Evidence Based Practice Review

Lighting your Way into Home Modifications, 2nd ed.

PEER REVIEWED

Authored by
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Abstract

Background: The aging process causes changes in the human visual system that lead to significant decreases in mobility performance. Older people and people with vision impairments often struggle to walk around and orientate, not only in new but also in familiar environments, such as residential hallways. Lighting is one of the environmental parameters that can either improve or impair the mobility of people in residential hallways.

Objectives: To identify the characteristics of the lighting system that would enable independent and safe mobility of older people and people with vision impairments in a residential hallway.

Search Methods: Systematic search through the HMinfo Library, Google Scholar and Standard Electronic Databases to retrieve 117 scientific publications, 1 legislative document, 4 Australian Standards, 2 International Standards and 3 industry guides.

Data Collection and analysis: 117 publications were identified, and 27 studies were analysed and included in the review.

Results: The mobility performance of people with vision impairments in hallways is better in photopic, than in mesopic or scotopic conditions. Generally, within the photopic range, the higher the illuminance levels, the better the performance of the participants. Ambient lighting systems and systems that provide perceptual cues of the environment are preferred by people and lead to better performances.

Authors Conclusions: The lighting of residential hallways should be adapted to the time of day and the needs of the users, to provide safe and independent movement, without disrupting the daily rhythms of people. Hybrid lighting systems, comprising of low ambient lighting and wayfinding elements seem to be effective for mobility in mesopic and scotopic conditions.

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Keywords

Vision Impairments; Older people; Lighting; Residential Hallways; Safe and Independent Movement

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Contribution of Authors

This is the 2nd edition of the Evidence Based Practice Review: Lighting your way into home modifications, published in the Proceedings of the International Conference on Aging, Disability & Independence, by IOS Press.

Konstantina Vasilakopoulou undertook the research for this document. She developed the content, formatted and wrote the Review.

Catherine Bridge provided guidance and reviewed the document.

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This Systematic review used some of the introductory material of the first edition. All the references of the first edition were examined against the inclusion criteria described in this document.

HMinfo have a policy of undertaking a review process prior to the publication of research documents. The reviews are performed by Specialist Review Panels in accordance with the HMinfo Specialist Review Panel: Terms of Reference, available at the HMinfo website: www.homemods.info.

The following Specialist Review Panel members provided their expertise and feedback for this document:

Jennifer Moon	Community Education & Access Advisor, Guide Dogs NSW/ACT
Emma Bartley	Independent Living Service Coordinator, Guide Dogs NSW/ACT

Aldyfra Lukman	Lecturer, Architecture Department, Universitas Pembangunan Jaya (UPJ)

The authors would also like to thank Ms D. Hammond (Occupational Therapy Australia) and Mr N. Loder (NSW Land & Housing Corporation), members of the HMinfo Advisory Committee, for their invaluable help and their constructive feedback during the review process.

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Glossary

Contrast sensitivity	Measure of visual performance describing the capacity of a person to discriminate between similar shades (Katz, 2019).
Correlated Colour Temperature (CCT)	A term used to describe the colour emitted by white light sources. Lamps with a CCT rating below 3200 K are usually considered warm sources, those with a CCT between 3200 and 4000 K are considered neutral whereas those with a CCT above 4000 K are usually considered cool in appearance.
Electroluminescence	The emission of light in response to the passage of an electric current or to a strong electric field (Arugula & Simonian, 2016).
Illuminance	The amount of light (luminous flux) incident on a surface area. Illuminance is measured in lux.
Light-emitting diodes (LEDs)	Semiconductor devices that emit light when an electric current is passed through them.
Mesopic vision	The vision under intermediate illuminations, when rods start becoming sensitive and cones are still active. The quality and range of colours perceived are reduced.
Old or Older people	People aged 65 and over (Australian Institute of Health and Wellfare, 2018).
Percentage Preferred Walking Speed (PPWS)	Walking efficiency/speed measure.
Phosphorescent materials	Materials that absorb high energy light (usually ultraviolet), and appear to glow for several seconds up to some days after the light source has been turned off.
Photopic vision	The vision under well-lit conditions, when visual perception is primarily cone-mediated and colours are perceived.
Scotopic vision	The vision under dim-lit conditions, when vision is rod-mediated. Colour perception is limited.
Vision impairment	The functions limitations of the human visual system, which impacts the individual’s ability to function in the standard

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	manner of other human beings (Guide Dogs Australia, 2018).
Weight Transfer Time (WTT)	Measure of postural stability.

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Background

The aging process causes changes in the human visual system that lead to significant decreases in performance. According to C. Owsley (Owsley, 2011), some of the age-related visual functions that deteriorate are spatial contrast sensitivity, scotopic contrast sensitivity, dark adaptation, processing of time-varying targets, visual processing speed, etc. The disorders that are often associated to age are cataract, age-related macular degeneration, open-angle glaucoma, diabetic retinopathy and many more (Klein, 1991).

People with age-related eye disorders, as well as population with other vision impairments experience significant limitations in their everyday activities, such as driving, reading and cooking. Mobility performance is also affected, as people with vision impairments walk slowly, present higher occurrence of bumping into objects and might have poor balance, compared to healthy individuals (Popescu et al., 2011). The reduced ability to perform everyday tasks and to walk independently leads to changes in people's habits and way of life (Eilertsen, Horgen, Kvikstad, & Falkenberg, 2016). People with impaired vision often move activities to earlier in the day, when daylight is available (Eilertsen et al., 2016), reduce the times they walk outside by themselves and feel uncomfortable in unfamiliar places (Brown & Brabyn, 1987). These changes affect people's quality of life (Langelaan et al., 2007), their well-being and emotional state (Wahl, Schilling, Oswald, & Heyl, 1999).

One of the most common issues people with vision impairments face is that they are not able to see well under lighting levels that people with normal sight consider comfortable and adequate (Black et al., 1997). For example, 75-year-old people without vision impairments need twice as much light as 45-year-olds, to perform the same visual task (McNair, Pollock, & Cunningham, 2017). "Bad quality" lighting (inadequate, causing glare, etc) can have a significant impact on people's lives and is one of the most important environmental parameters casing falls and injuries to people over 65 (Butler, 2017; Hedge, 2017). Trips, falls and injuries of older people and people with vision impairments often occur in residential environments, including hallways.

Residential hallways are indoor spaces with distinctive characteristics:

- Even though they are usually narrow, people often put furniture there, such us tables, coat hanger stands, plants, etc;
- They connect spaces (for example to go from the bedroom to the bathroom, someone needs to go through a hallway) and are mostly used for circulation and movement, rather than for other activities;
- They are usually close to the front door and often function as transition spaces linking outdoors with indoors;

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- They rarely have openings and thus daylight availability.

Proper lighting design, in terms of amount, distribution and colour of light, is necessary for providing a safe and comfortable home environment for everyone and especially for people with age-related or other vision impairments. This review focuses on the effect of the lighting of residential hallways on the mobility of these people. It is assumed that the results of this study will be relative to both old people with vision impaired due to age as well as adults with other types of vision impairments, regardless of age.

Importance of the Review

This review aims to identify studies and other resources that give evidence for the effectiveness of lighting systems to enable independent, safe and comfortable movement of people with vision impairments in residential hallways. The results of the review can be used as a guide for future research on this subject. Some of the conclusions might also be useful for consumers and professionals (e.g. Occupational therapists) to choose an appropriate lighting system for hallways.

Prior Review

The first edition of this systematic review was published in 2006. The current edition aims to build on the findings and the literature of the first edition to draw more useful conclusions and identify research gaps and opportunities.

Objectives

The aim of this systematic review is to collect the available research material and summarize its results related to the amount and the distribution of the light that enables people with impaired vision to traverse a residential hallway, based on scientific evidence.

More specifically, the studies reviewed should address the following questions:

1. how much light is needed on the reference plane of the hallway, i.e. the floor, for people with vision impairments to traverse it safely and comfortably?

2. which type of lighting system or which distribution of light is preferred by people with vision impairments and improves their mobility performance?

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Methods

This document presents the results of the collection and review of literature, studying the effect of lighting on the mobility of people with vision impairments in hallways. The methodology that has been used was developed by the Home Modification Information Clearinghouse (Bridge & Phibbs, 2003), based on the Campbell Systematic Review (CSR) Protocol.

Research Question

Which are the characteristics of the lighting system that would enable independent and safe mobility of people with vision impairments in a residential hallway?

Question Refinement Strategy

Following the HMinfo systematic review protocol (Bridge & Phibbs, 2003), the research question was refined into an operational format that could be researched systematically by application of appropriate search criteria.

Problem	Intervention	Outcome	Comparison	Target population
Lighting	Wayfinding lighting	Independent, safe and comfortable movement	General lighting	People with vision impairments

Table 1. Question refinement strategy

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Search Terms

The question refinement guided the term search for this systematic review. The list of the search terms used is given in Table 2.

