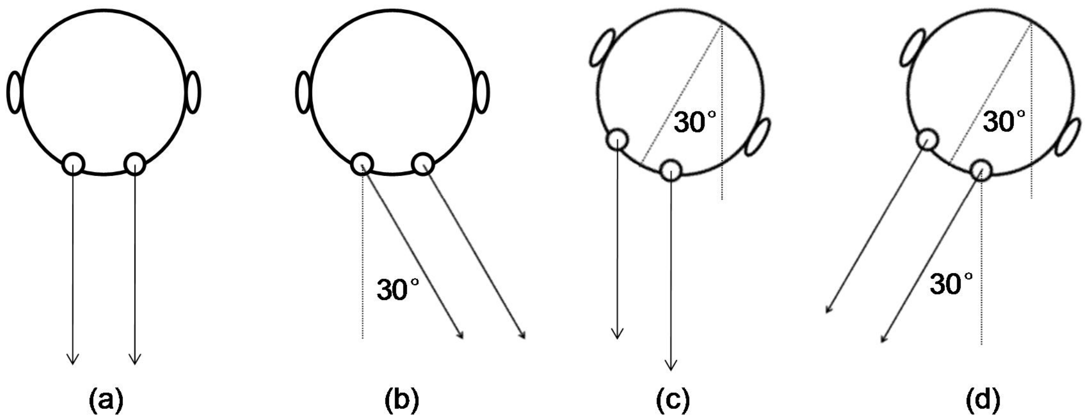


**Figure 5.1** Plan diagrams to show head and eye geometries for the gaze fixation target images from the uulmHPG database (Weidenbacher et al., 2007). These are (a) head forward, eyes direct; (b) head forward, eyes averted; (c) head rotated, eyes direct; and (d) head rotated, eyes averted.

Target images were presented on a non-self-luminous screen (Pixel Qi® PQ3Qi-01, 10.1 inch display) having a resolution of 1024 × 600 pixels. Self-luminous screens are those which require an internal light source (back light) to present screen images, and thus emit light to their surroundings: non-self-luminous screens do not have an internal light source and instead require ambient light for display images to be seen. The non-self-luminous status, achieved by switching off the screen back-light, was used to avoid mixing screen-generated light with the test light conditions. The facial expression and gaze direction photographs provided by the databases are in colour. However, at the low light levels of the current study, the target images showed very little colour. The body posture photographs are achromatic.

The screen was located inside a test booth (Figure 5.2) permitting changes in luminance (by adjustment of an iris) and spectral power distribution (by changing lamp type) with negligible changes in spatial distribution (Fotios and Cheal, 2009). The screen was placed on the floor of the booth and lit from overhead. It was observed from a distance of 65cm which was maintained using a chin rest with forehead restraint. For the luminance measurement on target face, reading from luminance meter were taken by aiming at the central part around nasal, as shown in Figure 5.3.

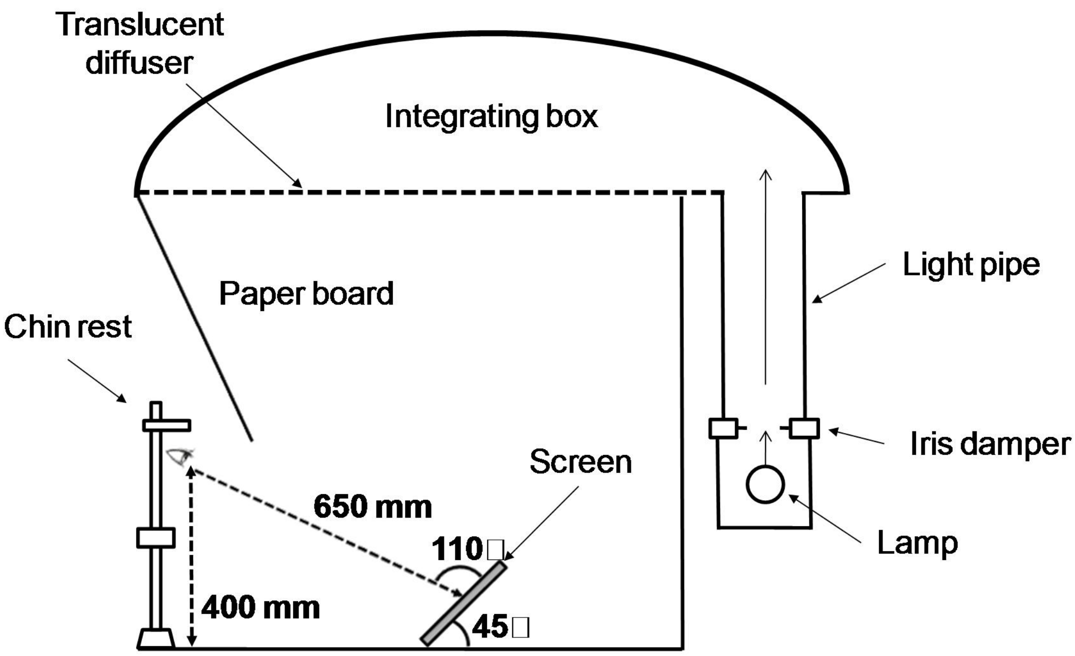


**Figure 5.2** Section through apparatus used to observe target images under different lighting settings

**Figure 5.3** Illustration of how luminance on target face (at 4 m) was measured

## 5.3 Experiment No. 1

### 5.3.1 Test Variables

Six lighting conditions were used. There were two types of lamp, high pressure sodium (HPS) and a metal halide lamp (MH). The parameters of the lamps as used in experiment No.1 and No.2 are listed in Table 5.1. Three light levels were used: screen luminances of 0.01 cd/m$^2$, 0.1 cd/m$^2$ and 1 cd/m$^2$, as measured using a Konica-Minolta LS100 luminance meter. These arose from illuminances of approximately 0.2, 2.0 and 20 lux at the surface of the screen, chosen to bracket the range of light levels expected in residential streets in the UK, and with the two log-unit range giving reasonable expectation of detecting an effect of light level.

**Table 5.1** Parameters of three lamps used in experiment No.1 and No.2

| Lamp | CCT | S/P Ratio | $R_a$ |
|---|---|---|---|
| **High Pressure Sodium (HPS)** | 2000 K | 0.57 | 25 |
| **Metal Halide (MH)** | 4200 K | 1.77 | 92 |
| **CosmoPolis$^{TM}$ (CPO)** | 2868 K | 1.22 | 70 |

The sizes of target images were manipulated to represent different observation distances. Following review of interpersonal distance in Chapter 2 and with limitations imposed by the screen size, the simulated distances were 4 m, 10 m and 15 m for facial expression; 2 m, 4 m and 10 m for gaze direction; and 10 m, 30 m and 135 m for body postures (Table 5.2). According to pre-tests, these target sizes should present a range of performance from equal-to-chance level to a useful level.

**Table 5.2** Visual size (minutes of arc) of targets for simulated distance (m)

| Target | Face | | | | Body | |
|---|---|---|---|---|---|---|
| | Facial expression | | Gaze direction | | Body posture | |
| | Simulated distance (m) | Size (min.) | Simulated distance (m) | Size (min.) | Simulated distance (m) | Size (min.) |
| **Nearer distance** | **4** | 172 | **2** | 343 | **10** | 583 |
| **Middle distance** | **10** | 69 | **4** | 172 | **30** | 194 |
| **Farther distance** | **15** | 46 | **10** | 69 | **135** | 43 |

**Note**: Visual sizes were calculated assuming a face size of 200 mm from chin to top of head and a body size of 1700 mm from feet to top of head.

### 5.3.2 Procedure

Thirty test participants were recruited from staff and students of the University of Sheffield, and other residents of Sheffield. They were paid a small fee for their contribution. Past work suggests that the age and gender of test participants may affect judgements based on facial information (Bullimore et al., 1991; Konar et al., 2013) and thus the sample was balanced across these groups to examine difference: 16 were male and 14 were female; 15 were from a younger age group (18-40 years old, approximate mean age is 25 years) and 15 were drawn from an older age group (40-65 years, approximate mean age 54 years); they were drawn from European, North American, Middle East and Asian population to cover most of the ethnic groups. All test participants had normal or corrected-to-normal visual acuity as tested using a Landolt ring test, and all had normal colour vision according to the Ishihara test under a daylight-simulating source. Each test session started with 20 minutes for adaptation to the low light level.

The responses sought were judgements of emotions conveyed through facial expression (anger, disgust, fear, happiness, neutrality or sadness), body posture (anger, fear, happiness or sadness), and gaze direction (gaze toward or averted from the test participant). Past studies of facial recognition have tended to permit constant fixation on the target face, but this is likely to be an unrealistic proxy for real-world interpersonal judgements as there is a common inclination to avoid looking directly at others in some social situations. In the current work, each target was presented for 1000 ms, with no time limit for input of the subsequent response. Note that the 1000 ms was an estimate of typical duration made before the analysis reported in Chapter 3 which suggests 500 ms. Responses were given using a button box, with one button for each of the available responses.

A series of practice trials were used to present and confirm understanding of the response options. Initially the available options (e.g. six different facial expressions) were shown simultaneously to illustrate all possible options. Twenty-four example face targets (the six expressions for four target people not used in trials; 16 body postures; 16 gaze direction faces) were shown in random order under office lighting conditions and without time limit, to allow these expressions to be learned.

The three tasks (categorical perception of facial expression, body posture and gaze direction) were carried out in separate blocks, and block order was counterbalanced. Within each task, images of different size, and featuring different expressions, postures or gaze directions, were presented in a counter-balanced order. The order in which lamp type and luminance were experienced was counterbalanced across the sample. Figure 5.4 shows an example photograph taken during the experiment under the MH lamp. The presence of illuminance meter with its sensor positioned on specific location of the floor is to take measurements of illuminance that are correlated to the target luminances on screen, so that they are adjusted promptly without disturbing the participants.

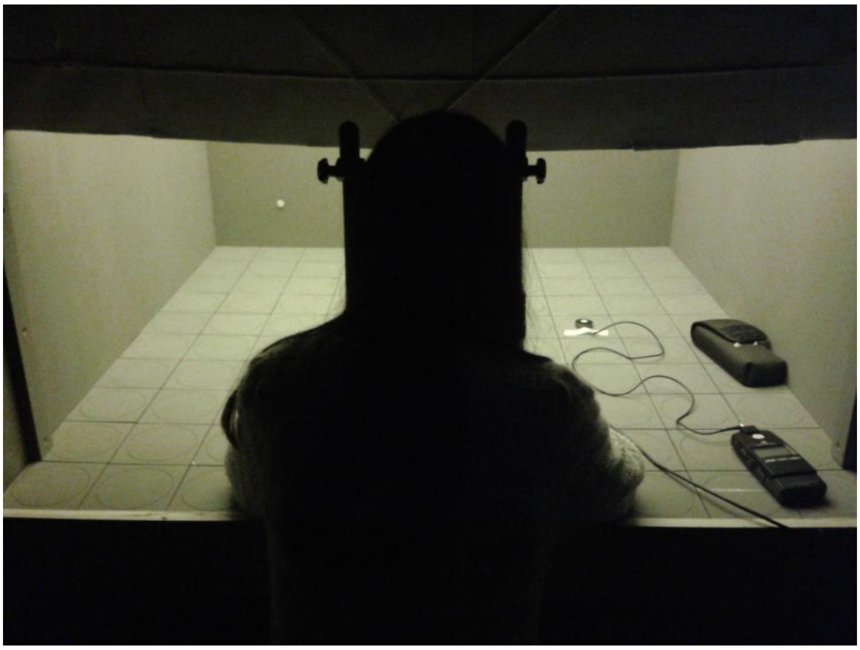

**Figure 5.4** An example photograph taken during the experiment, taken from behind a seated test participant

## 5.4 Experiment No. 2

### 5.4.1 Test Variables

Eighteen lighting conditions were used. There were three types of lamp; high pressure sodium, metal halide, and CosmoPolis$^{TM}$ (CPO), see Table 5.1 for specific parameters. Six light levels were used: screen luminances of 0.01, 0.03, 0.1, 0.33, 1.00, and 3.33 cd/m$^2$, as measured by a Konica-Minolta LS-100 luminance meter. These arose from illuminances of approximately 0.2, 0.6, 2.0, 6.0, 20 and 60 lux at the surface of the screen, chosen to bracket the range of light levels expected in residential streets in the UK, and with a range of more than two log-units giving reasonable expectation of detecting an effect of light level. Note that luminance of 3.33 cd/m$^2$ was not possible for MH lamp due to limitation of the apparatus so that 2.50 cd/m$^2$ was used instead.

The sizes of target images were manipulated to represent different observation distances. For facial expression, two distances of 4 m and 15 m were used for which there are four reasons. First, data from eye tracking study carried out in actual environment indicates that pedestrians tend to look at other people at an interpersonal distance of about 15m (Chapter 3). Second, observation on face at 4m is the basis of current standards, so it was included in order to be compared with. Third, distances of 4m and 15m were also used in the first study therefore the results of this study can be validated. Fourth, according to the results of the first study, these target sizes should present a range of performance from equal-to-chance level to a useful level.

Emotions conveyed by body posture were used as variation in target images and to check the effect of duration; these were set only at one size (30 m), one luminance, but with three durations (500, 1000 and 3000 ms).

### 5.4.2 Procedure

Twenty test participants were recruited from staff and students of the University of Sheffield, and other residents of Sheffield. They were paid a small fee for their contribution. The sample was balanced across these groups to examine difference: 12 were male and eight were female; their ages ranged from 18 to 50 years old with an approximate mean age of 27; they were drawn from European, North American, Middle East and Asian population to cover most of the ethnic groups. All test participants had normal or corrected-to-normal visual acuity as tested using a Landolt-ring test, and all had normal colour vision according to the Ishihara test under a daylight-simulating source. Each test session started with 20 minutes for adaptation to the low light level.

The responses sought were judgements of emotions conveyed through facial expression (anger, disgust, fear, happiness, neutrality or sadness) and body posture (anger, fear, happiness or sadness). Past studies of facial recognition have tended to permit constant fixation on the target face, but this is likely to be an unrealistic proxy for real-world interpersonal judgements as there is a common inclination to avoid looking directly at others in some social situations. In the current work, each target was presented for one of two durations, 500 ms and 1000 ms, this being chosen to simulate the brief observation of an unknown approaching person expected in real situations (as described in Chapter 3), with no time limit for input of the subsequent response. Responses were given using a button box, with one button for each of the available responses.

A series of practice trials were used to present and confirm understanding of the response options. Initially the available options (e.g. six different facial expressions) were shown simultaneously to illustrate all possible options. Twenty-four example face targets (the six expressions for four target people not used in trials; 16 body postures) were shown in random order under office lighting conditions and without time limit, to allow these expressions to be learned.

The six different luminances for a given lamp were carried out as a block before moving to the next lamp, with the lamp order and luminance order being counterbalanced. For a given condition of lamp and luminance, the target photographs (faces of different expression and size) were presented in a random order. Within the six luminance blocks for a particular lamp, the body posture trial was included after completion of the first three blocks. The one session of body posture under 0.10 cd/m$^2$ after three sessions of facial expression as a break or mind refresh for participants.

## 5.5 Summary

This chapter provided a description of the procedure, apparatus and variables used in two experiments exploring the effect of lighting on judgements of emotion based on facial expression, body posture and gaze direction. These data are summarised in Table 5.3. The results are presented in Chapter 6.

**Table 5.3** Main parameters of the two experiments

| Parameters | Experiment No. 1 | Experiment No. 2 |
|---|---|---|
| **Stimuli** | Facial expression, body posture and gaze direction | Facial expression |
| **Luminance (cd/m$^2$)** | 0.01, 0.1 and 1 | 0.01, 0.03, 0.10, 0.33, 1.00 and 3.33 |
| **Lamps** | HPS and MH | HPS, MH and CPO |
| **Distances (m)** | Face: 4, 10 and 15<br>Body: 10, 15 and 135<br>Gaze: 2, 4 and 10 | 4 and 15 |
| **Durations (ms)** | 1000 | 500 and 1000 |
| **Participants recruited** | 15 younger +15 older | 20 younger |

# CHAPTER 6 RESULT AND ANALYSIS

## 6.1 Introduction

In this chapter, results obtained from the experiments described in Chapter 5 are presented and analysed. Statistical analyses are performed to examine if the effect of lighting (luminance and SPD) on the ability of making interpersonal judgement are significant or not. Other factors such as target size and observation duration are also examined and analysed. The raw experimental results are recorded in Appendix A.

## 6.2 Results of Experiment No. 1

For each trial, the data were recorded as 1 for correct identification or 0 for incorrect identification. For each combination of luminance and size and lamp there were 24 target images for facial expressions, 16 target images for body postures and gaze direction. For each test participant their score was the total number of correct identifications from these targets, hence leading to a distribution of 30 scores (across the 30 test participants) from which statistical measures were derived.

The results are shown in Figure 6.1 (a-c) and Tables 6.1, 6.2, and 6.3. These are the median frequencies and interquartile ranges for correctly identifying emotion or gaze direction.

As luminance increases, there is an apparent increase in the probability of correctly identifying emotions conveyed by facial expression or body posture. For the identification of gaze direction, luminances of 0.01 and 0.10 cd/m$^2$ lead to performance at the chance level, and only the luminance of 1.00 cd/m$^2$ leads to performance above chance level. There appears to be little difference in task performance between the HPS and MH lamps.

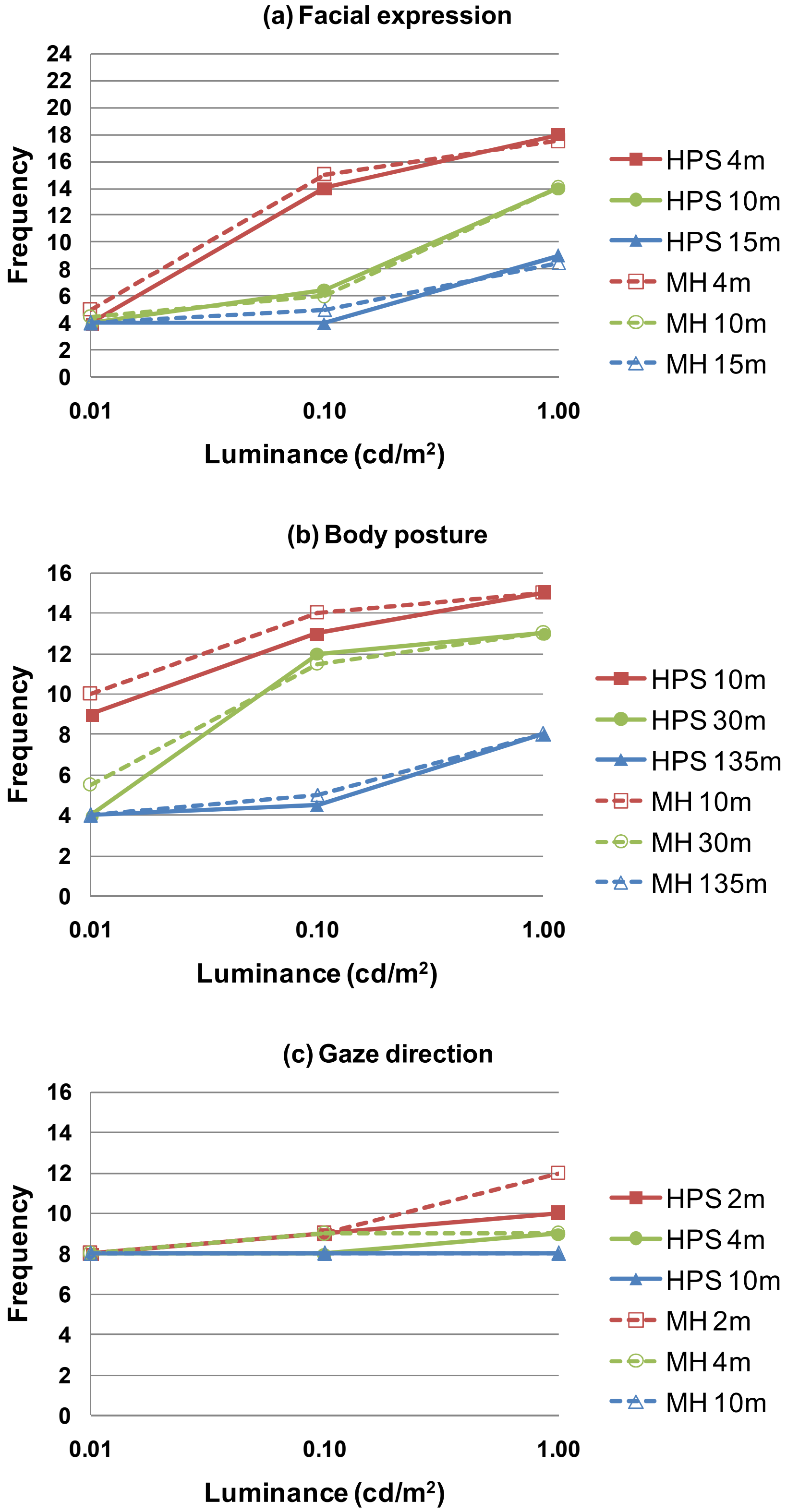


**Figure 6.1** Median frequencies for correct identification of emotion from facial expression (a), body posture (b), and gaze direction (c). The legends show lamp type (MH or HPS lamp) and simulated target distance.

**Table 6.1** Median frequency (and interquartile range: 25th to 75th percentile) of correct identification of facial expression. Note: for these data, maximum frequency is 24; chance frequency is 4.

| Simulated distance to target | Luminance ($cd/m^2$) | Median frequency (and interquartile range) of correct identification of facial expression. | | | | | |
|---|---|---|---|---|---|---|---|
| | | HPS lamp | | | MH lamp | | |
| | | Young | Old | Combined | Young | Old | Combined |
| **4 m** | **1** | 19 (16-21) | 17 (14-19) | 18 (15.75-20) | 19 (17-20) | 17 (15-20) | 17.5 (16.5-20) |
| | **0.1** | 16 (13-18) | 12 (8-15) | 14 (10-16) | 16 (15-18) | 12 (8-17) | 15 (11.75-17.25) |
| | **0.01** | 4 (3-8) | 4 (3-4) | 4 (3-5.25) | 6 (5-7) | 4 (3-5) | 5 (4-6) |
| **10 m** | **1** | 14 (12-16) | 12 (5-15) | 14 (8.75-16) | 15 (13-16) | 13 (5-16) | 14 (10.75-16) |
| | **0.1** | 8 (6-11) | 5 (4-9) | 6.5 (4-11) | 8 (5-13) | 6 (4-7) | 6 (4-11) |
| | **0.01** | 5 (3-6) | 4 (4-5) | 4 (4-5) | 5 (4-7) | 4 (4-5) | 4.5 (4-5.25) |
| **15 m** | **1** | 12 (7-15) | 6 (7-10) | 9 (5-12) | 10 (8-15) | 7 (4-11) | 8.5 (6.5-12.25) |
| | **0.1** | 6 (4-7) | 4 (3-4) | 4 (3-6) | 5 (3-6) | 4 (3-6) | 5 (3-6) |
| | **0.01** | 4 (3-5) | 4 (3-4) | 4 (3-5) | 4 (3-5) | 4 (3-5) | 4 (3-5) |

**Table 6.2** Median frequency (and interquartile range: 25th to 75th percentile) of correct identification of body posture. Note: for these data, maximum frequency is 16; chance frequency is 4.

| Simulated distance to target | Luminance ($cd/m^2$) | Median frequency (and interquartile range) of correct identification of body posture. | | | | | |
|---|---|---|---|---|---|---|---|
| | | HPS lamp | | | MH lamp | | |
| | | Young | Old | Combined | Young | Old | Combined |
| **10 m** | **1** | 15 (14-16) | 14 (12-15) | 15 (13.75-15) | 15 (14-16) | 14 (12-15) | 15 (13-15) |
| | **0.1** | 13 (13-15) | 12 (11-13) | 13 (11.75-14) | 14 (13-15) | 13 (12-15) | 14 (13-15) |
| | **0.01** | 10 (8-12) | 7 (4-9) | 9 (6-11) | 11 (10-12) | 8 (5-10) | 10 (7.75-11.25) |
| **30 m** | **1** | 13 (12-14) | 12 (11-13) | 13 (12-14) | 14 (13-15) | 13 (10-13) | 13 (12.75-14) |
| | **0.1** | 13 (12-14) | 8 (6-11) | 12 (7.75-13) | 13 (11-14) | 9 (8-12) | 11.5 (8.75-13) |
| | **0.01** | 5 (4-7) | 3 (2-5) | 4 (2.75-5) | 6 (4-7) | 4 (3-6) | 5.5 (3-7) |
| **135 m** | **1** | 9 (8-10) | 6 (3-8) | 8 (4-9.25) | 10 (9-11) | 7 (4-8) | 8 (5.75-10) |
| | **0.1** | 5 (3-7) | 4 (3-5) | 4.5 (3-6) | 5 (3-7) | 5 (4-5) | 5 (4-6) |
| | **0.01** | 4 (3-5) | 4 (3-5) | 4 (3-5) | 4 (3-5) | 4 (3-4) | 4 (3-5) |

**Table 6.3** Median frequency (and interquartile range: 25th to 75th percentile) of correct identification of gaze direction. Note: for these data, maximum frequency is 16; chance frequency is 8.

| Simulated distance to target | Luminance ($cd/m^2$) | Median frequency (and interquartile range) of correct identification of gaze direction. | | | | | |
|---|---|---|---|---|---|---|---|
| | | HPS lamp | | | MH lamp | | |
| | | Young | Old | Combined | Young | Old | Combined |
| **2 m** | **1** | 12 (10-13) | 10 (9-10) | 10 (9-12.25) | 14 (11-14) | 11 (9-13) | 12 (9.75-14) |
| | **0.1** | 10 (9-11) | 9 (7-9) | 9 (8-10) | 10 (9-11) | 8 (8-9) | 9 (8-10) |
| | **0.01** | 8 (7-10) | 7 (7-8) | 8 (7-9.25) | 8 (7-9) | 8 (7-10) | 8 (7-9) |
| **4 m** | **1** | 9 (8-10) | 9 (8-9) | 9 (8-10) | 10 (8-13) | 9 (8-11) | 9 (8-12) |
| | **0.1** | 8 (7-9 | 8 (8-8) | 8 (7-8.25) | 9 (8-9) | 9 (7-9) | 9 (7-9) |
| | **0.01** | 9 (7-9) | 8 (7-9) | 8 (7-9) | 8 (7-9) | 8 (7-9) | 8 (7-9) |
| **10 m** | **1** | 9 (7-11) | 8 (7-9) | 8 (7-9.25) | 8 (7-9) | 8 (7-9) | 8 (7-9) |
| | **0.1** | 8 (7-9) | 8 (7-9) | 8 (7-9) | 8 (6-9) | 9 (8-9) | 8 (7.75-9) |
| | **0.01** | 8 (7-10) | 8 (6-10) | 8 (6.75-10) | 8 (8-10) | 8 (6-8) | 8 (6-9) |

For the facial expression targets, the 24 images comprised six expressions from each of four people; thus there was a 1/6 probability of correctly identifying the expressed emotion by chance, a frequency of 4 in Figure 6.1a. For the body posture targets, the 16 images comprised four postures from each of four people; thus there was a 1/4 probability of correctly identifying the conveyed emotion by chance, a frequency of 4 in Figure 6.1b. For gaze direction, the 16 images comprised four poses from each of four people, of which two were direct gazes; thus there was a 1/2 probability of correctly identifying direct gaze by chance, a frequency of 8 in Figure 6.1c.

At the lowest target luminance of 0.01 cd/m$^2$, only body postures at 10 m were identified at frequencies above the chance level. Shorter interpersonal distances increased the probability of correctly identifying emotions conveyed by facial expression or body posture: this may be due to the larger visual size subtended. For gaze direction, at low light levels (0.01 and 0.1 cd/m$^2$) there is no apparent difference between the three simulated distances: for the higher light level (1.0 cd/m$^2$) there is a higher probability for detecting the gaze direction of the closer targets than of the distant targets.

These graphs suggest a plateau-escarpment relationship between light level and correct judgement as tends to characterise visual performance (Boyce and Rea, 1987). According to the escarpment-plateau relationship, the knee (transitional point between escarpment and plateau) in the curves provides one estimate of appropriate lighting level, as illustrated in Figure 6.2. This is because luminance higher than that at the ‘knee’ would produce negligible further benefit but a lower luminance would lead to a rapid decline in visual performance. At higher target luminances performance reaches a plateau above which increasing luminance gives diminishing returns in terms of increased probability of correct identification. At low target luminance, performance is at chance level and further reductions in luminance do not reduce performance. In the intermediate range, the escarpment, a change in light level can affect performance more appreciably.

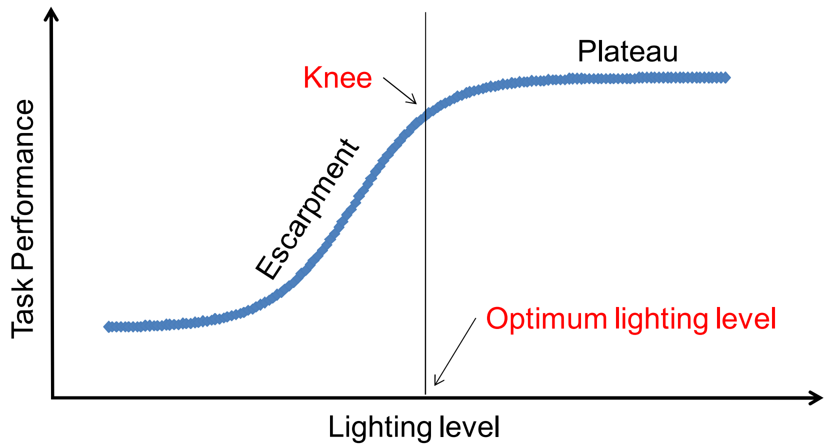


**Figure 6.2** Illustration of optimum lighting level identified by knee in plateau-escarpment relationship

## 6.3 Analysis of Experiment No. 1

Five variables are examined: luminance, lamp type, size (i.e. target images at different distances), age and gender of participants. The data were recorded as frequency of correct categorical judgement of facial expression, body posture and gaze direction. Analysis of these data using a range of metrics (including skewness, kurtosis, Kolmogorov-Smirnov test and Shapiro-Wilks test) did not suggest they are drawn from a normally-distributed population and hence statistical analyses were carried out using non-parametric tests.