Problem	Intervention	Outcome	Comparison	Target population
lighting	wayfinding lighting	mobility	general lighting	disability
OR	OR	OR	OR	OR/AND
illuminance	floor lights	navigation	ambient lighting	elder/elders/elderly
OR	OR	OR	OR	OR/AND
light	hallway light	locomotion	ceiling lighting	low vision
OR	OR	OR	OR	OR
illumination	corridor light	wayfinding	diffused lighting	vision impairment
OR	OR	OR	OR	OR
luminance	LED	walking	task lighting	visual impairment
	OR	OR		OR
	phosphorescent	access		partially sighted
				OR
				sight
				OR
				disorder

Table 2. Search Terms

Inclusion and exclusion criteria

The criteria for the inclusion and exclusion of material were chosen to ensure relevance to the research question and the expected outcomes. The criteria led to the identification of the number of useful datum sources, the exclusion of duplicates, of non-related material and studies/documents that could not be utilized, due to factors such as language (other than English), perceived weakness in methodology, etc. More specifically, the inclusion criteria were:

- All sources of literature should be attainable through the UNSW Library website or via the internet;
- All sources of literature should be in English language;
- All sources of literature should be relevant to at least two search terms of different categories;
- All sources of literature should be based on studies that exclusively involve human subjects;

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- Sources of literature from all levels of evidence are eligible for inclusion in the review. However, each source was weighed according to their level of evidence and potential for biasing the review;
- Only sources that were published less than 50 years ago should be included. Older sources are considered to have limited relevance to current practice.

All documents and studies that did not meet one or more of the above criteria were excluded from the review. Additionally, editorials and whole of subject books and conference papers were also excluded. Publications available only through purchase were also excluded.

Search Strategy

The search for relevant studies and other material was performed between June and September 2018. The sources and databases where the review material was identified, are:

- HMinfo Clearinghouse publications and libraries;
- Academic databases and search engines;
- UNSW library sources;
- Legislative and regulatory documents;
- World Wide Web- 'Google' search engine.

HMinfo Clearinghouse libraries

All the material published by the HMinfo researchers, as well as studies and reports by external sources were searched. Also, papers and other publications from the HMinfo endnote library were considered. Some of the content of the current study is taken by the original article, published in conference proceedings (Pitch & Bridge, 2006).

Academic databases and search engines

Most of the sources for this study were acquired from academic search engines, i.e. Google Scholar.

UNSW library sources

A small amount of studies and some legislative and regulatory documents were identified in academic databases through the UNSW library website.

Online (World Wide Web) Search

Google search was used to find grey literature relevant to the subject.

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Outcomes of Search

With the use of the search terms listed in Table 2, 117 potentially relevant scientific studies were identified. The bibliography of the original study by Pitch and Bridge (Pitch & Bridge, 2006) was included in the 117 studies that were considered. 11 of the studies had to be excluded as they were duplicates or textbooks. Out of the 106 remaining studies, 79 had to be excluded as they didn't meet the inclusion criteria. Most of the excluded studies were about the mobility of people with vision impairments but did not investigate lighting solutions. Other studies investigated lighting settings for daily tasks (reading, sewing, cooking) but not for mobility performance in hallways or other relevant spaces. Finally, the rest of the studies that were excluded were about wayfinding for people with normal vision, tactile maps and general studies about ageing and vision. Finally, 27 studies that met the inclusion criteria were reviewed.

Apart from the scientific sources, The National Construction Code (2016) and six (6) Australian and International Standards and guides were included in the review.

Finally, 3 industry guides were located. These documents do not provide information strictly relevant to the research question and cannot be included in the review, however, they are briefly mentioned as useful material.

The review process, with the number or relevant studies and other documentation, is outlined in Figure 1.

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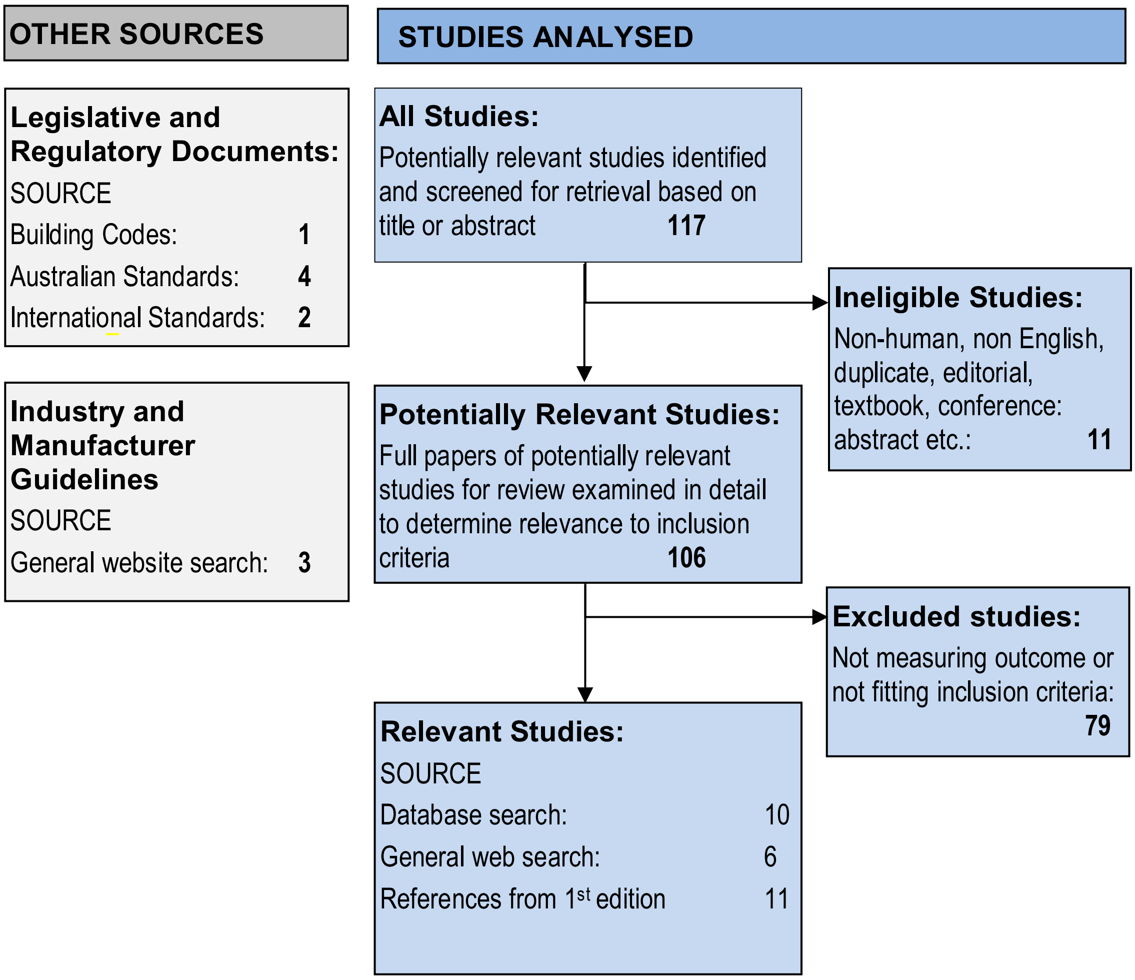

Figure 1. Review process

Legislative and Regulatory Documents

This section lists the regulatory documents, Australian Standards and some of the most useful International Standards and Guides that provide information for lighting of hallways and corridors in places of residence or public buildings. Some of these resources have special references and provisions for buildings used by older people and people with impaired vision. Analytical information about the relevant content is available in Appendix I.

Regulatory Documents

National Construction Code of Australia (2016)

The NCC includes recommendations for the artificial lighting of residential hallways, for the systems to comply with the fire safety regulations (evacuation lighting) and the

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power density limitations for energy efficiency. For quantitative recommendations on lighting, NCC calls up the respective Australian Standards.

Australian Standards

AS 1680.0:2009 Interior Lighting, Part 0: Safe Movement

AS 1680.0:2009 includes recommendations for circulation spaces in public buildings. Appendix A, Lighting for the Partially Sighted, acknowledges the need for increased lighting levels in spaces used by people with impaired vision.

AS 1680.1:2006 Interior and workplace lighting - General principles and recommendations

The Standard includes recommendations that apply to interiors in which “specific visual tasks are undertaken”. The Standard notes that the recommended levels are usually adequate for healthy individuals and that in case the interior is mainly used by older people, the maintained illuminance could reach up to 160 lux, if glare is avoided.

AS 1680.2.1:2008 Interior and workplace lighting - General principles and recommendations

Appendix D of AS 1680.2.1 gives recommendations on the maintained illuminance, colour rendering, colour temperature and maximum glare index for circulation spaces in interior spaces. No references are made for lighting for older people or people with vision impairments.

AS 4299:1995 Adaptable housing

The Australian Standard gives recommendations about the lighting in adaptable housing.

International Standards and Guidelines

CIBSE Lighting Guide 9: Lighting for Communal Residential Buildings, 2013

According to the CIBSE guide LG9, corridors should be lit at 100 lux during the day and at 20 lux during nigh time. Vertical illumination is described as an important parameter for facial recognition.