Analyses of these data required multiple application of the statistical tests with a risk of capitalising on chance (a type I error) and thus suggesting a difference to be real when it is not. The results were thus analysed with reference to a Bonferroni corrected threshold and to the overall pattern of results.

### 6.3.1 Facial Expression

Figure 6.1a suggests that there is better recognition of facial expression at higher luminances, and with targets of larger size (i.e. shorter simulated distance), but does not suggest a difference the two types of lamp. At the lower luminance (0.01 cd/m$^2$), the median results for all combinations of distance and lamp type are at chance level.

The Friedman test suggests that luminance has a significant effect on categorical judgement of facial expression ($p$<0.001) in all six combinations of lamp type and distance. For six tests, the Bonferroni corrected threshold is p=0.0083 (i.e. 0.05/6). When data at the three luminances are considered separately using the Wilcoxon Signed Ranks test, differences between luminances are significant at all distances for both lamps ($p$<0.001), except between 0.1 cd/m$^2$ and 0.01 cd/m$^2$ at 15 m for either the HPS or MH lamps ($p$=0.065 and 0.153 respectively): In these cases the results are at chance level being the smallest target and the lower light levels. The Wilcoxon test does not suggest that lamp type has a significant effect on categorical judgement of facial expression for any lighting level and at any distance. The Friedman test suggests that distance has significant effect on categorical judgement of facial expression ($p$<0.001) for both lamp types at luminances of 1.0 cd/m$^2$ and 0.1 cd/m$^2$. It did not suggest a significant effect of distance at the lowest luminance level (0.01cd/m$^2$) which may be because the judgements are at chance level at this low luminance.

### 6.3.2 Body Posture

Figure 6.1b suggests that there is better recognition of body posture at higher luminances, and with targets of larger size (i.e. shorter simulated distance), but does not suggest a difference between the two types of lamp.

The Friedman test suggests that luminance level has a significant effect on categorical judgement of body posture ($p$<0.001) in all six cases (lamp type and distance). When data at three luminance levels are considered separately using the Wilcoxon test, differences between luminance levels are significant at all distance for both lamps ($p$<0.001), except for just one case, this being the comparison of the two lower luminances (0.1 cd/$m^2$ and 0.01 cd/$m^2$) at the greatest distance (135m) under the HPS lamp ($p$=0.141).

The Wilcoxon test does not suggest that lamp type has a significant effect on categorical judgement of body postures for six of nine conditions. The three cases of distance and luminance where a significant difference between lamps was suggested are 135m at 1.0 cd/$m^2$ ($p$=0.043), 10m at 0.1cd/$m^2$ ($p$=0.048) and 10 m at 0.01cd/$m^2$ ($p$=0.011). These cases are those in the middle of the luminance and distance combinations: When the task is either relatively difficult (i.e. small and low luminance) or easy (i.e. large and high luminance) then lamp type did not affect the task.

The three target sizes used in the body posture tests represented distances of 10 m, 30 m and 135 m. The Friedman test suggests that distance has a significant effect on categorical judgement of body postures ($p$<0.001) in all six cases (lamp type and luminance). When data at three distances are considered separately using the Wilcoxon test, differences between all possible distance pairs are significant ($p$<0.001) with only one exception: It did not suggest a significant difference between 30 m and 135m for the HPS lamp at 0.01 cd/$m^2$.

### 6.3.3 Gaze Direction

Figure 6.1c suggests that recognition of gaze direction tends to be at chance level except when using the higher luminance with the largest target size (shortest distance) and does not suggest a difference between the two types of lamp.

The Friedman test suggests that luminance level has a significant effect on categorical judgement of gaze direction ($p$<0.001) at 2 m and 4 m for both lamp types. The Wilcoxon test suggests differences between the two luminances are significant at 2m for both lamps ($p$<0.001), but at 4 m the results are mixed: There is a significant difference between 0.1 and 1.0 cd/$m^2$ for both lamps, and also a difference between 0.01 and 1.0 cd/m$^2$ for the MH lamp. The Friedman test does not suggest a significant effect of luminance at the largest distance (10 m).

The Wilcoxon test does not suggest that lamp type has a significant effect on categorical judgement of facial expression in seven of the nine conditions, but does suggest a significant difference for the higher luminance (1cd/m$^2$) for both of the shorter distances (2 m and 4 m). Figure 5c suggests these cases lie in an apparent escarpment region. According to the Friedman and Wilcoxon tests, the difference between test distances is significant at 1.0 cd/m$^2$ for both lamps; at 0.1 cd/m$^2$ the difference is significant under the HPS lamp but not under the MH lamp, and at 0.01 cd/m$^2$ the differences are not suggested to be significant.

### 6.3.4 Age and Gender of Participant

Tables 6.1, 6.2 and 6.3 show that younger test participants tended to respond correctly more frequently than did the older group. Differences between the age groups examined using the Mann-Whitney test are suggested to be significant ($p<0.01$) for judgements of facial expression, body posture and gaze direction. The Mann-Whitney test did not suggest differences between male and female test participants to be significant.

## 6.4 Results of Experiment No. 2

For each trial, the data were recorded as '1' for correct identification or '0' for incorrect identification. For each combination of luminance and size and lamp there were 24 facial expression targets, and for each test participant their score was the number of correct identifications from these 24 targets, hence leading to a distribution of 20 scores (across the 20 test participants) from which statistical measures were derived. The results are shown in Figure 6.3 and Table 6.4. These are the median frequencies and inter-quartile ranges for correctly identifying emotion from facial expression. The six facial expressions per target lead to a 1/6 probability of correctly identifying the expressed emotion by chance, a frequency of 4 in Figure 6.3.

As luminance increases, there is an apparent increase in the probability of correctly identifying emotions conveyed by facial expression. Little effect of observation duration was found when the frequencies of correct identification were higher than 16 or lower than 8. However, in the range of 8 to 16, the frequencies of correct identification with longer duration (1000 ms) were slightly higher than the ones with shorter duration (500 ms). Shorter interpersonal distances increased the probability of correctly identifying emotions conveyed by facial expression: this may be due to the larger visual size subtended. There appears to be little difference in task performance among the HPS, MH and CPO lamps.

Similar to the results of experiment 1, Figure 6.3 suggests a plateau-escarpment relationship between light level and correct judgement. At higher target luminances performance reaches a plateau above which increasing luminance gives diminishing returns in terms of increased probability of correct identification. At low target luminance, performance is at chance level and further reductions in luminance do not reduce performance. In the intermediate range, the escarpment, a change in light level can affect performance more appreciably.

At luminances of no more than 0.10 $cd/m^2$, facial expressions at 15 m were identified at frequencies around chance level. At luminances of no less than 0.33 $cd/m^2$, frequencies of correct identification of facial expression reached to a plateau at around 20. The upper limit of or maximum identification probabilities (about 83.3%) found in the current data approach those exhibited (81.3%) when the databases were validated under good lighting conditions with unlimited exposure durations (Ebner et al., 2010).

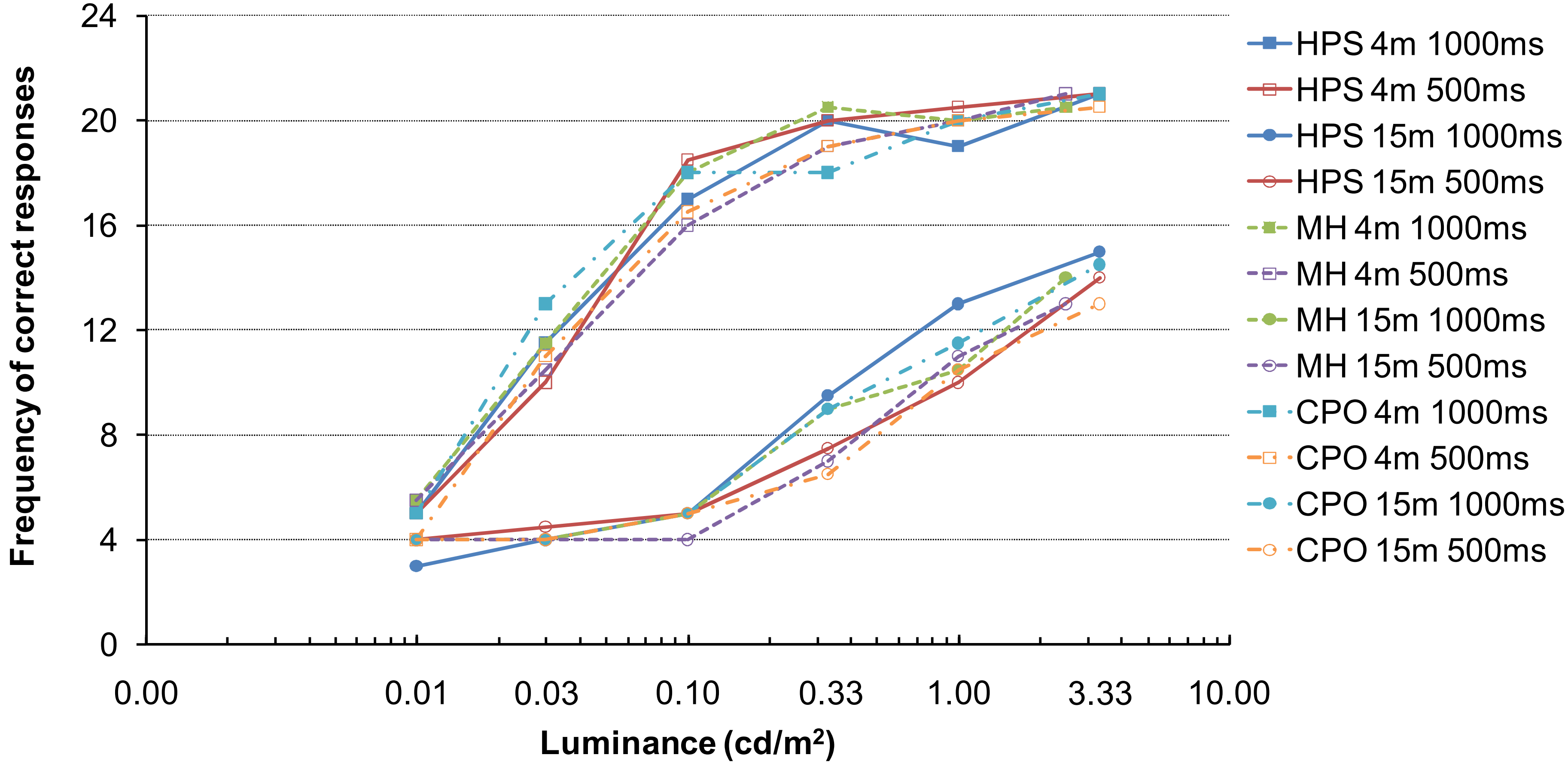


**Figure 6.3** Median frequencies for correct identification of emotion from facial expression. The legends show lamp type (HPS, MH or CPO lamp), duration of presenting and simulated target distance

**Table 6.4** Median frequency (and interquartile range: 25th to 75th percentile) of correct identification of emotion conveyed by facial expression. Note: for these data, maximum frequency is 24; chance frequency is 4.

| **Simulated distance to target** | **Luminance ($cd/m^2$)** | **Median frequency (and interquartile range) of correct identification of facial expression** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **HPS lamp** | | **MH lamp** | | **CPO lamp** | |
| | | **1000 ms** | **500 ms** | **1000 ms** | **500 ms** | **1000 ms** | **500 ms** |
| **4 m** | **3.33*** | **21** (18.75-23) | **21** (19-22) | **20.5** (19-22) | **21** (18.5-22) | **21** (19-22) | **20.5** (18-22) |
| | **1.00** | **19** (17-21) | **20.5** (18-21.25) | **20** (18.5-21.25) | **20** (19-21.25) | **20** (19-22) | **20** (17.75-21) |
| | **0.33** | **20** (18-21.25) | **20** (16.75-21.25) | **20.5** (17.75-22) | **19** (18-20.25) | **18** (16-22) | **19** (17-22) |
| | **0.10** | **17** (15-20) | **18.5** (14-20) | **18** (15.75-20) | **16** (14.5-17) | **18** (15-20) | **16.5** (15.5-20) |
| | **0.03** | **11.5** (10-14.25) | **10** (7.75-13.25) | **11.5** (9-14.25) | **10.5** (7.75-13) | **13** (10.25-15.25) | **11** (8.75-13) |
| | **0.01** | **5** (3.75-6) | **5** (2.75-7) | **5.5** (4-6.5) | **5.5** (4-7) | **5** (4-7.25) | **4** (4-5.25) |
| **15 m** | **3.33*** | **15** (12.75-17) | **14** (11.25-18) | **14** (11-15.75) | **13** (9.75-15) | **14.5** (12.75-17) | **13** (9-16.25) |
| | **1.00** | **13** (10-15) | **10** (7.75-13) | **10.5** (8.75-13) | **11** (7-12) | **11.5** (10-14.25) | **10.5** (9-13.25) |
| | **0.33** | **9.5** (6-11) | **7.5** (4-10.25) | **9** (5-10.5) | **7** (5.75-9.25) | **9** (4.75-10.25) | **6.5** (5-8.5) |
| | **0.10** | **5** (4.75-7) | **5** (4.75-6.25) | **5** (3.75-7) | **4** (4-5.25) | **5** (3-6) | **5** (3-6) |
| | **0.03** | **4** (2.75-4) | **4.5** (4-5) | **4** (3-4.25) | **4** (3-6) | **4** (3-5) | **4** (2.75-5) |
| | **0.01** | **3** (2-4) | **4** (3-5) | **4** (3-6) | **4** (3.75-5) | **4** (3-4.25) | **4** (3-4.25) |

*__Note__: for MH lamp, the luminance used was 2.50 $cd/m^2$ rather than 3.33 $cd/m^2$ due to limitation of the apparatus.

## 6.5 Analysis of Experiment No. 2

Four variables are examined: luminance (x6), lamp type (x3), equivalent distance (x2) and duration of observation (x2). Analysis of the results using a range of metrics (including skewness, kurtosis, Kolmogorov-Smirnov test and Shapiro-Wilks test) suggested that approximately half of the 72 distributions were drawn from a normally-distributed population while the others were not or the analysis was not conclusive. To be consistent to Experiment No.1, statistical analyses were hence carried out using non-parametric tests. The analyses were however repeated using parametric tests for confirmation and these led to the same conclusions being drawn.

Analyses of these data required multiple application of the statistical tests, and thus a risk of capitalising on chance (a type I error) and thus suggesting a difference to be real when it is not. The results were thus analysed with reference to a Bonferroni corrected threshold and to the overall pattern of results.

### 6.5.1 Effect of Target Size (Distance)

The effect of target size (simulates distance) is suggested by the Friedman test to be significant ($p<0.001$) with the targets' larger size leading to a greater frequency of correct recognition. Application of the Wilcoxon test to compare results for the 4 m and 15 m distances in each of the 36 test conditions (6 luminance levels, 3 lamps, 2 duration) suggests that the differences are significant ($p<0.001$), except for five cases, these results being at chance level being the lowest lighting level of 0.01 cd/m$^2$.

### 6.5.2 Effect of SPD

The Friedman test does not suggest that lamp type has a significant effect on categorical judgement of facial expression for any luminance or target size with any duration of observation ($p>0.20$ for all 24 combinations of duration, luminance and distance). Since the effect of lamp type was not significant, subsequent analyses were carried out using the mean result across lamp type for each participant for each combination of duration, distance and luminance.

### 6.5.3 Effect of Duration

The Wilcoxon test suggests a significant effect of duration ($p<0.01$) in four of the 12 conditions, these being luminances of 3.33 and 1.00cd/m$^2$ at 15 m, and luminances of 0.33 and 0.03 cd/m$^2$ at 4 m, with performance at 1000 ms being higher than at 500 ms. Three of these cases lie in the escarpment region of the performance curve.

### 6.5.4 Effect of Luminance

The Friedman test suggests that luminance has a significant effect on correct identification of facial expression ($p<0.001$) for all combinations of size and duration. Differences between adjacent luminance pairs were examined using the Wilcoxon test as shown in Table 6.5.

**Table 6.5** Results of Wilcoxon tests on the effect of luminance for adjacent pairs

| **Combinations of conditions** | **Adjacent pairs between six luminance levels** | | | | |
|---|---|---|---|---|---|
| | **0.01 vs 0.03** | **0.03 vs 0.10** | **0.10 vs 0.33** | **0.33 vs 1.00** | **1.00 vs 3.33** |
| **4m, 1000ms** | p<0.001 | p<0.001 | p<0.001 | p=0.276 | p=0.021 |
| **4m, 500ms** | p<0.001 | p<0.001 | p<0.001 | p=0.021 | p=0.089 |
| **15m, 1000ms** | p=0.625 | p=0.001 | p<0.001 | p<0.001 | p<0.001 |
| **15m, 500ms** | p=0.294 | p=0.011 | p=0.003 | p<0.001 | p<0.001 |

When the five adjacent pairs of six luminance levels are considered separately using the Wilcoxon test, significant differences ($p<0.01$) were found for 13 cases. For seven cases the differences were not suggested to be significant (the shaded cells in Table 2). These cases are those whose frequencies of correct identification are in the plateau rather than escarpment of the performance curve, i.e. when task difficulty is either at a maximum and where extra luminance does not lead to better performance or at a minimum where judgements are at chance level.

## 6.6 Summary

Two experiments were carried out to examine the effect of lighting on interpersonal judgements.

The first experiment collected force-choice judgements of emotion and gaze direction after 1000ms exposure under 18 combinations of luminance, lamp type and distance (simulated by target size). Better performance was found with higher luminance and larger target size, but with diminishing returns according to a plateau-escarpment relationship.

The second experiment is essentially a repeat study on facial expressions and included a greater number of test luminances, a third type of lamp (CPO), and an additional, shorter, duration of observation (500ms). Luminance and distance were found having significant effect on expression recognition: the effect of lamp was not significant and the effect of duration was suggested to be significant only within the escarpment region of the performance versus luminance.

Table 6.6 summarises the results of statistical analysis on judgements of facial expression of both of the two experiments. The results are to be used provide evidence for estimating appropriate parameters of outdoor lighting for pedestrians.

For example, results of the first experiment for judgements of emotion from facial expression suggest a minimum luminance on face of 0.1-1.0 $cd/m^2$, if facial expressions are desirable to be accurately identified at 4m. Further discussion on optimum lighting level is provided in Chapter 7.

**Table 6.6** Statistical analysis results on facial expression of the two experiments

| | **Experiment No. 1** | **Experiment No. 2** |
|---|---|---|
| Effect of luminance | Yes | Yes |
| Effect of lamp SPD | No | No |
| Effect of target size | Yes | Yes |
| Effect of duration | Not tested | Yes on escarpment<br>No on plateau |
| Effect of participants' age group | Yes | Not tested |

# CHAPTER 7 DISCUSSION

## 7.1 Introduction

This chapter compares the results firstly between the two experiments described in Chapters 5 and 6 and then with past studies. The results are then used to investigate identification of optimum luminance and SPD for interpersonal judgement as a critical visual task of pedestrians, which is one of the main objectives of this thesis. A further pilot/verification study using chromatic stimuli was carried out to check if the absence of effect of SPD is because the stimuli used in the two experiments were reduced to near-achromatic. Results of individual facial expressions in experiment No.2 were examined as there is evidence that some facial expressions are easier to be detected than others. Limitations of this work and recommendations for further works are also identified.

## 7.2 Repeatability of the Experiments

The results of experiment No.1 demonstrate that the ability to recognise emotions from facial expression, body posture, and gaze direction is affected by luminance and target distance: higher luminances and closer distances (i.e. subtending a larger visual size) tend to increase the frequency of correct judgements. The test results tend to exhibit a plateau-escarpment relationship, with a diminishing increase in performance after a certain high luminance and/or short distance is reached, and reducing to chance performance at low levels of luminance and large distances. An effect of lamp type was found in judgements of body posture and gaze direction for those conditions lying on an apparent escarpment but a difference between lamps was not found in judgements of facial expression.

The results of experiment No.2 also demonstrate that the ability to recognise emotions conveyed by facial expression is affected by luminance and target size:

higher luminances and closer distances (i.e. subtending a larger visual size) tend to increase the frequency of correct judgements. With three more additional luminance levels used in this study than experiment No.1, the plateau-escarpment relationship was exhibited more clearly: with a diminishing increase in performance after a certain high luminance and/or short distance is reached, and reducing to chance performance at low levels of luminance and/or large distances. Effect of duration was found in judgements of facial expression for those conditions lying on apparent escarpment, but not in plateau region. No effect of lamp type was found for any given condition.

One aim of experiment No.2 was to validate by repetition the results of experiment No.1. The conditions common to both experiments are a duration of 1000 ms, distances of 4 m and 15 m, the MH and HPS lamps, and luminances of 0.01, 0.1, and 1.0 cd/m$^2$.The samples compared are the 20 participants in the experiment No.2, these being aged less than 50 years old, and the 15 participants from younger group (aged less than 45 years old) in the experiment No.1. Figure 7.1 shows these data, with correct expression recognition frequencies being averaged across lamp type. These data are for observers aged <50 years with duration of 1000 ms, averaged across lamp type, for the experiment No.1 and No.2. Error bars show interquartile range. Note that for clarity the data points for the first study have been translated slightly to luminances of 0.0105, 0.105, 1.05 cd/m$^2$ rather than 0.01, 0.1, and 1.0 cd/m$^2$.

For trials at 15 m, results of the two studies coincide: for trials at 4 m, experiment No.2 found slightly higher performance than did the previous experiment. The Mann Whitney test for independent samples was to compare results from the two studies for each combination of distance, luminance and lamp type. This did not suggest difference between the two experiments to be significant in ten cases ($p>0.12$) but for two cases (HPS, 0.01 cd/m$^2$, 15m and MH, 0.1 cd/m$^2$, 4m) the difference was close to significance ($p=0.08$ and $p=0.06$ respectively). It was therefore concluded that, for similar test conditions, experiments No.1 and No.2 led to similar results.

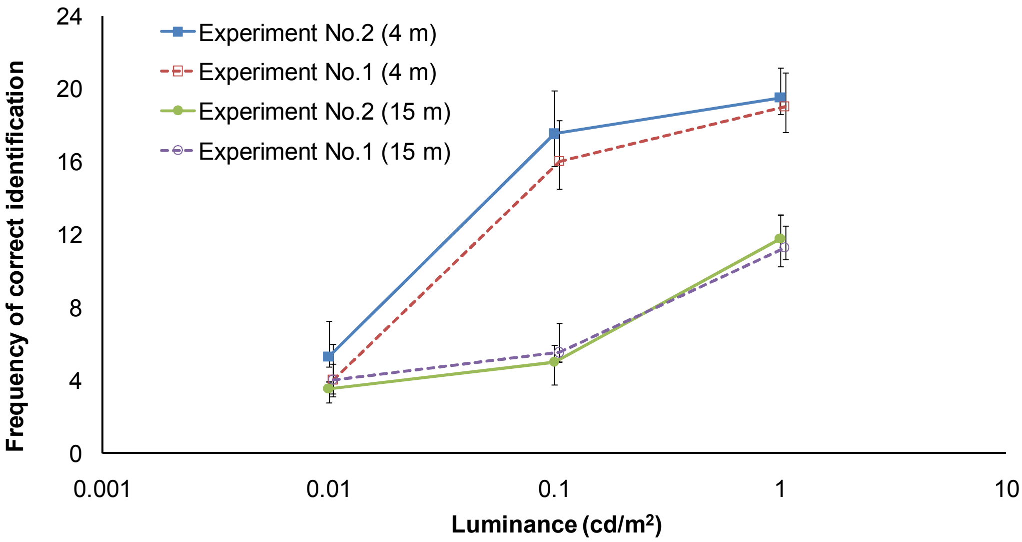


**Figure 7.1** Median frequencies of correct identification on facial identification with duration of 1000ms from young group plotted against luminance level

## 7.3 Comparison with Previous Studies

### 7.3.1 Effect of Luminance

Caminada and van Bommel (1980) used a stop-distance procedure to examine facial recognition and concluded that semi-cylindrical illuminances ($E_{SC}$) of 0.8 lux and 2.7 lux were needed for recognition at 4 m and 10 m respectively. In the current study, the target luminances of 0.01, 0.03, 0.1, 0.33 and 1.0 cd/m$^2$ correspond approximately with semi-cylindrical illuminances of 0.07, 0.23, 0.7, 2.33 and 7.0 lux respectively. These semi-cylindrical illuminances were measured (Hagner E4-X meter with SD-11 detector) at the position of the screen, thus representing the semi-cylindrical illuminances measured at the target face as reported by Caminada and van Bommel. Thus at 4 m, the current results suggest a semi-cylindrical illuminance in the range of 0.7 to 2.33 lux (Table 7.1) while the value reported by Caminada and van Bommel (0.8 lux) lies at the lower end of this range; at 10 m, the current data suggest a semi-cylindrical illuminance of 7.0 lux or greater, which is higher than the value (2.7 lux) reported by Caminada and van Bommel.

**Table 7.1** Comparison of semi-cylindrical illuminances suggested in different studies

| Study | Semi-cylindrical illuminance (lux) | |
|---|---|---|
| | **4 m distance** | **10 m distance** |
| Caminada & van Bommel, 1980 | 0.8 | 2.7 |
| Rombautset *al*, 1989 | 0.4 | 3.0 |
| Results of current work | 0.7-2.33 | ≥7.0 |

The current estimates of light level are also slightly higher than the findings from the study of facial recognition by Rombauts *et al* (1989) who investigated illuminance and facial recognition. Their results suggest a semi-cylindrical illuminance of 0.4 lux is required for identification at 4 m, approximately 3.0 lux for identification at 10 m, and an asymptote of around 20 to 25 lux beyond which higher $E_{SC}$ did not lead to better recognition.

Thus the current data suggest illuminances that are higher than those reported in past studies. This higher illuminance may be because the task was more difficult, as recognition of facial expression can be more difficult than recognition of facial identity (Gao and Maurer, 2011) and through the limited observation permitted.

Another reason may be that stimuli used in this work were presented as images, while real persons were used as targets by Caminada and van Bommel (1980) and Rombauts *et al* (1989). Note however that when Boyce and Gutkowski (1995) interpreted the Rombauts *et al* (1989) data, they suggested a vertical illuminance of 33 lux is needed at a distance of 17 m, which is of a similar order to the current results which suggest an illuminance of greater than 20 lux is needed in the plane of the target for identification of expression at 10 m. Rombauts *et al* also suggested that confident face recognition is not possible beyond 17 m: The results of this work suggest recognition of facial expression is not significantly better than chance at 15 m.

Dong *et al* (2014) carried out two facial recognition experiments using matching and naming/identification at five observation durations and three target luminances, to explore task difficulty. It was found that recognition probability are related to task difficulty defined by luminance and duration, and identification/naming is a more difficult task than matching. Figure 7.2 shows the results found in the two experiments and in Dong *et al* (2014) for young observers in a form of proportion (a frequency of 21 is set as 100%). A plateau and escarpment relationship similar to the results of current work was revealed. The apparent plateau is reached when luminance is greater than 1.00 cd/m$^2$. It also can be seen that the two data points of Dong et al (2014) at luminance of 0.10 cd/m$^2$ lie between the results of the current work at the same luminance. Note that the distance used in Dong et al (2014) was 10 m, while 4 m and 15 m were used in this work.

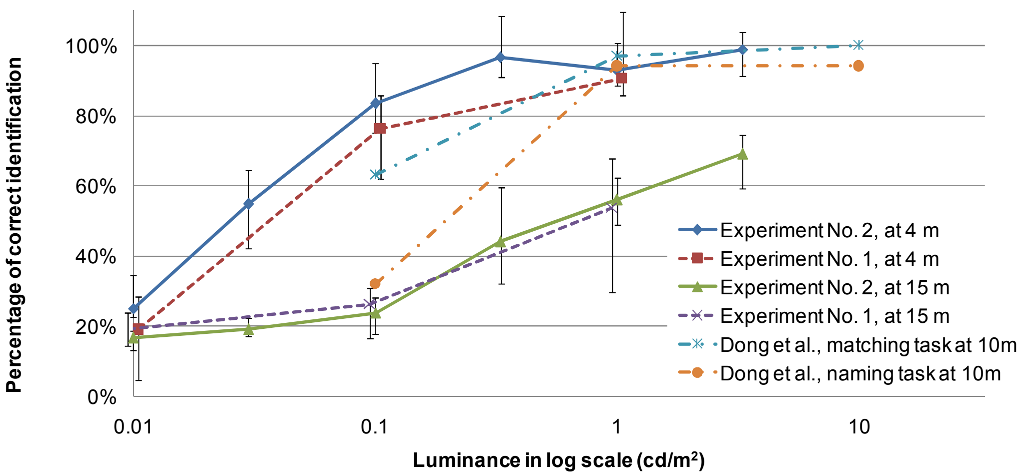


**Figure 7.2** Median frequencies (percentages) of correct identification on facial identification with duration of 1000ms from young group against luminance level

### 7.3.2 Effect of SPD

Results of both experiments show that there is no effect of SPD at any condition on recognition of facial expressions. In trials involving recognition of body posture and gaze direction in Experiment No.1, however, there was a significant effect of SPD in those conditions lying in an apparent escarpment region, near the middle of the range of luminance and distance combinations. In Experiment No.2, similarly results for effect of duration on judgements of facial expression were found for those conditions lying on apparent escarpment, but not in plateau regions.