ANSI/IES RP-28-16 Lighting and the Visual Environment for Seniors and the Low Vision Population

This document, published by the Illuminating Engineering Society of North America and accepted as an American Standard, includes minimum recommended values of lighting levels as well as special considerations for different spaces in residential environments, used by older people or people with low vision.

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Studies Analysed

Twenty-seven (27) studies that met the inclusion criteria were identified and reviewed. These studies investigated the impact of lighting on the mobility of older people or people with impaired vision. The subjects were humans with vision impairments due to age or diseases, or with simulated vision problems. Some studies were testing alternative lighting settings and others were assessing the lighting conditions of existing environments and proposed lighting modifications. It needs to be mentioned that not all of the studies that were reviewed in the 1st edition of this study were considered relevant and included in the current edition.

Nationality, date and origin of studies

The majority (63%) of the papers reviewed for this study have been produced by researchers in USA (37%) (Elliott, Bullimore, Patla, & Whitaker, 1996; M. G. Figueiro, Gras, Rea, Plitnick, & Rea, 2012; Mariana G. Figueiro et al., 2008; Geruschat, Turano, & Stahl, 1998; Hegde & Rhodes, 2010a; Jeon & Hong, 2009; T. Kuyk, Elliott, & Fuhr, 1998b, 1998a; T. K. Kuyk & Elliott, 1999; Mital, Ayer, & Gorman, 1991; Turano, Geruschat, Stahl, & Massof, 1999) and the UK (26%), while 7% of the studies are Australian (Figure 2). The included studies were published from 1991 to 2017.

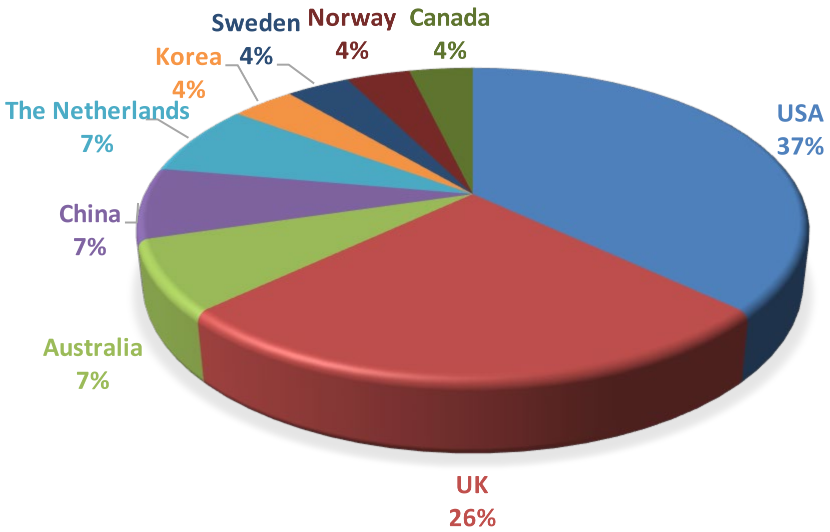

Figure 2. Nationality of literature reviewed

The specialization of the teams that performed the reviewed studies was mainly in optometry and health sciences (55%), while 22% of the authors worked in the field of light and lighting and 15% worked in architecture or building science university departments or research institutes (Figure 3). The allocation of the studies in scientific fields shows that more than half (59%) of the research on the orientation and mobility of people with impaired vision is done by health and social scientists, who are more interested in identifying the parameters that might improve orientation, mobility and

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stability, or reduce accidents, etc, without necessarily recommending environmental solutions.

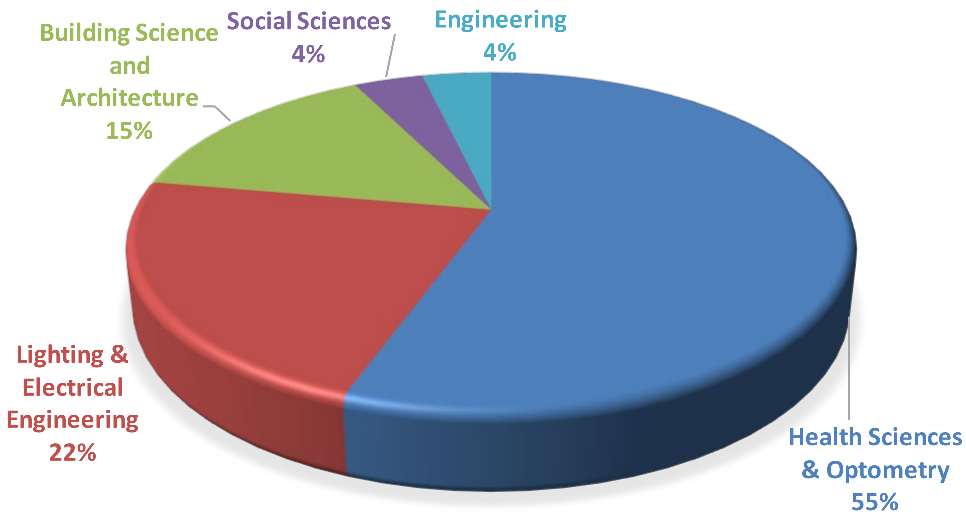

Figure 3. Allocation of the studies in scientific fields

Variables

The studies included in this systematic review investigate common parameters, as they all study the effect of lighting on tasks that can be carried out in hallways or similar spaces, by people with vision impairments. Even though there is a common goal, i.e. to find the lighting conditions under which performance is the best possible, the methodologies followed by the researchers differ significantly.

The main variables that have been identified and distinguish the methodological approaches, are:

- The sub-population sample;
- the type of vision impairment of the subjects;
- the tasks and/or activities;
- the setting in which the study took place;
- the measures or assessment parameters, and
- the lighting conditions studied.

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Sub-population sample & the vision impairments studied

Seventeen (63%) of the studies included in this review investigated the mobility of adults (Aizlewood & Webber, 1995; Black et al., 1997; Brunnstrom & Sorensen, 1999; Cheng, Ju, Sun, & Lin, 2016; G. K. Cook, Wright, Webber, & Bright, 1999; G. Cook, Yohannes, Le Scoullier, Booy, & O'neill, 2005; Cornelissen, Bootsma, & Kooijman, 1995; Elliott et al., 1996; Geruschat et al., 1998; Haymes, Guest, Heyes, & Johnston, 1994; T. Kuyk et al., 1998b, 1998a; T. K. Kuyk & Elliott, 1999; Lovie-Kitchin, Woods, & Black, 1996; Proulx, Benichou, Hum, & Restivo, 2007; Turano et al., 1999; Wright, Cook, & Webber, 1999), twelve out of which used participants with vision impairments (Black et al. 1997; Brunnstrom and Sorensen 1999; Cook et al. 2005, 1999; Cornelissen, Bootsma, and Kooijman 1995; Geruschat, Turano, and Stahl 1998; Kuyk and Elliott 1999; Kuyk, Elliott, and Fuhr 1998c, 1998b; Lovie-Kitchin, Woods, and Black 1996; Turano et al. 1999; Wright, Cook, and Webber 1999). The other five studies examined the effect of lighting conditions on the mobility of healthy subjects or simulated vision impairments in healthy individuals.

Nine of the remaining studies (33.3%) investigated the mobility of older people (all the subjects were over 65 years old) (Alexander, 2013; Eilertsen et al., 2016; Evans, Sawyerr, Jessa, Brodrick, & Slater, 2010; M. G. Figueiro et al., 2012; Mariana G. Figueiro et al., 2008; Mariana G. Figueiro, Plitnick, Rea, Gras, & Rea, 2011; Hegde & Rhodes, 2010a; Mital et al., 1991; Sinoo, van Hoof, & Kort, 2011), with only two of them having subjects with specific vision impairments (Alexander 2013; Evans et al. 2010). The rest of these studies did not specify if the participants had vision impairments.

One study (Jeon & Hong, 2009) included participants with a broader range of ages, including children, where the vision impairments were simulated.

There are three main vision impairments that were studied in the reviewed papers; retinitis pigmentosa, age-related macular degeneration and cataract. Eight studies included a mixed sample, where the subjects could have any of these three or other types of impairments (Brunnstrom & Sorensen, 1999; G. K. Cook et al., 1999; G. Cook et al., 2005; Cornelissen et al., 1995; Evans et al., 2010; T. Kuyk et al., 1998a, 1998b; Wright et al., 1999). Interestingly, five of these papers were written by health scientists (Brunnstrom & Sorensen, 1999; Cornelissen et al., 1995; Evans et al., 2010; T. Kuyk et al., 1998a, 1998b), two by researchers in the lighting field (G. K. Cook et al., 1999; Wright et al., 1999) and one by people in the building/architecture fields (G. Cook et al., 2005). This fact shows that optometrists and health scientists may occasionally consider acceptable the use of a mixed sample of vision impairments for the assessment of mobility performance.