Some of the past studies on facial recognition suggest an effect of SPD and some do not, as discussed in section 2.7. Reviews of past studies and results from recent studies (Dong et al., 2014; Lin and Fotios, 2013) suggest that effect of lighting on performance of interpersonal judgement is sensitive to difficulty of task affected by observing distance and duration. Previous studies tend to use stop-distance approach and allow unlimited observation duration while this work constrains factors like observation distance and duration with the aim of better isolating lighting as independent variable. In contrary to the findings on SPD in current work, the significant effect of SPD found in some past studies may actually be caused by two reasons: (1) different studies presented different levels of task difficulty; (2) the incidental difference between changeable distances and/or durations rather than lighting settings.

## 7.4 Optimum Luminance

Results of experiment No. 1 (Figure 6.1) provide preliminary information for estimating optimum luminance. If identification of gaze direction is important, the results suggest a need for face luminances of at least 1.00 cd/m$^2$ to ensure probability of correct identification is above the chance level. The facial expression and body posture data suggest a plateau-escarpment relationship, and the knee in these curves provides one estimate of appropriate light level: lower luminances would allow a rapid decline in visual performance, while higher luminances offer no benefit. The maximum identification probabilities found in the current data (73% for facial expression and 89% for body posture) approach those exhibited when the databases were validated under good lighting conditions with longer exposure durations (4 s for body, unlimited for face), which suggests the plateau is reached in the current data: 81.3% for facial expression (Ebner et al., 2010) and 92.6% for body posture (de Gelder and van den Stock, 2011). Unfortunately, similar information is not available for the gaze direction database. For facial expressions at 4 m this knee is somewhere in the range of 0.10-1.00 cd/$m^2$, increasing to >1.00 cd/$m^2$ for identification at 10m. For body posture, this knee appears to be reached at 10 m and 30 m at a luminance of 0.10 cd/$m^2$.

The results from experiment No.2 (Figure 6.3) demonstrate that the ability to recognise emotions conveyed by facial expression is affected by luminance and target size: higher luminances and shorter distances (i.e. subtending a larger visual size) tend to increase the frequency of correct judgements. The three additional luminance levels used in the experiment No.2 better define the relationship between luminance and performance than did the experiment No.1. In particular, the plateau-escarpment relationship is exhibited more clearly: with a diminishing increase in performance after a certain high luminance and/or short distance is reached, and reducing to chance performance at low levels of luminance and/or large distances.

According to the escarpment-plateau relationship, the knee in the curves provides one estimate of appropriate light level. Figure 6.3 indicates an optimum luminance of 0.33 cd/$m^2$ for recognition at 4 m. Experiment No.1 suggested minimum luminance of 0.1-1.0 cd/$m^2$ if facial expressions were to be identified accurately at 4 m: the conclusion interpreted from the current data is within that range.

However, the data for 15 m do not appear to have yet reached a plateau, with the apparent trend being that luminances greater than 3.33 cd/$m^2$ would bring further increase in recognition ability. Thus an extended trend line based on performance of judgements on facial expression was used to make the estimate.

The data points in Figure 7.3 are the experimental results, the median frequency of which facial expression were correctly identified with an observation duration of 500ms at distances of 4m and 15m. The curves in Figure 7.3 are the best fit curves as fitted using Four Parameter Logistic Equation (4PLE), which was used in visual object detection (Fotios and Cheal, 2009; Harris, 2006). For the current analysis, one additional parameter was added with several other necessary modifications and can be expressed as:

$$F = F_{max} - \frac{F_{max} - F_{min}}{1 + (\frac{\log L - C}{\log L_m - C})^S}$$

F: dependent variable, frequency of correct identification of facial expressions.

$F_{max}$: constant, maximum frequency, $F_{max}$ = 21.

$F_{min}$: constant, minimum frequency when performance is to chance level, $F_{min}$ = 4.

L: independent variable, luminance (cd/$m^2$)

$L_m$: luminance (cd/$m^2$) at which F = $(F_{max}+F_{min})/2$

S: slope of curve when $L=L_m$

C: constant, indicating the shift from ‘0’ point on x axis.

The best fit lines were established by varying $L_m$, S and C to minimise the sum of squared errors between the frequency of correct identification found by experiment and the values predicted by the equation. For results of 4 m, this included the complete range of frequencies from about chance level (4) to on-plateau identification. For results of 15 m however, the frequencies of correct identification do not reach to the plateau, therefore the best fit line was extended to higher luminance in order to predict the knee in plateau-escarpment for estimate the optimal luminance. As expected, the curves are S-shaped, with ranges in luminance causing a rapid change of frequency of correct identification in the middle of the range, but becoming flatter near the ends of the range of luminance where identification approaches chance or maximum level.

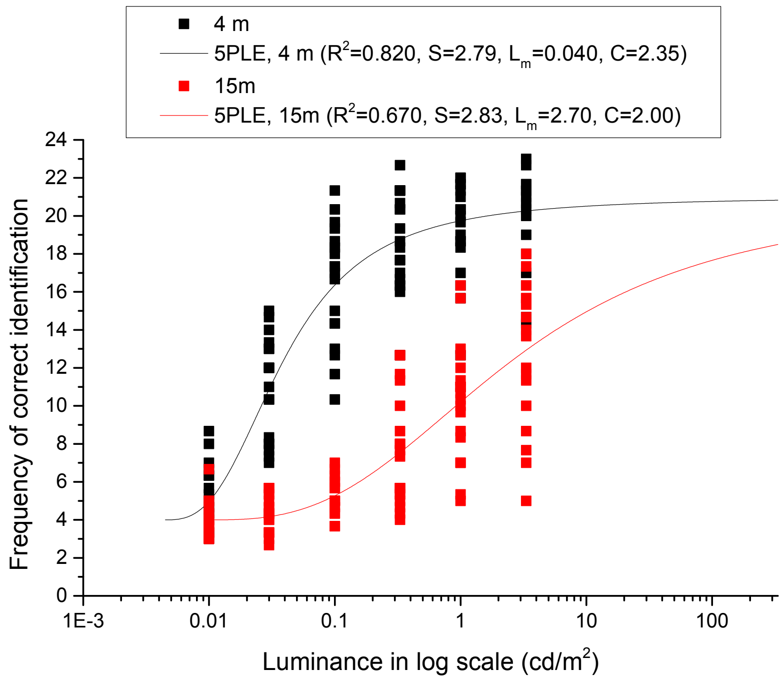


**Figure 7.3** Frequency of correct identification of emotion conveyed by facial expression and best fit lines based on 4PLE

Nevertheless, there is one problem of 4PLE that it is not known whether the plateau of maximum performance would be at the same frequency of correct response as for the 4 m task since the 15 m targets subtend a smaller visual size than at the observers eye than do the 4 m targets: this may result in a plateau of maximum performance at a lower level of performance. Therefore, linear extrapolation was carried out as an alternative estimate for the 15 m data by extending the trend exhibited by luminances from 0.33 to 3.33 cd/m$^2$ and for results averaged across lamp type and duration. The frequency plateau equivalent to the 4 m distance (81%) is reached at a luminance of 43.8 cd/m$^2$, while a lower frequency of correct response (f=16: 66%) is reached at a luminance of 7.5 cd/m$^2$. Further tests at a higher luminance would be required to confirm these estimates.

Another alternative approach to identifying the optimum luminance is to set the probability of correct recognition expected and interpolate the luminance required to provide this for a given task. For a 50% probability of correct identification, the current data suggests luminances of approximately 0.03 cd/m$^2$ at 4 m, and 1.0 cd/m$^2$ at 15 m. The above two estimated optimum luminances are equivalent to illuminances of 0.6 and 20 lux respectively. The range between these two values approximately matches the range of 2-15 lux that is suggested by current standards and guidance (British Standards Institution, 2003b; International Commission on Illumination, 2010). Further research is required to establish what the correct probability of recognition should be and whether this changes with distance. The estimated optimum luminances were interpolated from these data to explore how this might be done pending investigation of other influences such as target colour and glare.

## 7.5 Individual Facial Expressions

The analyses stated so far utilised the recognition rate averaged across all six expressions. It is expected that different expressions will have different recognition rates. Table 7.2 shows the results from Ebner et al (2010) when validating their FACES database under good lighting conditions with unlimited exposure durations. The happy and neutral expressions were correctly identified most frequently and the sad and disgust expressions identified least frequently. For the current data in experiment No.2, the easiest conditions for expression recognition are those with the highest luminance (3.33 cd/m$^2$) and the largest size (4 m distance): the proportions of correct recognition, and the rank order of correct recognition, are in good agreement with those of Ebner et al (2010). The hardest conditions for expression recognition are those with the lowest luminance (0.01

cd/m²) and the smallest size (15 m distance): other than for the neutral expression, the proportions of correct recognition in these conditions are around that expected by chance performance (0.17).

**Table 7.2** Proportion of correct identification of unique facial expressions as reported by Ebner et al (2010) and as found in the current study. The expressions are listed in descending order as defined by the results of Ebner et al (2010).

| **Expression** | **Ebner et al, 2010** | **Data from experiment No.2** | |
|---|---|---|---|
| | | **Easiest conditions 3.33 cd/m²; 4 m** | **Hardest conditions 0.01 cd/m²; 15 m** |
| Happy | 0.96 | 0.95 | 0.14 |
| Neutral | 0.87 | 0.93 | 0.32 |
| Angry | 0.81 | 0.80 | 0.11 |
| Fear | 0.81 | 0.79 | 0.12 |
| Sad | 0.73 | 0.81 | 0.10 |
| Disgust | 0.68 | 0.77 | 0.19 |

Under good visual (easiest) conditions, Table 7.2 suggests differences in the ability to recognise different facial expressions. Figure 7.4 shows the experimental results of Figure 6.3 broken down by facial expression, with these data being averaged across lamp type and duration. Past studies (Dong et al., 2014; Lin and Fotios, 2013) suggested that an effect of SPD is more likely to occur when the task is difficult, identified here as conditions falling in the escarpment region of Figure 7.4. The effect of SPD and duration were investigated at two such conditions: (i) the fear expression at 1.0 cd/m², 15 m, and (ii) the happy expression at 0.33 cd/m², 15m. For control, a third case was also examined, (iii), the happy expression at 0.33 cd/m², 4m, this being an apparently easy condition and where an effect of SPD and duration would not be expected.

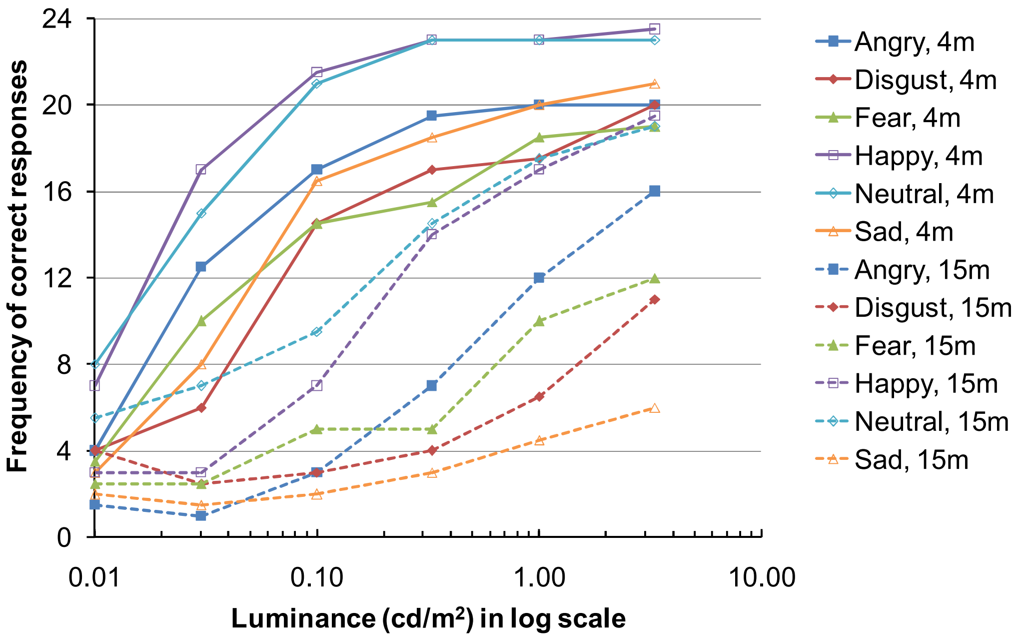


**Figure 7.4** Median frequencies for correct identification of emotion from facial expression for the six expressions at the two test distances (as identified in the legend). These data are averaged across duration and lamp type. *Note: For convenience, data for the for MH lamp at 2.50 cd/m$^2$ are merged with data for the CPO and HPS lamps at 3.33 cd/m$^2$.

Within each of these three cases there were six conditions, these being the six combinations of the three lamp types and the two durations. The Friedman test did not suggest differences between these conditions to be significant for cases (ii) and (iii) but was close to significance for case (i) (p=0.08). The Wilcoxon Signed Ranks test was used to examine individual pairs within cases (i) and (ii): this did not suggest the effect of SPD to be significant, but did suggest the effect of duration to be significant in two situations (fear, 1.0 cd/m$^2$, 15 m, $p<0.01$; happy, 0.33 cd/m$^2$, 15 m, $p<0.05$) with a lower frequency of correct expression recognition at the shorter duration (500 ms).

Six facial expressions were used in this work, of which one might be considered a positive emotion (happy), one ambivalent (neutral) and four to be negative (angry, disgust, fear and sad). Further experimental work might consider whether it is appropriate to use all six expressions, or whether it might be interesting to pick the most salient for interpersonal evaluations (e.g. fear) or to balance the number of positive and negative emotions presented during trials.

## 7.6 Summary

This chapter compared the results of the refined experiment No.2 with experiment No.1 and suggested the results are repeatable and consistent. Comparisons with previous studies suggest illuminances that are slightly higher than those reported in past studies. Results of both experiments show that there is no effect of SPD at any condition on recognition of facial expressions. Optimum luminances were interpolated from these data to explore how this might be done pending investigation of other influences such as target colour and glare. For a 50% probability of correct identification, the current data suggests luminances of approximately 0.03 cd/m$^2$ at 4 m, and 1.0 cd/m$^2$ at 15 m. Further work including glare, luminance uniformity, 3D targets rather than images, and the influence of target contrast and colour, may reveal more desired evidences.

# CHAPTER 8 CONCLUSION

## 8.1 Conclusions for This Work

This work explored lighting and interpersonal judgement for pedestrians in residential roads. Literature review confirmed the lack of empirical evidence underpinning current standards and the incompletion of past studies solely based on facial recognition with inconsistent results. Recognition of facial expression is proposed as an alternative task in addition to facial recognition.

Conclusions are listed below corresponding to the research questions raised in section 1.4:

**1) Does interpersonal judgement matter for pedestrian?**

The importance of making interpersonal judgement of another person has been empirically verified by the results of eye-tracker videos recorded by James Uttley (Fotios et al., 2014b; Fotios et al., 2014c): other pedestrians are fixated at high probability.

**2) What are the desirable distance and duration?**

Analysis on eye-tracker videos suggested that experiments seeking to examine the effect of lighting on interpersonal judgements should use an interpersonal distance of 15 m and restrict observation duration to 500 ms.

**3) What elements of interpersonal judgement are critical?**

The first pilot study examined the interpersonal information observed at different distances and suggests that recognition of facial features is a subtask of particular interest.

**4) Can interpersonal judgement be quantified?**

The second pilot study found that standard facial expressions and body postures did not lead to consistent judgements therefore suggesting any effect of lighting being investigated would be confounded by the inconsistent responses.