Seven (26%) of the twenty-seven studies, included subjects with no significant vision impairments (Aizlewood & Webber, 1995; Cheng et al., 2016; Eilertsen et al., 2016; M. G. Figueiro et al., 2012; Mariana G. Figueiro et al., 2008, 2011; Proulx et al., 2007). Three (3) studies used older people living in community dwellings as subjects, some of

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which may have had vision impairments, without this being mentioned in the respective papers (Hegde & Rhodes, 2010b; Mital et al., 1991; Sinoo et al., 2011).

Three (3) studies used subjects with no significant vision problems, but vision impairments were simulated. In one of those studies, reduced visibility conditions were established using eye-patches for the subjects, to simulate smoky conditions in an underground subway station (Jeon & Hong, 2009). The other two studies simulated retinitis pigmentosa (Haymes et al., 1994) and cataract (Elliott et al., 1996) with goggles and visors, respectively.

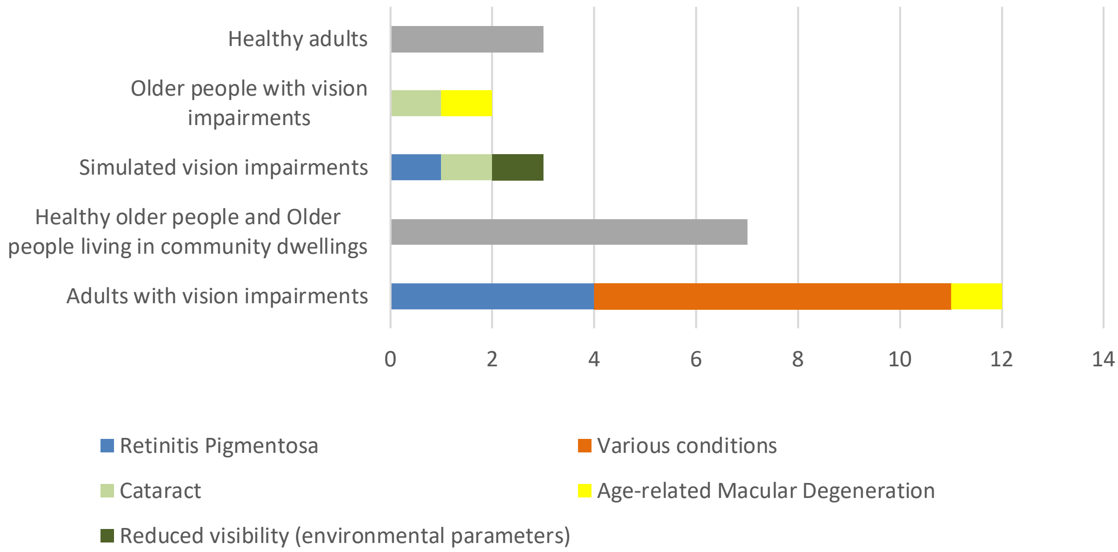

Figure 4. Sub-population sample and vision impairments of the subjects

Tasks studied

The studied tasks included in the reviewed papers were mainly mobility related, like walking in hallways or in exterior pathways. Many of the studies also studied other tasks along with mobility, like postural control, wayfinding or the performance of daily activities. Some very useful studies were on postural control and on foot placing, tasks or activities related to mobility in residential hallways. The tasks studied in one paper have not been listed, as they were not specific; the paper investigated the illuminance levels and people's opinions on the visual environment of nursing homes, without assessing the task performance under different lighting conditions (Sinoo et al., 2011). The summary of the types of tasks studied in the reviewed papers is given in Table 3.

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Table 3. Type of task and the number of studies in which the task is included

Task studied	Number of studies
Mobility	8
Various daily activities (reading, writing, face recognition, knitting/sewing, etc)	5
Evacuation	2
Postural control	2
Mobility & obstacle avoidance	3
Mobility and wayfinding	2
Mobility and postural control	1
Object detection and recognition	1
Colour discrimination	1
Mobility and foot placing (safe navigation in cluttered environments)	1
No specific task	1

All the studies included in this review were quantitative ones, using primary data. They all included human subjects and investigated either their subjective preference on the visual environment or lighting conditions and/or specific parameters measured by the researchers. An analysis of the methodologies and the main findings of each study is included in Appendix 2.

Setting

Most of the included studies were carried out in laboratories, where researchers had full control of the environment. Use of labs enables the installation of different lighting technologies, arranging courses, positioning obstacles and recording the experimental procedure and the required measures accurately. Also, it is considered to be a safer space for the subjects, as all the security precautions are usually taken.

Five (18.5%) of the studies took place in corridors of community dwellings (Hegde & Rhodes, 2010a; T. Kuyk et al., 1998a; T. K. Kuyk & Elliott, 1999; Mital et al., 1991; Sinoo et al., 2011) and four (14.8%) in residential hallways (Brunnstrom & Sorensen, 1999; G. Cook et al., 2005; Eilertsen et al., 2016; Turano et al., 1999). Even though community dwelling corridors seem to be similar to residential corridors, the differences can be important. The corridors in community homes are usually more wide than residential ones and might receive natural lighting, whereas, residential hallways are usually only artificially lit. Also, common corridors in community dwellings might be used for sitting, reading, chatting while standing or walking. So, when studies ask for the users' opinion on the lighting conditions, the rated experience might be different

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from that in residential hallways, where the tasks are walking, opening doors or finding keys.

Four studies (14.8%) were focused on the performance of walking in exterior pathways (Haymes et al., 1994; T. Kuyk et al., 1998a; T. K. Kuyk & Elliott, 1999; Turano et al., 1999). These were included as the layout of pathways resembles that of hallways (elongated space, with or without obstacles).

Three of the studies that were carried out in outdoor courses also included walking in interior spaces (one in private residences and two in community dwellings) and are included under two categories in Table 4.

Table 4. Settings in which the experiments took place

Setting	Number of studies
Lab- Controlled environment	15
Community dwelling or rehabilitation centre	5
Outdoor course (pathway)	4
Private homes	4
Office building	1
Subway station	1

Measures and parameters investigated

The most popular measure that was assessed in the included studies was the preference or the opinion of the subjects (48.15% of studies) on a visual environment. The participants' opinions were recorded with the use of questionnaires or by interviewing the subjects. Depending on the nature of the study, the subjects were asked to assess the visual/lighting environment of their private homes or community dwellings (Brunnstrom & Sorensen, 1999; G. Cook et al., 2005; Eilertsen et al., 2016; Hegde & Rhodes, 2010a; Mital et al., 1991; Turano et al., 1999), and if any interventions were applied, these were also assessed (Brunnstrom & Sorensen, 1999). The studies that included more than one lighting settings or levels were also interested in recording the subjects' opinions and preferences (Aizlewood & Webber, 1995; Cheng et al., 2016; G. K. Cook et al., 1999; Evans et al., 2010; Mariana G. Figueiro et al., 2008; Geruschat et al., 1998; Wright et al., 1999), apart from recording objective parameters.

The objective measures of how well the subjects were able to see and as a result how safe they felt to perform an action, recorded and studied were, the time taken to perform an action (37% of studies) (Black et al., 1997; G. K. Cook et al., 1999; Elliott et al., 1996; Evans et al., 2010; Geruschat et al., 1998; Jeon & Hong, 2009; T. Kuyk et al., 1998a, 1998b; T. K. Kuyk & Elliott, 1999; Wright et al., 1999), the mistakes made (33.3%) (Alexander, 2013; Black et al., 1997; Elliott et al., 1996; Evans et al., 2010;

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Geruschat et al., 1998; T. Kuyk et al., 1998b, 1998a; T. K. Kuyk & Elliott, 1999; Proulx et al., 2007), the moving speed (11%) (Aizlewood & Webber, 1995; Jeon & Hong, 2009; Proulx et al., 2007) or the Percentage of Preferred Walking Speed (7.5%) (Haymes et al., 1994; Lovie-Kitchin et al., 1996) and the velocity (3.7%) (Mariana G. Figueiro et al., 2011) of the subjects when walking.

Five of the studies (18.5%) used illuminance measurements to assess the lighting conditions in non-lab environments (G. Cook et al., 2005; Eilertsen et al., 2016; Hegde & Rhodes, 2010a; Mital et al., 1991; Sinoo et al., 2011) and three of those compared the measured illuminance levels to the levels recommended by respective standards (Eilertsen et al., 2016; Hegde & Rhodes, 2010a; Mital et al., 1991).

Studies that were focused on balance, object recognition or colour discrimination used other measures (Weight Transfer Time, step length variability, etc), as can be seen in Table 5. Also, many of the studies included measures of visual function, however, it is out of the scope of this study to include these parameters.

Table 5. Measures that were used in the included studies

Measure	Number of studies
Ranked preference/Subjects' opinions	13
Time taken to perform task	10
Number of 'mistakes' made by the subject (contact with an obstacle or researcher, coming to a complete stop, straying outside the pathway, avoidance strategies when none were required, etc)	9
Illuminance measurements	5
Moving speed	3
Percentage of Preferred Walking Speed (PPWS)	2
Velocity	1
Step length variability	1
Stride length	1
Weight transfer time (WTT)	1
Postural control	1
Foot placement error and variability (for avoiding obstacles)	1
Lighting level at which objects were detected and recognized	1
Colour discrimination test	1
Evacuation route	1

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Lighting conditions

The goals, as well as the expected outcomes of the reviewed studies varied. Some of them aimed to find how much more lighting is needed for people with vision impairments to navigate through a specific course, while others aimed to identify the best possible lighting system for a task. Others wanted to record the lighting conditions in private spaces and in combination with the subjects' opinions or the comparison to recommended levels, assess the lighting conditions.

Table 6 summarizes the lighting conditions under which the studies were conducted, depending on their goals. Six (22.2%) of the studies used lighting surveys to record the illuminance levels of private residences or community dwellings, without any interventions from the researchers (Brunnstrom & Sorensen, 1999; G. Cook et al., 2005; Eilertsen et al., 2016; Hegde & Rhodes, 2010a; Mital et al., 1991; Sinoo et al., 2011). Nine studies (33.3%) investigated the effect of different lighting levels, without changing the lighting system, i.e. the distribution of the light, the Correlated Colour Temperature or colour rendering properties of the sources (Black et al., 1997; Cornelissen et al., 1995; Evans et al., 2010; Geruschat et al., 1998; Haymes et al., 1994; T. Kuyk et al., 1998a, 1998b; T. K. Kuyk & Elliott, 1999; Lovie-Kitchin et al., 1996). Twelve studies (44.4%) used different lighting systems (and levels), to identify the setting with the highest rating or the best performance (Aizlewood & Webber, 1995; Alexander, 2013; Cheng et al., 2016; G. K. Cook et al., 1999; Elliott et al., 1996; M. G. Figueiro et al., 2012; Mariana G. Figueiro et al., 2008, 2011; Jeon & Hong, 2009; Proulx et al., 2007; So, Alsterstad, Brunnstro, & Sjo, 2004; Wright et al., 1999). This category includes studies with several lighting systems lighting up different parts of a course and studies where various lighting systems were tested on the same course, consecutively.

Table 6. Lighting conditions under which performance was assessed

Lighting conditions	Number of studies
In-situ lighting conditions	6
Variable lighting levels with the same lighting systems (no sudden changes or glare sources)	9
Variable lighting levels and systems	12

Summary of the main findings of the studies

The studies that have been included in this review can be categorized according to the methodologies used and their main findings. These categories are:

1. Studies that investigate existing spaces/buildings (such as private homes or community dwellings) and summarize the lighting conditions, by comparing the illuminance levels to those recommended by the Standards or by using the subjective ratings of the residents;

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2. Studies that aim to investigate the effect of various illuminance levels on the performance of the subjects, compared to people with good vision;

3. Studies that aim to compare different lighting and/or wayfinding systems, depending on the objective performance of the subjects.

The following paragraphs aim to investigate the main findings of each of the above described categories and indicate similarities and differences between them. The discussion following this analysis aims to highlight common findings and identify gaps in the research.

The effect of increased lighting levels

The majority of the studies performed in private or nursing homes concluded that the lighting levels in hallways or corridors are perceived as comfortable or adequate by older people or people with vision impairments, even when they are below the levels recommended by the relevant Standards (G. Cook et al., 2005; Eilertsen et al., 2016; Hegde & Rhodes, 2010a; Turano et al., 1999). Some of the studies identify as the cause for the average to good ratings as the familiarity with the environment (Hegde & Rhodes, 2010a) or the fact that some people with vision impairments have mental representations of their surroundings, which enable them to feel safe and walk around their homes with confidence (Turano et al., 1999). Another explanation could be that people move the most visually demanding daily activities to the hours of the day when daylight is available or they do not understand that the lighting is not enough because they expect their vision to deteriorate with time (Eilertsen et al., 2016).

In only one of the studies performed in a real environment the participants perceived the lighting levels as inadequate, even though the measurements showed that they were actually higher than the recommended values (Mital et al., 1991). Since the participants in this study were older people, who might or might not have vision impairments, this observation might indicate that there are parameters other than lighting levels, such as lighting distribution, that might affect people's opinions.

All the studies that investigated the effect of the lighting levels on the mobility of people with impaired vision, found that the higher lighting level settings that were tested were associated to better performance and got the highest rating from the participants. Generally, higher illuminance levels resulted in higher walking speed (Evans et al., 2010; Mariana G. Figueiro et al., 2011; Geruschat et al., 1998; T. Kuyk et al., 1998a, 1998b; T. K. Kuyk & Elliott, 1999) and PPWS (Haymes et al., 1994; Lovie-Kitchin et al., 1996), as well as fewer "mistakes" and better detection and avoidance of obstacles (Black et al., 1997; Cornelissen et al., 1995; Elliott et al., 1996; Geruschat et al., 1998; T. Kuyk et al., 1998b; T. K. Kuyk & Elliott, 1999). Also, higher lighting levels had an impact on the Weight Transfer Time (WTT) which was better, than under dimmer illumination (M. G. Figueiro et al., 2012).

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Even though the above-mentioned studies include experiments where different lighting levels were tested, it is difficult to draw conclusions on a range of lighting levels for which the mobility performance is significantly improved, or which is preferred by people with impaired vision. There are two main reasons for this. Firstly, the experiments in the included studies compared the performance of the participants under different illumination conditions (usually the comparison was between photopic and mesopic conditions or even between photopic, mesopic and scotopic conditions), where the function of the human visual system changes (Table 7). The second reason is, that even if there were two experiments that studied the mobility performance under the same lighting levels, the differences in the setting and the vision loss types of the participants would not enable a direct comparison.

As a general conclusion, the mobility performance of people with vision impairments was better under photopic conditions, than under mesopic and scotopic conditions (Black et al., 1997; Elliott et al., 1996; Haymes et al., 1994; T. Kuyk et al., 1998a, 1998b; T. K. Kuyk & Elliott, 1999; Lovie-Kitchin et al., 1996). For different lighting levels within the photopic range, the higher lighting levels were generally preferred, apart from two studies, in which participants with vision impairments found the brightest lighting conditions worse than the dimmer settings (Cornelissen et al., 1995; Evans et al., 2010).

As expected, people with impaired vision had generally worse mobility performances than the normal-sighted controls, under all lighting conditions (Alexander, 2013; Black et al., 1997; Geruschat et al., 1998; Lovie-Kitchin et al., 1996).

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Table 7. Lighting levels tested in the included studies

Study	Lighting levels tested
Evans et al., 2010	50 lx, 200 lx, 800 lx
Lovie-Kitchin, 1996	25 lx, 450 lx
Black et al., 1997	25-28 lx, 360-500 lx
Cornelissen et al., 1995	1.6 lx, 5 lx, 16 lx, 50 lx, 160 lx, 500 lx, 1600 lx, 5000 lx
Cheng et al., 2016	30 lx, 1000 lx (in 2 different CCTs- 2800 and 6000 K)
Alexander, 2013	0.7 lx, 600 lx
Geruschat et al., 1998	8.6 - 47.3 lx, subjects wearing goggles that reduced transmission to 11%
Haymes et al., 1994	Photopic, mesopic and scotopic illumination
Elliott et al., 1996	Photopic, scotopic illumination and glare sources
T. Kuyk, Elliott, & Fuhr, 1998b	Photopic (62 cd/m^2) and mesopic conditions (2.5cd/m^2)
T. Kuyk et al., 1998c	Photopic (62 cd/m^2) and mesopic conditions (2.5cd/m^2)
T. K. Kuyk & Elliott, 1999	Photopic (62 cd/m^2) and mesopic conditions (2.5cd/m^2)

Notes on Table 7: Approximate Luminance range for photopic, mesopic and scotopic conditions:

Photopic: >3 cd/m^2, Mesopic: >0.001 cd/m^2 and < 3 cd/m^2, scotopic: <0.001 cd/m^2 (Götze, Conti, Keinath, Said, & Bengler, 2014)

As a guide, if the eyes are adjusted to an environment with average luminance of 3 cd/m^2 and the average reflectance of the surrounding is 30%, the illuminance would approximately be 30 lux (AGi32 Lighting Analysts, n.d.).

Apart from low lighting levels, glare sources were also found to decrease PPWS in the study by Lovie-Kitchin et al. (Lovie-Kitchin et al., 1996).

Lighting systems tested

The experimental studies that tested different lighting systems, investigated the participants' acceptability of those systems and the differences in mobility performance under each one of them. The systems can be sorted in three major categories: 1. Ambient lighting, provided either by overhead luminaires or by night lights; 2. Emergency lighting, including exit signs and/or low overhead lighting according to legislation of the country where the system was tested, plus one enhanced overhead emergency lighting system and 3. Wayfinding systems, usually including tracks and signs from phosphorescent or photoluminescent materials, electroluminescent, incandescent or LED wayfinding systems. Some studies tested combinations of these systems, i.e. traditional night lighting with outlining of the route or obstacles and LED wayfinding system with emergency lighting. Table 8 lists these lighting systems and gives indicative illuminance values provided by these systems, as given in the respective studies.