**5) Does lighting affect the performance of interpersonal judgement?**

The first experiment collected forced choice judgements of emotion and gaze direction after 1000ms exposure under 18 combinations of luminance, lamp type and distance. Better performance was found with higher luminance and larger target size, but with diminishing returns according to a plateau-escarpment relationship.

The second experiment is essential a repeat study on facial expressions and included a 72 combinations of luminance, lamp type, distance and duration. Luminance and distance were found having significant effect on expression recognition: the effect of lamp was not significant and the effect of duration was suggested to be significant only within the escarpment region of the performance versus luminance. Effect of lighting on performance of interpersonal judgement was found being sensitive to difficulty of task defined by observing distance (exhibited by target size) and duration. This is also confirmed by results from recent studies (Dong et al., 2014; Lin and Fotios, 2013).

**6) What is the optimum lighting condition?**

The results were used to estimate appropriate light levels for outdoor lighting. For example, a luminance of 1.0 $cd/m^2$ permits facial expressions to be identified with a 50% probability of correct identification at a distance of 15 m.

## 8.2 Limitations and Recommended Further Works

This work is reported to better understand the relationship between lighting and expression recognition through understanding of how performance changes with variation in parameters of lighting and the task. The optimum luminances described should not be taken as recommendations, as better understanding and more parameters need to be examined before the findings of this study become exploitable. Further parameters include glare, luminance uniformity, 3D targets rather than images, and the influence of target contrast and colour.

The experimental data may be used to provide tentative estimates of appropriate light levels, because these were evaluations of achromatic images in the laboratory rather than a real person in natural outdoor settings. In natural settings, the targets are likely to allow evaluation in parallel from body posture, gaze direction, gait, clothing, acoustic signals and etc.

In experiment No.1, most of the data points on gaze direction were near chance level (a frequency of 8), which indicated that gaze direction test was not successful because eyes, the critical feature for gaze direction, are too small in size to show a meaningful effect of light.

Glare caused by light sources such as vehicle, road lamp, building and shops is ubiquitous in real visual environment of pedestrians on street/road after dark. Estimation of optimum lighting characteristics should considerate such glare. Further work including glare after identifying its typical extensity and intensity will be needed.

Using 3D targets would enable variations in spatial distribution of lighting to be considered. A study by Hill and Bruce (1996) showed that edge information which can be preserved mostly by photograph, alone is not sufficient for facial recognition. Absence or disruption of shadow and shading information also play a role. However, procedure that enables repeatable presentation of target and affordability are limiting factors of using 3D stimuli.

In this work, colour images of faces were rendered to be near grey-scale by the non-self-luminous screen, under the low (mesopic) light levels used in the experiments. To confirm the findings on SPD, it is necessary to check the effect of colour on performance of interpersonal judgement. Hence a supplementary experiment using a new apparatus constructed to maintain image colour is being carried out by a colleague (Dr Holly Castleton). This apparatus employs a conventional colour projector in which the standard lamp is replaced by a test lamp (e.g. high pressure sodium), with the projection screen back-lit by an identical lamp. The aim of this supplementary experiment is to reveal an effect of colour on recognition of facial expression by using both grey-scale and colour images as stimuli. The initial results do not suggest such an effect to be significant.

# APPENDIX A: RAW EXPERIMENTAL RESULTS

## Appendix A.1 Raw Results of Experiment No.1

The specific gender and age group information of the 30 participants as shown below (participant number #):

- 16 Male: 3, 4, 5, 8, 10, 11, 12, 13, 14, 18, 19, 20, 22, 24, 25 and 27.
- 14 Female: 1, 2, 6, 7, 9, 15, 16, 17, 21, 23, 26, 28, 29 and 30.
- 15 Older: 1, 5, 8, 11, 15, 17, 18, 19, 20, 21, 22, 23, 24, 29 and 30.
- 15 Younger: 2, 3, 4, 6, 7, 9, 10, 12, 13, 14, 16, 25, 26, 27 and 28.

The identity numbers of selected stimuli are listed below:

**Facial expression (FACES)**:

- #015: old male
- #066: young male
- #112: old female
- #140: young female

**Body postures (BEAST)**:

- #04 and #15 (female)
- #09 and #10 (male).

**Gaze directions (uulmHPG)**:

- #02: male, glasses
- #09: female, glasses
- #12: female, no glasses
- #15: male, no glasses

Table A.1 – A.6 show raw experimental results of experiment No.1 for three target stimuli (facial expression, body posture and gaze direction) under two lamps (HPS and MH).

**Table A.1** Raw results on facial expression of experiment No.1 under HPS

| **Lamp** | **HPS** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **1** | **1** | **1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **10** | **15** | **4** | **10** | **15** | **4** | **10** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | |
| 1 | 17 | 8 | 4 | 9 | 4 | 4 | 4 | 5 | 2 |
| 2 | 16 | 13 | 11 | 22 | 11 | 8 | 8 | 2 | 3 |
| 3 | 21 | 16 | 15 | 18 | 12 | 6 | 2 | 5 | 1 |
| 4 | 16 | 12 | 7 | 16 | 6 | 7 | 4 | 10 | 2 |
| 5 | 18 | 14 | 5 | 12 | 4 | 2 | 1 | 5 | 4 |
| 6 | 14 | 7 | 4 | 10 | 4 | 6 | 5 | 5 | 5 |
| 7 | 20 | 18 | 12 | 16 | 7 | 6 | 12 | 3 | 4 |
| 8 | 13 | 7 | 5 | 10 | 2 | 2 | 6 | 4 | 3 |
| 9 | 18 | 13 | 4 | 14 | 5 | 2 | 5 | 6 | 3 |
| 10 | 19 | 17 | 15 | 17 | 13 | 6 | 8 | 2 | 7 |
| 11 | 20 | 14 | 10 | 15 | 7 | 4 | 4 | 4 | 4 |
| 12 | 20 | 16 | 6 | 13 | 7 | 5 | 3 | 6 | 3 |
| 13 | 21 | 16 | 12 | 18 | 8 | 7 | 3 | 1 | 2 |
| 14 | 15 | 11 | 7 | 13 | 11 | 6 | 0 | 4 | 5 |
| 15 | 14 | 9 | 4 | 8 | 5 | 3 | 3 | 4 | 3 |
| 16 | 19 | 15 | 12 | 14 | 10 | 3 | 7 | 5 | 6 |
| 17 | 15 | 12 | 6 | 12 | 6 | 3 | 3 | 4 | 0 |
| 18 | 18 | 15 | 12 | 15 | 11 | 4 | 4 | 4 | 3 |
| 19 | 20 | 18 | 10 | 16 | 12 | 8 | 3 | 4 | 5 |
| 20 | 14 | 5 | 1 | 7 | 4 | 3 | 4 | 4 | 4 |
| 21 | 20 | 14 | 12 | 15 | 14 | 8 | 2 | 5 | 4 |
| 22 | 19 | 16 | 8 | 15 | 9 | 4 | 6 | 4 | 4 |
| 23 | 7 | 4 | 3 | 10 | 4 | 3 | 4 | 4 | 4 |
| 24 | 16 | 5 | 6 | 6 | 4 | 4 | 4 | 4 | 4 |
| 25 | 19 | 14 | 10 | 10 | 2 | 2 | 3 | 4 | 9 |
| 26 | 22 | 14 | 15 | 19 | 6 | 6 | 8 | 5 | 5 |
| 27 | 21 | 18 | 15 | 17 | 14 | 7 | 4 | 10 | 4 |
| 28 | 16 | 12 | 13 | 14 | 11 | 4 | 3 | 3 | 5 |
| 29 | 17 | 4 | 7 | 8 | 5 | 3 | 3 | 5 | 3 |
| 30 | 19 | 19 | 15 | 15 | 6 | 5 | 3 | 2 | 5 |

**Table A.2** Raw results on facial expression of experiment No.1 under MH

| **Lamp** | **MH** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **1** | **1** | **1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **10** | **15** | **4** | **10** | **15** | **4** | **10** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | |
| 1 | 18 | 5 | 4 | 8 | 4 | 4 | 4 | 5 | 2 |
| 2 | 17 | 16 | 10 | 19 | 12 | 3 | 4 | 4 | 5 |
| 3 | 23 | 18 | 15 | 20 | 13 | 3 | 6 | 5 | 7 |
| 4 | 17 | 13 | 8 | 12 | 2 | 5 | 5 | 5 | 3 |
| 5 | 17 | 10 | 3 | 11 | 3 | 8 | 6 | 5 | 4 |
| 6 | 13 | 9 | 8 | 12 | 5 | 5 | 8 | 7 | 3 |
| 7 | 20 | 13 | 10 | 18 | 16 | 10 | 12 | 6 | 4 |
| 8 | 14 | 3 | 7 | 12 | 2 | 6 | 5 | 8 | 6 |
| 9 | 20 | 15 | 7 | 15 | 6 | 4 | 6 | 5 | 3 |
| 10 | 20 | 16 | 16 | 17 | 11 | 3 | 5 | 4 | 3 |
| 11 | 17 | 16 | 11 | 15 | 4 | 4 | 3 | 4 | 4 |
| 12 | 19 | 15 | 9 | 16 | 10 | 5 | 5 | 7 | 0 |
| 13 | 19 | 15 | 16 | 16 | 6 | 5 | 6 | 3 | 5 |
| 14 | 18 | 14 | 8 | 15 | 4 | 5 | 6 | 8 | 7 |
| 15 | 15 | 14 | 4 | 14 | 6 | 2 | 5 | 5 | 4 |
| 16 | 17 | 13 | 12 | 16 | 13 | 6 | 10 | 2 | 3 |
| 17 | 17 | 11 | 4 | 11 | 7 | 5 | 3 | 4 | 1 |
| 18 | 19 | 14 | 11 | 18 | 6 | 1 | 2 | 7 | 3 |
| 19 | 22 | 16 | 14 | 18 | 12 | 7 | 10 | 5 | 2 |
| 20 | 15 | 7 | 5 | 6 | 0 | 1 | 4 | 4 | 4 |
| 21 | 22 | 17 | 13 | 17 | 11 | 6 | 2 | 2 | 5 |
| 22 | 20 | 14 | 8 | 16 | 10 | 3 | 2 | 3 | 5 |
| 23 | 10 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 |
| 24 | 13 | 13 | 8 | 6 | 4 | 4 | 4 | 4 | 4 |
| 25 | 17 | 15 | 15 | 14 | 5 | 3 | 5 | 7 | 4 |
| 26 | 21 | 16 | 10 | 15 | 6 | 4 | 7 | 5 | 3 |
| 27 | 22 | 20 | 15 | 18 | 13 | 6 | 4 | 3 | 5 |
| 28 | 17 | 12 | 8 | 15 | 8 | 6 | 6 | 4 | 4 |
| 29 | 15 | 5 | 3 | 9 | 6 | 4 | 4 | 3 | 5 |
| 30 | 21 | 16 | 10 | 20 | 7 | 5 | 4 | 4 | 3 |

**Table A.3** Raw results on body posture of experiment No.1 under HPS

| **Lamp** | **HPS** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **1** | **1** | **1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.01** | **0.01** |
| **Distance (m)** | **10** | **30** | **135** | **10** | **30** | **135** | **10** | **30** | **135** |
| **Participant number** | **Frequency of correct response (0-16)** | | | | | | | | |
| 1 | 14 | 12 | 4 | 11 | 6 | 4 | 1 | 2 | 4 |
| 2 | 16 | 14 | 11 | 16 | 14 | 7 | 12 | 7 | 3 |
| 3 | 15 | 14 | 9 | 13 | 13 | 5 | 10 | 7 | 5 |
| 4 | 14 | 12 | 2 | 12 | 14 | 4 | 14 | 7 | 4 |
| 5 | 15 | 13 | 6 | 13 | 11 | 5 | 11 | 2 | 3 |
| 6 | 13 | 11 | 8 | 13 | 12 | 7 | 10 | 3 | 4 |
| 7 | 16 | 13 | 10 | 14 | 14 | 5 | 13 | 5 | 5 |
| 8 | 11 | 12 | 3 | 11 | 8 | 3 | 7 | 2 | 7 |
| 9 | 14 | 11 | 6 | 12 | 12 | 5 | 10 | 5 | 3 |
| 10 | 15 | 13 | 13 | 15 | 13 | 4 | 13 | 9 | 5 |
| 11 | 15 | 14 | 6 | 15 | 7 | 4 | 9 | 5 | 6 |
| 12 | 16 | 15 | 5 | 14 | 13 | 9 | 12 | 4 | 4 |
| 13 | 15 | 15 | 10 | 15 | 11 | 2 | 9 | 6 | 0 |
| 14 | 15 | 13 | 8 | 13 | 12 | 2 | 6 | 4 | 5 |
| 15 | 12 | 13 | 2 | 10 | 6 | 5 | 1 | 3 | 5 |
| 16 | 16 | 13 | 9 | 15 | 14 | 3 | 11 | 4 | 4 |
| 17 | 14 | 11 | 4 | 11 | 2 | 3 | 3 | 6 | 3 |
| 18 | 15 | 13 | 10 | 12 | 13 | 6 | 9 | 5 | 3 |
| 19 | 15 | 14 | 9 | 13 | 12 | 5 | 10 | 1 | 5 |
| 20 | 12 | 11 | 4 | 14 | 3 | 3 | 5 | 5 | 5 |
| 21 | 14 | 11 | 10 | 12 | 9 | 6 | 7 | 3 | 1 |
| 22 | 11 | 12 | 6 | 10 | 12 | 1 | 7 | 3 | 3 |
| 23 | 13 | 12 | 3 | 10 | 8 | 2 | 4 | 4 | 4 |
| 24 | 11 | 14 | 8 | 11 | 7 | 4 | 5 | 4 | 4 |
| 25 | 14 | 14 | 8 | 13 | 14 | 8 | 8 | 2 | 5 |
| 26 | 16 | 15 | 10 | 14 | 14 | 3 | 11 | 5 | 1 |
| 27 | 14 | 12 | 9 | 13 | 12 | 4 | 6 | 4 | 4 |
| 28 | 15 | 13 | 8 | 13 | 11 | 7 | 8 | 5 | 2 |
| 29 | 15 | 11 | 2 | 13 | 7 | 6 | 9 | 2 | 5 |
| 30 | 16 | 13 | 8 | 14 | 10 | 5 | 7 | 2 | 6 |