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Table 8. The tested lighting systems described in the included studies

Lighting category	Lighting system	Illuminance (lux) on the floor (unless otherwise stated)
Ambient lighting	General overhead lighting	32
		70
		650 at the cornea
	Low level lighting provided by night lights	<=0.015 at the cornea
		1.57
Emergency lighting	Exit signs	-
	Overhead emergency lighting & exit signs	1.72 - 2.14
	Enhanced overhead emergency lighting & exit signs	6.9
Wayfinding systems	Phosphorescent or photoluminescent systems (tracks, tiles, stripes, signs)	-
	Electroluminescent systems (tracks, signs)	0.18
	Incandescent wayfinding system (tracks, signs)	1.57
	LED wayfinding system (tracks, signs)	0.7-0.9
Combinations	Night lights supplemented by outlining the pathway or obstacles or doors, using LED direct or indirect lighting, laser lines or photoluminescent materials	-
	LED system providing upward and downward-directed LED strips on one side of a corridor and emergency lighting	-

General lighting systems were associated with higher walking speeds in corridors when compared to emergency or wayfinding lighting (Mariana G. Figueiro et al., 2011; Wright et al., 1999) and to better weight-transfer-times (WTT) when compared to lower illumination provided by night lights (M. G. Figueiro et al., 2012). In the study by Wright et al. (Wright et al., 1999), where many different types of lighting systems were tested (photoluminescent, overhead emergency, ceiling-mounted general lighting, electroluminescent, LED wayfinding and miniature incandescent wayfinding systems), the photoluminescent wayfinding system received the lowest score among the participants, who found it too dim, and was the one to cause lower walking speeds and

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3 incomplete runs, because the participants were not happy to continue. An interesting observation in the study by Aizlewood et al. (Aizlewood & Webber, 1995) was that the enhanced photoluminescent wayfinding system that was used, provided lower visibility of obstacles than emergency lighting, electroluminescent and incandescent wayfinding systems.

The results of the research of Figueiro et al. (Mariana G. Figueiro et al., 2011) are very important, as they show that low ambient illumination provided by night-lights in combination with perceptual cues, result in higher velocity and smaller Step Length variability, thus improving postural stability and control. The perceptual cues in this case were laser lines outlining the pathway where the participants should walk. Interestingly, the velocity of the participants under these lighting conditions were comparable to the performance under high ambient illumination (650 lx at the cornea). In a similar study (M. G. Figueiro et al., 2012), it was found that WWTs under high ambient illumination (650 lx at the cornea) were similar with WWTs when low illumination (<=0.015 lx on cornea), was combined with robust veridical spatial cues provided by LED arrays affixed on a door frame.

Out of six tested lighting settings, participants in a study by Cook et al. (G. K. Cook et al., 1999), rated as second best the combination of overhead emergency lighting with LED wayfinding lighting (upward- and downward-directed LED strips on one side of the long straight corridor), after the overhead ambient lighting setting. Also, the walking speed under these lighting conditions was the highest, after the speed under the enhanced emergency lighting.

A study by Jeon at al. (Jeon & Hong, 2009) showed that phosphorescent wayfinding signs placed on the floor can lead to shorter courses as well as to reduced evacuation times, in a scenario where people needed to evacuate a subway station under smoke conditions.

Lighting control and automations

Two of the papers that have been reviewed investigate the acceptance of lighting automations in the participants’ places of residence. The participants’ opinions seem to be different in the two studies. While Mital et al. (Mital et al., 1991) found that automatically turning off the lights of the community dwelling corridor during the night made walking difficult, the work by Figueiro et al (Mariana G. Figueiro et al., 2008) showed a positive response of older people to automatically turning on and off night lights in home environments.

A third study, which recorded the satisfaction of older people living in independent living facilities (ILFs), on the lighting conditions, revealed that the spaces that received the higher rating were the bedrooms, where people had control over the lighting levels, with the use of task lighting (Hegde & Rhodes, 2010a).

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Industry and Manufacturer Guidelines

Luminaire manufacturers often publish lighting guides for specific applications, such as for museums and galleries, hospitals, educational buildings, etc. The most relevant guides that were derived were for the lighting of senior care facilities. Corridors in senior care facilities have a different use and types of users than residential hallways and the appropriate lighting systems for these two spaces may differ significantly. Thus, the manufacturer guides were not included in this review.

One of the few reports that includes recommendations for hallways is the Lighting Solutions Guide, by RNIB and Thomas Pocklington Trust (RNIB, 2013). The guide emphasises the need for glare free lighting and for task lighting in specific areas in hallways (next to a telephone, inside and outside entrance doors, inside cupboards, etc).

A very interesting publication was retrieved through the reference list of one of the reviewed studies. It is a guide on the access to the environment for blind people, published by the Danish Blind Society (Dansk Blindesamfund, 2015). The guide included specific recommendations for lighting of any type of space, as well as for private homes. The recommended illuminance for entrances and hallways is 200 lux, but the importance of the luminance and contrast of the visual scene is also highlighted.

The Design Guidelines for the Visual Environment published by the National Institute of Building Sciences (NIBS, 2015), includes the necessary terminology and the principles for designing spaces for people with vision impairments, but does not give specific quantitative recommendations for residential environments.

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Discussion and Future Research

This review investigates the effect of lighting of residential hallways on the mobility of people with vision impairments. Hallways are spaces where older people often trip and fall (G. Cook et al., 2005), and lighting is one of the environmental parameters that can contribute to these events (Carter, Campbell, Sanson-Fisher, Redman, & Gillespie, 1997). During the review process, it was apparent that the first factor that needs to be addressed is, which are the lighting or visual conditions under which the mobility performance is to be assessed. For example, a lighting system that would provide good lighting for mobility under photopic conditions, could be totally inappropriate for the same task under scotopic or mesopic conditions.

Many of the reviewed studies have concluded that mobility performance is improved under photopic conditions, in comparison to mesopic and scotopic conditions, both for people with vision impairments, as well as for people with normal vision. In some cases, it was shown that the higher the illuminance levels, the better the mobility performance. However, there were participants, usually people with cataract, that preferred dimmer settings and could not perform under very high illuminances (Evans et al., 2010). Glare has been a disabling factor for both participants with cataract, as well as glaucoma (Lovie-Kitchin et al., 1996; Ramulu, 2009).

Provision of high lighting levels from a general lighting system can be a simple and effective technique for tasks occurring during day time. Two important guides (Dansk Blindesamfund, 2015; IESNA, 2007) agree that 200 lux should be provided on the floor of residential hallways when people with impaired vision are the primary users. However, during the night, high level ambient lighting may have undesirable effects on people’s circadian regulation, which affects mood, sleep quality, metabolism, etc (M. S. Rea, Figueiro, & Bullough, 2002; Mark S Rea, Figueiro, Bierman, & Bullough, 2010). Studies that investigate the effect of different lighting systems on the mobility of people with vision impairments or older people are very useful in identifying solutions that could provide effective guidance under low illumination levels.

A useful conclusion that can be drawn from this type of studies included in the review, is that in scotopic or mesopic illumination conditions, participants performed better and gave higher scores to systems that combined some type of low ambient lighting with wayfinding elements or lighting that provided visual perceptual cues (G. K. Cook et al., 1999; M. G. Figueiro et al., 2012; Mariana G. Figueiro et al., 2011). Where ambient lighting was compared to wayfinding lighting in low lighting conditions, wayfinding was the system that resulted in faster performance (Mariana G. Figueiro et al., 2011). The ambient lighting systems that were tested were either overhead emergency lighting or traditional night lights. The wayfinding systems were LED strips on the edges of the corridor or outlining a door and laser lines on the walking plane. LED and electroluminescent wayfinding lighting proved to improve performances (G. K. Cook et

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al., 1999; Wright et al., 1999), while photoluminescent systems were not preferred by the participants (Wright et al., 1999).

This review has led to the identification of some research gaps and opportunities for future studies. One of the first parameters that needs to be determined is which is the best possible testing environment. One might assume that studies carried out in the participants' home environments are more relevant to this type of research. However, there might be biases when using environments familiar to the subjects, as they already know how to navigate in the space, even under different environmental conditions (lighting). A combination of environments could be an effective solution, where different lighting systems could be tested in a laboratory and the more efficient and/or preferred systems could be then tested in real environments for a period that would enable unbiased behaviours and more useful observations.

The studies that evaluated the mobility performance of people with vision impairments included groups of participants with either diverse eye conditions or a single eye condition (cataract, macular degeneration, retinitis pigmentosa, etc). Although each subject's visual abilities are different, even for subjects with the same impairment, precise lighting design recommendations would require a careful classification of the participants, according to their vision characteristics (visual acuity, visual fields, etc). This fact implies that a reliable study would require the collaboration of lighting specialists as well as optometry researchers.