**Table A.4** Raw results on body posture of experiment No.1 under MH

| Lamp | MH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Luminance (cd/m$^2$) | 1 | 1 | 1 | 0.1 | 0.1 | 0.1 | 0.01 | 0.01 | 0.01 |
| Distance (m) | 10 | 30 | 135 | 10 | 30 | 135 | 10 | 30 | 135 |
| Participant number | Frequency of correct response (0-16) | | | | | | | | |
| 1 | 10 | 9 | 4 | 11 | 9 | 4 | 5 | 4 | 5 |
| 2 | 16 | 16 | 10 | 16 | 15 | 3 | 11 | 6 | 5 |
| 3 | 16 | 14 | 12 | 13 | 13 | 6 | 14 | 10 | 3 |
| 4 | 14 | 13 | 6 | 14 | 11 | 7 | 12 | 4 | 5 |
| 5 | 15 | 14 | 4 | 13 | 12 | 5 | 11 | 7 | 5 |
| 6 | 15 | 13 | 5 | 13 | 12 | 7 | 11 | 6 | 1 |
| 7 | 15 | 15 | 10 | 14 | 13 | 5 | 15 | 6 | 5 |
| 8 | 12 | 13 | 5 | 9 | 8 | 5 | 6 | 2 | 3 |
| 9 | 14 | 13 | 7 | 14 | 10 | 7 | 10 | 3 | 5 |
| 10 | 14 | 14 | 9 | 12 | 14 | 5 | 9 | 6 | 5 |
| 11 | 14 | 13 | 8 | 13 | 8 | 4 | 7 | 4 | 4 |
| 12 | 16 | 14 | 10 | 15 | 12 | 5 | 10 | 3 | 4 |
| 13 | 16 | 15 | 9 | 16 | 13 | 6 | 15 | 7 | 5 |
| 14 | 15 | 14 | 9 | 13 | 13 | 3 | 11 | 5 | 4 |
| 15 | 11 | 11 | 6 | 11 | 9 | 5 | 4 | 0 | 3 |
| 16 | 16 | 15 | 9 | 15 | 15 | 8 | 11 | 9 | 3 |
| 17 | 14 | 11 | 7 | 13 | 8 | 6 | 4 | 3 | 3 |
| 18 | 16 | 12 | 7 | 14 | 13 | 2 | 12 | 5 | 2 |
| 19 | 15 | 16 | 12 | 16 | 13 | 8 | 12 | 9 | 4 |
| 20 | 13 | 10 | 5 | 12 | 3 | 1 | 6 | 4 | 4 |
| 21 | 15 | 13 | 10 | 15 | 13 | 5 | 10 | 6 | 3 |
| 22 | 12 | 13 | 8 | 14 | 10 | 6 | 8 | 0 | 4 |
| 23 | 15 | 13 | 4 | 15 | 8 | 4 | 10 | 5 | 3 |
| 24 | 13 | 10 | 7 | 14 | 7 | 4 | 4 | 9 | 4 |
| 25 | 14 | 14 | 11 | 13 | 10 | 3 | 9 | 8 | 4 |
| 26 | 15 | 13 | 10 | 15 | 11 | 5 | 12 | 7 | 4 |
| 27 | 13 | 13 | 13 | 14 | 14 | 6 | 10 | 7 | 5 |
| 28 | 15 | 15 | 11 | 15 | 14 | 2 | 10 | 3 | 3 |
| 29 | 13 | 10 | 3 | 15 | 7 | 4 | 10 | 3 | 3 |
| 30 | 15 | 13 | 7 | 12 | 11 | 5 | 8 | 6 | 4 |

**Table A.5** Raw results on gaze direction of experiment No.1 under HPS

| Lamp | HPS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Luminance ($cd/m^2$) | 1 | 1 | 1 | 0.1 | 0.1 | 0.1 | 0.01 | 0.01 | 0.01 |
| Distance (m) | 2 | 4 | 10 | 2 | 4 | 10 | 2 | 4 | 10 |
| Participant number | Frequency of correct response (0-16) | | | | | | | | |
| 1 | 10 | 9 | 8 | 9 | 8 | 7 | 7 | 8 | 8 |
| 2 | 12 | 8 | 8 | 10 | 7 | 9 | 10 | 10 | 9 |
| 3 | 13 | 13 | 11 | 6 | 9 | 7 | 8 | 9 | 10 |
| 4 | 14 | 9 | 6 | 10 | 10 | 11 | 8 | 6 | 8 |
| 5 | 11 | 8 | 7 | 10 | 7 | 6 | 8 | 11 | 9 |
| 6 | 12 | 7 | 11 | 11 | 8 | 8 | 11 | 9 | 8 |
| 7 | 14 | 10 | 8 | 12 | 9 | 8 | 7 | 10 | 8 |
| 8 | 8 | 7 | 7 | 6 | 8 | 4 | 9 | 10 | 6 |
| 9 | 10 | 9 | 8 | 9 | 8 | 9 | 8 | 8 | 8 |
| 10 | 13 | 10 | 11 | 11 | 8 | 8 | 11 | 7 | 10 |
| 11 | 10 | 10 | 9 | 11 | 8 | 8 | 10 | 7 | 8 |
| 12 | 13 | 10 | 7 | 10 | 8 | 9 | 10 | 7 | 6 |
| 13 | 12 | 8 | 11 | 8 | 7 | 9 | 10 | 9 | 6 |
| 14 | 9 | 8 | 10 | 9 | 5 | 10 | 11 | 9 | 9 |
| 15 | 9 | 9 | 7 | 7 | 8 | 8 | 8 | 7 | 6 |
| 16 | 10 | 9 | 9 | 10 | 8 | 10 | 7 | 7 | 9 |
| 17 | 9 | 9 | 10 | 7 | 8 | 10 | 7 | 7 | 7 |
| 18 | 10 | 10 | 11 | 9 | 10 | 7 | 7 | 9 | 11 |
| 19 | 13 | 13 | 8 | 9 | 7 | 8 | 5 | 8 | 12 |
| 20 | 7 | 8 | 6 | 9 | 9 | 10 | 7 | 5 | 10 |
| 21 | 10 | 9 | 8 | 9 | 8 | 8 | 8 | 8 | 6 |
| 22 | 9 | 9 | 6 | 8 | 8 | 7 | 8 | 8 | 6 |
| 23 | 8 | 7 | 8 | 8 | 8 | 9 | 8 | 7 | 12 |
| 24 | 9 | 6 | 9 | 7 | 8 | 8 | 6 | 9 | 9 |
| 25 | 10 | 7 | 5 | 8 | 10 | 6 | 6 | 9 | 10 |
| 26 | 9 | 7 | 9 | 9 | 7 | 7 | 8 | 9 | 10 |
| 27 | 12 | 13 | 3 | 12 | 6 | 7 | 7 | 9 | 7 |
| 28 | 13 | 11 | 9 | 9 | 7 | 6 | 7 | 7 | 6 |
| 29 | 10 | 9 | 7 | 7 | 10 | 8 | 7 | 8 | 8 |
| 30 | 10 | 9 | 8 | 9 | 8 | 9 | 5 | 9 | 7 |

**Table A.6** Raw results on gaze direction of experiment No.1 under MH

| **Lamp** | **MH** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **1** | **1** | **1** | **0.1** | **0.1** | **0.1** | **0.01** | **0.01** | **0.01** |
| **Distance (m)** | **2** | **4** | **10** | **2** | **4** | **10** | **2** | **4** | **10** |
| **Participant number** | **Frequency of correct response (0-16)** | | | | | | | | |
| 1 | 11 | 8 | 8 | 9 | 9 | 8 | 7 | 8 | 8 |
| 2 | 14 | 9 | 8 | 11 | 9 | 8 | 9 | 9 | 8 |
| 3 | 14 | 13 | 12 | 11 | 6 | 9 | 6 | 8 | 6 |
| 4 | 13 | 9 | 9 | 11 | 7 | 8 | 9 | 10 | 8 |
| 5 | 13 | 12 | 9 | 8 | 9 | 9 | 8 | 4 | 7 |
| 6 | 12 | 8 | 8 | 7 | 8 | 10 | 7 | 11 | 8 |
| 7 | 14 | 10 | 8 | 10 | 8 | 9 | 9 | 7 | 8 |
| 8 | 6 | 8 | 9 | 7 | 7 | 4 | 8 | 8 | 6 |
| 9 | 9 | 8 | 8 | 9 | 8 | 8 | 9 | 8 | 8 |
| 10 | 14 | 13 | 10 | 11 | 10 | 5 | 10 | 8 | 8 |
| 11 | 10 | 8 | 7 | 8 | 8 | 9 | 9 | 7 | 8 |
| 12 | 14 | 14 | 4 | 9 | 9 | 8 | 9 | 7 | 14 |
| 13 | 10 | 13 | 9 | 10 | 10 | 5 | 7 | 7 | 8 |
| 14 | 14 | 9 | 6 | 8 | 9 | 9 | 9 | 7 | 5 |
| 15 | 11 | 7 | 8 | 8 | 9 | 7 | 5 | 9 | 6 |
| 16 | 15 | 12 | 10 | 9 | 9 | 5 | 7 | 7 | 6 |
| 17 | 9 | 10 | 10 | 10 | 14 | 8 | 4 | 8 | 8 |
| 18 | 13 | 12 | 8 | 9 | 6 | 9 | 9 | 9 | 12 |
| 19 | 13 | 11 | 10 | 9 | 11 | 9 | 10 | 6 | 9 |
| 20 | 8 | 9 | 6 | 10 | 7 | 9 | 7 | 8 | 6 |
| 21 | 13 | 12 | 8 | 9 | 9 | 9 | 10 | 7 | 7 |
| 22 | 12 | 9 | 6 | 10 | 10 | 9 | 10 | 9 | 8 |
| 23 | 6 | 10 | 7 | 7 | 7 | 9 | 8 | 7 | 12 |
| 24 | 9 | 9 | 8 | 7 | 9 | 8 | 10 | 5 | 8 |
| 25 | 11 | 8 | 8 | 10 | 9 | 6 | 8 | 9 | 9 |
| 26 | 11 | 11 | 6 | 9 | 6 | 9 | 6 | 9 | 10 |
| 27 | 15 | 12 | 8 | 11 | 9 | 8 | 8 | 6 | 11 |
| 28 | 14 | 8 | 7 | 10 | 10 | 8 | 8 | 6 | 11 |
| 29 | 12 | 7 | 11 | 8 | 7 | 7 | 6 | 7 | 5 |
| 30 | 9 | 9 | 8 | 8 | 7 | 9 | 9 | 9 | 5 |

## Appendix A.2 Raw Results of Experiment No.2

The specific gender information of the 20 young participants as shown below (participant number):

- 12 Male: #2, #3, #5, #6, #7, #9, #11, #12, #13, #14, #16 and #18
- 8 Female: #1, #4, #8, #10, #15, #17, #19 and #20.

The identity numbers of selected stimuli are listed below:

**Facial expression (FACES)**:

- #015: old male
- #066: young male
- #112: old female
- #140: young female

Table A.7 - A.12 show raw experimental results of experiment No.2 for facial expression under three lamps (HPS, MH and CPO) and two durations (500 and 1000 ms).

**Table A.7** Raw results on facial expression of experiment No.2 under HPS and duration of 1000 ms

| **Lamp** | **HPS** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 23 | 17 | 17 | 13 | 19 | 9 | 15 | 4 | 11 | 0 | 5 | 2 |
| 2 | 23 | 19 | 21 | 15 | 21 | 13 | 21 | 5 | 14 | 4 | 3 | 3 |
| 3 | 18 | 12 | 16 | 10 | 18 | 6 | 14 | 5 | 6 | 2 | 3 | 2 |
| 4 | 23 | 18 | 22 | 13 | 20 | 6 | 20 | 5 | 11 | 4 | 5 | 5 |
| 5 | 19 | 14 | 17 | 5 | 20 | 4 | 11 | 7 | 12 | 2 | 6 | 4 |
| 6 | 16 | 6 | 15 | 8 | 13 | 7 | 12 | 4 | 7 | 4 | 6 | 3 |
| 7 | 21 | 19 | 23 | 16 | 23 | 16 | 20 | 9 | 14 | 4 | 5 | 4 |
| 8 | 17 | 17 | 19 | 13 | 19 | 11 | 19 | 9 | 18 | 5 | 17 | 4 |
| 9 | 21 | 10 | 18 | 8 | 18 | 2 | 16 | 5 | 12 | 1 | 5 | 2 |
| 10 | 21 | 8 | 18 | 5 | 20 | 4 | 11 | 3 | 10 | 4 | 9 | 2 |
| 11 | 22 | 15 | 21 | 14 | 20 | 11 | 19 | 5 | 10 | 4 | 5 | 4 |
| 12 | 22 | 15 | 21 | 14 | 20 | 11 | 19 | 5 | 10 | 4 | 5 | 4 |
| 13 | 23 | 16 | 23 | 16 | 23 | 19 | 22 | 8 | 17 | 6 | 3 | 2 |
| 14 | 23 | 19 | 22 | 17 | 23 | 10 | 20 | 7 | 14 | 3 | 4 | 1 |
| 15 | 18 | 13 | 16 | 12 | 17 | 6 | 17 | 6 | 7 | 3 | 4 | 5 |
| 16 | 23 | 14 | 20 | 13 | 22 | 12 | 17 | 3 | 15 | 3 | 3 | 1 |
| 17 | 18 | 12 | 15 | 10 | 15 | 10 | 15 | 5 | 10 | 4 | 2 | 2 |
| 18 | 21 | 15 | 19 | 14 | 18 | 9 | 17 | 7 | 16 | 5 | 13 | 5 |
| 19 | 21 | 14 | 19 | 15 | 21 | 9 | 15 | 3 | 10 | 1 | 5 | 3 |
| 20 | 23 | 16 | 20 | 15 | 23 | 10 | 20 | 11 | 17 | 3 | 6 | 4 |

**Table A.8** Raw results on facial expression of experiment No.2 under HPS and duration of 500 ms

| **Lamp** | **HPS** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 21 | 13 | 18 | 10 | 21 | 6 | 15 | 3 | 8 | 2 | 4 | 4 |
| 2 | 21 | 18 | 22 | 14 | 22 | 7 | 19 | 5 | 14 | 4 | 7 | 6 |
| 3 | 19 | 12 | 14 | 4 | 15 | 4 | 13 | 5 | 3 | 4 | 3 | 3 |
| 4 | 22 | 16 | 22 | 9 | 21 | 9 | 22 | 7 | 13 | 5 | 5 | 3 |
| 5 | 20 | 8 | 21 | 5 | 20 | 4 | 14 | 5 | 4 | 3 | 7 | 2 |
| 6 | 17 | 5 | 15 | 7 | 12 | 3 | 13 | 4 | 9 | 6 | 7 | 5 |
| 7 | 23 | 12 | 23 | 10 | 22 | 6 | 18 | 10 | 14 | 4 | 8 | 5 |
| 8 | 18 | 15 | 20 | 11 | 17 | 11 | 19 | 6 | 16 | 5 | 14 | 4 |
| 9 | 19 | 6 | 18 | 5 | 15 | 4 | 14 | 4 | 9 | 4 | 0 | 6 |
| 10 | 20 | 6 | 19 | 5 | 16 | 4 | 10 | 5 | 7 | 4 | 3 | 4 |
| 11 | 24 | 18 | 21 | 13 | 20 | 10 | 20 | 5 | 10 | 5 | 2 | 3 |
| 12 | 24 | 18 | 21 | 13 | 20 | 10 | 20 | 5 | 10 | 5 | 2 | 3 |
| 13 | 23 | 19 | 21 | 18 | 23 | 12 | 21 | 4 | 13 | 6 | 7 | 5 |
| 14 | 22 | 19 | 23 | 16 | 22 | 13 | 20 | 8 | 10 | 5 | 2 | 3 |
| 15 | 16 | 9 | 18 | 8 | 18 | 4 | 14 | 7 | 4 | 6 | 3 | 4 |
| 16 | 21 | 14 | 20 | 10 | 22 | 14 | 18 | 6 | 7 | 3 | 2 | 5 |
| 17 | 15 | 14 | 16 | 10 | 13 | 8 | 19 | 6 | 9 | 2 | 5 | 3 |
| 18 | 19 | 12 | 19 | 11 | 18 | 8 | 20 | 9 | 15 | 4 | 7 | 3 |
| 19 | 22 | 15 | 22 | 12 | 18 | 6 | 15 | 3 | 13 | 5 | 6 | 5 |
| 20 | 21 | 18 | 21 | 13 | 20 | 13 | 20 | 6 | 19 | 5 | 6 | 4 |