Two lighting parameters emerged as the most important for the mobility of people with vision impairments: the amount of light provided and the distribution. However, the spectral distribution of the light sources used is also important, as it has a direct effect on the acceptability of the visual environment and on standard human rhythms (Bellia, Bisegna, & Spada, 2011; Boyce, 2010; Hughes & Neer, 1981; Mark S. Rea, Bierman, Figueiro, & Bullough, 2008). Even though the Colour Temperature of the light was not one of the search terms of this review, one of the included studies investigated its effect on colour discrimination, reading performance and personal preference (Cheng et al., 2016). A detailed study on the ideal lighting for residential hallways should also investigate the effect of the light source CCT on the subjects' circadian rhythms and mobility performance, depending on the subjects' preference and level of lighting (photopic, mesopic or scotopic conditions).

Based on the literature review, photoluminescent and phosphorescent wayfinding systems were rated as the least preferred systems and led to the worse performances. However, the studies that investigated their effect and were included in this review are quite old. New materials might have much improved performances and could be tested in new projects. It must be mentioned though that the use of photoluminescent materials in homes could be problematic, as residential hallways often do not have openings, thus there would be lack of (natural) light that could "charge" them.

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Conclusions

This review aimed to study, collate and present the evidence on the quantity and quality of lighting required in residential hallways, for the safe and independent mobility of people with vision impairments. Even though there is no study answering the research question exactly, 27 studies of satisfying quality and adequate relevance to the research question were identified and reviewed.

Hallways are spaces where falls of older people and people with vision impairments are recorded (Evans et al., 2010). Lighting is one of the environmental parameters that can reduce the chances of falling or bumping on obstacles. The outcomes of this review reveal that the amount and the distribution of the light in the hallways play an important role on the mobility performance of people and that hybrid systems, combining ambient and wayfinding lighting might have the best results for people with impaired vision.

There is much work that needs to be done on the field of home lighting for people with vision impairments, that could give directions on the right lighting levels and the spatial and spectral distribution of the light that would enable people to be safe and independent in their own homes.

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Appendix 1: Standards Relevant to Lighting for Hallways to enable Safe Movement of People with Vision Impairments

AS 1680.0:2009

Interior Lighting, Part 0: Safe Movement

AS 1680.0:2009 includes recommendations for circulation spaces in public buildings. The minimum illuminance that should be achieved is 20 lux. Appendix A, Lighting for the Partially Sighted, acknowledges the need for increased lighting levels in spaces used by people with impaired vision, but does not give any recommendations for increasing the illuminance levels in circulation spaces of public buildings.

AS 1680.1:2006

Interior and workplace lighting - General principles and recommendations

The Standard includes recommendations that apply to interiors in which “specific visual tasks are undertaken”. The recommended maintained illuminance for movement and orientation, for spaces like corridors, walkways, etc, described by the Standard as places that are rarely visited, is 40 lux. Moreover, the uniformity of the circulation spaces should be no less than 0.3. The Standard notes that these levels are usually adequate for healthy individuals and that in case the interior is mainly used by older people, the maintained illuminance could reach up to 160 lux, if glare is avoided.

AS 1680.2.1:2008

Interior and workplace lighting - General principles and recommendations

Appendix D of AS 1680.2.1 gives recommendations on the maintained illuminance, colour rendering, colour temperature and maximum glare index for circulation spaces in interior spaces. The recommended maintained illuminance for corridors, passageways and ramps is 40 lux. Some of the additional advice of the Standard are useful. It is noted that apart from the horizontal illuminance on the reference plane (which, in the case of corridors is the floor), vertical illuminance is important as it enables recognition of faces and obstacles. No references are made for lighting for older people or people with impaired vision.

AS 4299:1995

Adaptable housing

The Australian Standard on adaptable housing recommends uniform lighting along the paths of travel throughout the building. The levels should be set according to AS 1680.1, however a level of 150 lux is recommended as appropriate for lip reading. An important feature in this publication is the requirement for provision of electrical

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systems able to provide more lighting for people with impaired vision, if and when required. The recommended lighting levels for entries and passageways are 50-150 lux for houses with residents with normal vision and 300 lux for people with impaired vision. The respective illuminance levels for ramps (and stairs) are 50-160 and 350 lux. It is also recommended that hallways should receive daylight when possible.

International Standards and Guidelines

CIBSE Lighting Guide 9
Lighting for Communal Residential Buildings, 2013

The CIBSE (Chartered Institution of Building Services Engineers) lighting guides and codes of practice are documents used by engineers in Europe. Lighting Guide 9 (LG9) is the only guide giving recommendations for Residential Buildings (residential homes, social housing, elderly/nursing homes, etc). According to LG9, corridors should be lit at 100 lux during the day and at 20 lux during nigh time. Vertical illumination is described as an important parameter for facial recognition.

ANSI/IES RP-28-16
Lighting and the Visual Environment for Seniors and the Low Vision Population

This document, published by the Illuminating Engineering Society of North America and accepted as an American Standard, includes minimum recommended values of lighting levels as well as special considerations for different spaces in residential environments, used by older people or people with low vision. The recommended maintained illuminance in hallways during day hours is 200 lux, while during the night it is 50 lux. This document also refers to the colour of the light that is most appropriate for use during the night and the location/mounting position of luminaires that are meant to be used during the night. As the human circadian system is more sensitive to blue light (460-480 nm), the recommended light colour for illuminating hallways and bathrooms during the night is red or amber. Long-wavelength light (red or amber) can provide the levels needed for discrimination of the surroundings and it also minimises the sleep disturbances. Luminaires mounted low enough to light up the floor and the obstacles that might cause falls are preferred, as the light entering the eyes is reduced.

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Appendix 2: Matrix of Analysis

The following table includes the main parameters of the reviewed studies, sorted according to the task investigated. The task types are given in Table 3. Table … includes the legend for the outcomes

Note that the main findings in this table focus only on those relevant to the Review, such as the impact of various parameters on activities related to mobility.

Table 9. Outcomes Legend

Outcome 1	Improved mobility
Outcome 2	Improvement of performance relevant to daily tasks
Outcome 3	Improved evacuation performance
Outcome 4	Improved wayfinding performance
Outcome 5	Improved postural control
Outcome 6	Improved object detection
Outcome 7	Improved quality of life

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Mobility							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Haymes et al., 1994)	Australia	Whether retinal illuminance affects mobility performance of people with severe retinitis pigmentosa.	PPWS remained relatively constant in photopic conditions, with small variation between subjects. PPWS decreased with reduced retinal illuminance in mesopic conditions with an increase in in-between subject variation. A mean PPWS of 61% was reached for retinal illuminances in the scotopic range. Generally, in mesopic and scotopic range of retinal illuminances, there was variation in mobility performance.	Pathway on a residential street	Lighting levels	Simulated vision impairments	Outcome 1
(Elliott et al., 1996)	UK-USA-Canada	Investigation of the relation between clinical tests of vision and real-world visual performance in people with cataract.	The study was interested in the 10-20% of cataract patients who have reasonable acuity but complain of visual problems in the real world. The cataract simulation caused minimal loss to visual acuity, yet a significant reduction in walking ability in dim illumination. There was no significant change in mobility orientation when the experiment was carried out in photopic conditions. The lack of an effect of the simulation on mobility orientation in normal illumination suggests that it is the reduction in contrast or illumination of the	Lab-Controlled	Lighting levels and Glare sources	Simulated vision impairments	Outcome 1

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Mobility							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
			simulations which is decreasing mobility orientation in dim illumination rather than a restriction of the field of view. This suggests that good acuity may not ensure safe mobility orientation in dim illumination in patients with cataract and other media opacities.				
(Lovie-Kitchin et al., 1996)	Australia	How illumination affects the mobility performance of people with retinitis pigmentosa.	The RP group showed significantly reduced PPWS and greater numbers of errors than the control group. Reduced illumination further reduced the mobility scores of the RP group and a glare source on one section of the course caused a further decrease in PPWS under low illumination. Visual field extent and contrast sensitivity predicted mobility performance on the indoor course.	Lab-Controlled	Lighting levels	Adults with vision impairments	Outcome 1

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Mobility							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Black et al., 1997)	UK	Investigation of the relationship between clinical vision measures and mobility performance under different illumination levels for subjects with retinitis pigmentosa.	People with RP have worse mobility than people with normal vision, more so under reduced illumination levels. The RP group made approximately 50% more errors under the low illumination compared with the high illumination. Visual field extent was the strongest predictor of mobility performance.	Lab-Controlled	Lighting levels	Adults with vision impairments	Outcome 1
(Turano et al., 1999)	USA	To determine the distribution of perceived ability for independent mobility in people who are at various stages of retinitis pigmentosa.	Four of the six most difficult mobility situations were related to lighting conditions: walking at night, adjusting to lighting changes, walking in dimly lit indoor areas, and walking in high-glare areas. At the easiest extreme were mobility situations such as moving about in the home and walking in familiar areas, for which the RP subjects reported little or no difficulty. This finding implies that vision may not be as critical when people already have a mental representation of their surroundings and the objects in those surroundings remain stationary.	Private homes/ exterior areas, etc.	Difficulty of tasks	Adults with vision impairments	Outcome 1