**Table A.9** Raw results on facial expression of experiment No.2 under MH and duration of 1000 ms

| Lamp | MH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 22 | 14 | 21 | 13 | 22 | 4 | 18 | 3 | 10 | 6 | 6 | 4 |
| 2 | 23 | 18 | 21 | 17 | 20 | 12 | 20 | 5 | 17 | 4 | 5 | 2 |
| 3 | 18 | 13 | 17 | 10 | 18 | 8 | 15 | 5 | 11 | 3 | 4 | 9 |
| 4 | 21 | 15 | 24 | 11 | 17 | 9 | 21 | 8 | 10 | 5 | 11 | 3 |
| 5 | 22 | 13 | 21 | 8 | 23 | 7 | 18 | 7 | 14 | 4 | 6 | 6 |
| 6 | 19 | 11 | 13 | 6 | 11 | 5 | 14 | 2 | 9 | 3 | 4 | 2 |
| 7 | 20 | 15 | 23 | 10 | 23 | 13 | 15 | 7 | 15 | 6 | 8 | 3 |
| 8 | 19 | 13 | 19 | 12 | 19 | 10 | 16 | 5 | 15 | 4 | 9 | 6 |
| 9 | 19 | 5 | 19 | 8 | 18 | 4 | 19 | 8 | 6 | 2 | 3 | 5 |
| 10 | 19 | 5 | 15 | 7 | 17 | 5 | 13 | 3 | 8 | 3 | 6 | 0 |
| 11 | 22 | 11 | 20 | 9 | 22 | 9 | 23 | 4 | 9 | 4 | 4 | 4 |
| 12 | 22 | 11 | 20 | 9 | 22 | 9 | 23 | 4 | 9 | 4 | 4 | 4 |
| 13 | 22 | 20 | 21 | 17 | 22 | 10 | 20 | 7 | 15 | 3 | 6 | 6 |
| 14 | 22 | 19 | 22 | 17 | 21 | 12 | 18 | 2 | 12 | 1 | 1 | 4 |
| 15 | 15 | 9 | 19 | 13 | 16 | 5 | 16 | 4 | 13 | 4 | 6 | 4 |
| 16 | 22 | 19 | 22 | 13 | 22 | 13 | 20 | 7 | 13 | 4 | 5 | 4 |
| 17 | 19 | 14 | 16 | 13 | 17 | 9 | 18 | 7 | 11 | 4 | 3 | 4 |
| 18 | 20 | 14 | 20 | 9 | 21 | 4 | 16 | 5 | 13 | 3 | 11 | 6 |
| 19 | 22 | 18 | 17 | 8 | 18 | 5 | 14 | 3 | 7 | 6 | 3 | 8 |
| 20 | 20 | 14 | 23 | 11 | 22 | 12 | 19 | 11 | 18 | 5 | 9 | 3 |

**Table A.10** Raw results on facial expression of experiment No.2 under MH and duration of 500 ms

| **Lamp** | **MH** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 21 | 15 | 19 | 11 | 18 | 6 | 13 | 3 | 9 | 6 | 9 | 5 |
| 2 | 23 | 14 | 23 | 13 | 23 | 10 | 17 | 4 | 13 | 4 | 4 | 7 |
| 3 | 20 | 13 | 20 | 7 | 18 | 7 | 13 | 7 | 5 | 3 | 3 | 3 |
| 4 | 20 | 15 | 20 | 15 | 19 | 7 | 16 | 5 | 12 | 4 | 5 | 4 |
| 5 | 22 | 13 | 21 | 12 | 21 | 9 | 17 | 5 | 15 | 3 | 7 | 5 |
| 6 | 13 | 7 | 12 | 5 | 13 | 6 | 12 | 4 | 8 | 4 | 4 | 4 |
| 7 | 19 | 11 | 21 | 11 | 20 | 12 | 18 | 4 | 13 | 3 | 8 | 4 |
| 8 | 17 | 8 | 19 | 12 | 17 | 5 | 16 | 4 | 13 | 4 | 7 | 6 |
| 9 | 20 | 9 | 19 | 4 | 18 | 5 | 13 | 4 | 5 | 6 | 6 | 3 |
| 10 | 16 | 4 | 16 | 4 | 15 | 5 | 15 | 4 | 8 | 8 | 5 | 3 |
| 11 | 22 | 10 | 23 | 8 | 19 | 7 | 17 | 4 | 7 | 3 | 4 | 4 |
| 12 | 22 | 10 | 23 | 8 | 19 | 7 | 17 | 4 | 7 | 3 | 4 | 4 |
| 13 | 21 | 16 | 23 | 13 | 23 | 9 | 22 | 6 | 16 | 6 | 2 | 5 |
| 14 | 22 | 17 | 21 | 16 | 19 | 12 | 21 | 4 | 11 | 1 | 4 | 4 |
| 15 | 12 | 9 | 15 | 12 | 14 | 6 | 16 | 4 | 10 | 4 | 6 | 7 |
| 16 | 22 | 16 | 20 | 12 | 19 | 14 | 17 | 1 | 17 | 4 | 8 | 1 |
| 17 | 17 | 12 | 16 | 7 | 21 | 9 | 15 | 8 | 9 | 5 | 7 | 4 |
| 18 | 21 | 14 | 21 | 8 | 18 | 3 | 19 | 6 | 16 | 6 | 10 | 5 |
| 19 | 23 | 15 | 20 | 7 | 18 | 5 | 5 | 6 | 7 | 3 | 5 | 1 |
| 20 | 21 | 15 | 22 | 12 | 21 | 10 | 16 | 4 | 13 | 7 | 7 | 4 |

**Table A.11** Raw results on facial expression of experiment No.2 under CPO and duration of 1000 ms

| **Lamp** | **CPO** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 21 | 17 | 19 | 4 | 15 | 5 | 15 | 5 | 8 | 6 | 4 | 7 |
| 2 | 20 | 14 | 20 | 14 | 22 | 9 | 20 | 6 | 14 | 4 | 4 | 2 |
| 3 | 18 | 13 | 21 | 12 | 16 | 2 | 15 | 3 | 7 | 6 | 7 | 4 |
| 4 | 22 | 17 | 23 | 16 | 20 | 11 | 20 | 4 | 18 | 4 | 8 | 4 |
| 5 | 21 | 12 | 19 | 9 | 20 | 6 | 18 | 5 | 15 | 3 | 6 | 4 |
| 6 | 16 | 10 | 15 | 7 | 16 | 5 | 10 | 5 | 11 | 3 | 5 | 4 |
| 7 | 22 | 17 | 22 | 16 | 19 | 12 | 20 | 5 | 14 | 3 | 9 | 3 |
| 8 | 17 | 14 | 19 | 11 | 16 | 14 | 18 | 3 | 16 | 4 | 10 | 4 |
| 9 | 19 | 9 | 23 | 10 | 17 | 4 | 11 | 2 | 11 | 5 | 5 | 4 |
| 10 | 21 | 7 | 20 | 6 | 16 | 3 | 18 | 4 | 8 | 5 | 5 | 2 |
| 11 | 23 | 18 | 23 | 14 | 22 | 9 | 18 | 2 | 16 | 3 | 4 | 4 |
| 12 | 23 | 18 | 23 | 14 | 22 | 9 | 18 | 2 | 16 | 3 | 4 | 4 |
| 13 | 22 | 18 | 22 | 18 | 23 | 15 | 20 | 9 | 16 | 6 | 4 | 5 |
| 14 | 22 | 17 | 22 | 15 | 20 | 10 | 18 | 3 | 14 | 5 | 1 | 8 |
| 15 | 15 | 12 | 17 | 10 | 17 | 6 | 14 | 4 | 8 | 3 | 5 | 4 |
| 16 | 21 | 15 | 20 | 14 | 23 | 10 | 21 | 8 | 15 | 2 | 5 | 3 |
| 17 | 19 | 13 | 18 | 11 | 17 | 4 | 16 | 8 | 8 | 5 | 4 | 1 |
| 18 | 22 | 17 | 19 | 15 | 17 | 10 | 18 | 6 | 12 | 1 | 10 | 3 |
| 19 | 20 | 14 | 21 | 10 | 16 | 4 | 15 | 5 | 12 | 4 | 3 | 5 |
| 20 | 23 | 16 | 19 | 10 | 22 | 14 | 20 | 10 | 11 | 5 | 10 | 5 |

**Table A.12** Raw results on facial expression of experiment No.2 under CPO and duration of 500 ms

| **Lamp** | **CPO** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Luminance ($cd/m^2$)** | **3.33** | **3.33** | **1.00** | **1.00** | **0.33** | **0.33** | **0.10** | **0.10** | **0.03** | **0.03** | **0.01** | **0.01** |
| **Distance (m)** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** | **4** | **15** |
| **Participant number** | **Frequency of correct response (0-24)** | | | | | | | | | | | |
| 1 | 22 | 16 | 19 | 5 | 17 | 5 | 17 | 5 | 4 | 4 | 7 | 4 |
| 2 | 19 | 14 | 21 | 11 | 19 | 6 | 16 | 2 | 9 | 6 | 5 | 7 |
| 3 | 18 | 11 | 17 | 10 | 16 | 3 | 12 | 6 | 5 | 2 | 3 | 4 |
| 4 | 22 | 16 | 23 | 15 | 18 | 8 | 20 | 3 | 11 | 4 | 7 | 4 |
| 5 | 22 | 9 | 21 | 12 | 20 | 4 | 23 | 8 | 12 | 4 | 7 | 2 |
| 6 | 14 | 9 | 11 | 9 | 13 | 7 | 10 | 6 | 8 | 6 | 4 | 4 |
| 7 | 20 | 12 | 20 | 10 | 22 | 8 | 16 | 3 | 12 | 1 | 3 | 4 |
| 8 | 16 | 12 | 17 | 10 | 16 | 14 | 16 | 1 | 13 | 4 | 5 | 5 |
| 9 | 22 | 8 | 20 | 6 | 18 | 6 | 16 | 5 | 9 | 5 | 4 | 3 |
| 10 | 18 | 5 | 20 | 7 | 17 | 4 | 14 | 6 | 9 | 4 | 4 | 2 |
| 11 | 23 | 18 | 22 | 12 | 22 | 7 | 22 | 4 | 19 | 2 | 4 | 4 |
| 12 | 23 | 18 | 22 | 12 | 22 | 7 | 22 | 4 | 19 | 2 | 4 | 4 |
| 13 | 24 | 17 | 22 | 18 | 22 | 13 | 21 | 11 | 11 | 5 | 4 | 5 |
| 14 | 21 | 18 | 21 | 15 | 21 | 13 | 20 | 7 | 12 | 8 | 4 | 3 |
| 15 | 15 | 8 | 14 | 10 | 17 | 6 | 13 | 3 | 8 | 3 | 5 | 3 |
| 16 | 21 | 12 | 21 | 14 | 23 | 10 | 20 | 8 | 15 | 5 | 4 | 5 |
| 17 | 17 | 8 | 17 | 8 | 19 | 5 | 16 | 3 | 6 | 5 | 1 | 5 |
| 18 | 20 | 15 | 19 | 14 | 19 | 6 | 17 | 5 | 13 | 7 | 7 | 3 |
| 19 | 20 | 17 | 18 | 13 | 17 | 1 | 11 | 6 | 11 | 2 | 3 | 3 |
| 20 | 23 | 16 | 18 | 9 | 23 | 12 | 19 | 5 | 13 | 5 | 6 | 2 |

# APPENDIX B: PUBLICATIONS ARISING FROM THIS WORK

### Journal Papers

**Yang B** and Fotios S. (2014) Lighting and Recognition of Emotion Conveyed by Facial Expressions. *Lighting Research and Technology*. Published online before print September 11, 2014, doi: 10.1177/1477153514547753

Fotios S, **Yang B** and Uttley J. (2014) Observing Other Pedestrians: Investigating the Typical Distance and Duration of Fixation. *Lighting Research and Technology*. Published online before print April 3, 2014, doi: 10.1177/1477153514529299

Fotios S, Uttley J and **Yang B**. (2014) Using Eye-Tracking to Identify Pedestrians' Critical Visual Tasks. Part 2: Fixation on Pedestrians. *Lighting Research and Technology*. Published online before print April 8, 2014, doi: 10.1177/1477153514522473

Fotios S, **Yang B** and Cheal C. (2013) Effects of Outdoor Lighting on Judgements of Emotion and GazeDirection. *Lighting Research and Technology*. Published online before print November 11, 2013, doi: 10.1177/1477153513510311

**Yang B** and Fotios S. (2012) Inter-Personal Judgements for Pedestrians at Night: Exploring Information Perceived at Different Distances. *Ingineria Iluminatului* 14(1): 31-44.

### Conference Papers

Fotios S, **Yang B** and Edwards P. (2014) Empirical Evidence Towards Appropriate Lighting Characteristics for Pedestrians. *CIE 2014 Lighting Quality and Energy.* Kuala Lumpur, Malaysia: CIE Publication x039, 833-842

Fotios S, Dong M, **Yang B** and Lin Y. (2014) Interpersonal Judgements, Lamp Spectrum and Task Difficulty. *CIE 2014 Lighting Quality and Energy.* Kuala Lumpur, Malaysia: CIE Publication x039, 357-366

Fotios S, Uttley J and **Yang B**. (2014) Lighting for Pedestrians: What Are the Critical Visual Task? *CIE 2014 Lighting Quality and Energy.* Kuala Lumpur, Malaysia: CIE Publication x039, 164-173

Fotios S, **Yang B** and Cheal C. (2013) Estimating Design Light Levels for Pedestrians. *10th Biennial Conference on Environmental Psychology.* Magdeburg, Germany, 64.

Fotios S and **Yang B**. (2013) Exploring Interpersonal Judgements between Pedestrians. *12th LUXEUROPA European Lighting Conference.* Krakow, Poland, 231-236.

Fotios S and **Yang B**. (2013) Measuring the Impact of Lighting on Interpersonal Judgements of Pedestrians at Night-Time. *CIE Centenary Conference "Towards a New Century of Light".* Paris, France: CIE Publication x038, 990-998.

Fotios S and **Yang B**. (2013) Exploring Interpersonal Judgements between Pedestrians. *7th Lux Pacifica.* Bangkok, Thailand, 248-251.

Fotios S, Unwin J and **Yang B**. (2012) Lighting in Residential Roads: What Do We Need to Perceive? *Predicting Perceptions: Proceedings of the 3rd International Conference on Appearance.* Edinburgh, UK, 184-186.

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