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Mobility							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Geruschat et al., 1998)	USA	Investigation of the effects of RP on mobility performance under conditions of normal and reduced illumination. Investigation of the visual characteristics that covary with and predict mobility performance. Assessment of the relationship between traditional measures of mobility performance and self-reported mobility difficulties.	RP subjects walked more slowly than normal sighted in a simple course. Both groups of subjects walked more slowly when illumination was reduced. 5 mobility incidents for the RP group under normal illumination and 7 under reduced illumination. For the normal sighted 1 incident happened on each illumination level. The RP subjects reported more mobility difficulties and dissatisfaction than normally sighted subjects. Self-reported mobility difficulties are closely associated with walking speed.	Lab-Controlled	Lighting levels	Adults with vision impairments	Outcome 1

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Mobility							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(T. Kuyk et al., 1998a)	USA	Determination of the effects of illumination on mobility performance in real world situations. Determination of the visual factors that predict mobility performance in real world situations.	Compared to the photopic conditions, time to complete the hallway course in the mesopic condition increased by 38% whereas mobility incidents increased by 121%. The mobility performance measured in real world settings was significantly and positively correlated with performance measured in lab setting. The best predictors of performance in all settings were visual field extent and scanning ability.	Hallway of rehabilitation centre and outdoor course	Lighting levels	Adults with vision impairments	Outcome 1
(Hegde & Rhodes, 2010a)	USA	Investigation of whether illuminance levels & quality of lighting in ILFs are adequate to compensate for the reduced retinal illuminance & increased adaptation times of the aging eye.	The light levels measured in the IL facilities were lower than those recommended by IES RP-28-07. However, the residents rated the lighting as being average to good, which could be explained by their familiarity with their surroundings. The highest rating for the overall lighting was given to the bedrooms, which were the only areas where the average light level corresponded closely to the levels set by IES RP-28-07 and where residents had control over the light levels via the use of personal table lamps.	Community dwelling	Lighting levels	Older people in community dwelling	Outcomes 1,2

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Daily Activities							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Mital et al., 1991)	USA	Whether light is adequate or not in various spaces of a facility for older people.	Many areas that were illuminated to levels above those recommended by Standards were still perceived as dark by residents. Some areas that were lit below the recommended levels were perceived as dark. Automatic controls switching off lights during night-time made walking difficult. The corridor was considered dark by 50% of the participants. The illuminance that was inadequate (during the night) was: Min: 0, max: 42 lux, Med: 5.4 lux.	Community dwelling	Lighting levels	Older people in community dwelling	Outcomes 1,2
(Evans et al., 2010)	UK	The influence of lighting on the performance of daily activities.	Generally, higher light levels resulted in quicker performance. The brightest lighting was generally perceived to be the best and the dimmest was felt to be the worst. This effect was quite weak in the cataract group, stronger in the AMD group, and strongest in the combined cataract & AMD group. However, some participants in the cataract group found the dimmest setting to be optimal and some participants in all	Lab	Lighting levels	Older people with vision impairments	Outcome 2

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Daily Activities							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
			groups found the brightest setting to be worst. The preliminary data do not support the notion of a strong relationship between optimum light level and disease condition.				
(Eilertsen et al., 2016)	Norway	Performance of lighting surveys in the homes of healthy 75-year-olds. Subjective assessment of individuals' vision and general health, ADLs and IADLs, and well-being in respect to the indoor lighting.	The indoor lighting levels in the homes of 75-year-olds were evaluated. The lighting levels were significantly lower than the recommended levels by IES RP-28-07. The participants perceived their indoor lighting to be good and had few problems with their vision or performing ADLs or IADLs at home. One interpretation is that the participants had adapted their daily life to low lighting levels, or that they expected their vision to deteriorate as part of the normal aging process, and accordingly did not relate any perceived difficulties to insufficient lighting.	Private homes	Lighting levels	Healthy older people	Outcomes 1,2
(G. Cook et al., 2005)	UK	Identification of a range of areas and tasks within the home that are perceived by the vision	Bumping: Most of the bumping occurs in the lounge and in the bedroom, it also occurs, albeit less frequently, in the hallway and bathroom. Tripping or falling: Tripping occurs most frequently in the lounge. The	Private homes	Lighting levels	Adults with vision impairments	Outcomes 1,2

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Daily Activities							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
		impaired occupiers as being inadequately lit. Comparison of the illuminance provided within the homes with published good design practice for similar tasks and general areas. Investigation of the effectiveness of a range of lighting solutions that have been user tested by people with a sight loss.	hallway and the bedroom are also cited as areas where it occurs frequently. Surface illumination assessment: Overall, about two-third said the lighting in the hallways was good enough. A few of the participants said the lighting on the walls and floor were poor. Glare: Glare from light sources was not considered a problem in the hallway. Tasks: Lighting was largely enough for moving around in the hallway, and only half of respondents said the lighting for finding keys in the hallway was good enough.				
(Brunnstrom & Sorensen, 1999)	Sweden	Investigation of the effect of lighting on the daily activities (ADL) and quality of life of the vision impaired in their homes	Addition of task lighting in the living room had a marked effect on quality of life. Lighting improvements in the kitchen had an effect on the tasks carried out on the working surface.	Private homes	Lighting levels	Adults with vision impairments	Outcomes 1,2

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Daily Activities							
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		before and after light interventions were made in the kitchen, hall and bathroom.					

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Evacuation							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Jeon & Hong, 2009)	Korea-USA	The influence of phosphorescent guidance signs on people's evacuation in smoky conditions.	The phosphorescent tiles and stripes on the floor led to reduction in mean length of route and of the mean evacuation time of approximately 40-45%, as compared to a scenario with exit signs on and no general lighting. The phosphorescent stripes need to be close to one another to be effective. It was noticed that the phosphorescent signs worked very well in large spaces, where they helped people find their way.	Subway station	Various lighting systems	Simulated vision impairments	Outcome 3
(Proulx et al., 2007)	Canada	Investigation of the movement time and the behaviour of evacuees in four stairwell lighting situations (3 with phosphorescent stripes in different layouts and 1 with reduced (general) lighting levels (around 32 lux).	No significant difference in the speed of movement in the 4 installations. Very important to have markings across each step. The lack of specific marking to differentiate the last step of a flight or the landing was criticised by respondents of the 3 photoluminescent stairwells. A continuous demarcation line at 1.5 m could help silhouette other occupants of the stairwell, which could alleviate the problem of people bumping onto each other.	Office building	Various lighting systems	Healthy adults	Outcome 3

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Postural Control							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(M. G. Figueiro et al., 2012)	USA	Test the effectiveness of a lighting system (LED arrays affixed on door frame) together with night lights on the weight-transfer-time (WTT) of older people, with and without fall risks.	The high ambient illumination and the novel system tested (LED arrays on door frame) had similar WTTs. The WTTs were better (smaller) than for the lighting conditions where low ambient illumination was provided (wall/night lights).	Lab-Controlled	Various lighting systems	Healthy older people	Outcomes 1,5
(Mariana G. Figueiro et al., 2008)	USA	Investigation of the effectiveness of a novel self-luminous LED night lighting system providing linear spatial orientation cues plus low ambient illumination for increasing postural control in healthy seniors.	Clear influence of the visual environment on postural orientation (for all lighting conditions subjects leaned to the left when the door frame was tilted to the left and leaned more to the right when the door frame was tilted to the right). Subjects were less stable when the door frame was tilted than when the door frame tilt was consistent with proprioceptive and vestibular cues. Answers of subjects showed a clearly positive response to the on-off sensor, but no clear preference to the novel system, as compared to the conventional wall light.	Lab-Controlled	Various lighting systems	Healthy older people	Outcome 5

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Mobility & Obstacle Avoidance							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Aizlewood & Webber, 1995)	UK	Evaluation of wayfinding systems in smoke-free conditions by investigating the behaviour of adult (healthy) subjects on an escape route marked with several different systems.	In the corridor, the emergency lighting and the miniature incandescent system showed the same speeds and the electroluminescent the same with the photoluminescent (lower speeds than the previous two). At low illuminances, the wayfinding systems were considered by participants to be easier and more satisfactory than the illumination conditions (emergency lighting). At higher illuminances (more than 1 lux) there was less difference. Emergency lighting, electroluminescent, incandescent provided higher visibility of obstacles and photoluminescent provided low visibility of obstacles.	Lab-Controlled	Various lighting systems	Healthy adults	Outcomes 1,4
(T. Kuyk et al., 1998b)	USA	Investigation of the relationship between vision and mobility as a function of ambient lighting conditions and subjects' type of vision loss.	Mobility performance of a heterogeneous sample of vision impaired adults was adversely affected by reducing light levels from photopic to mesopic. On average, subjects made twice as many errors and took approximately 50% longer to complete the mobility course under mesopic conditions. Reduced illumination does not affect	Lab-Controlled	Lighting levels	Adults with vision impairments	Outcome 1

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			subjects in different types of vision loss groups the same way.				
(T. K. Kuyk & Elliott, 1999)	USA	Investigation of the effects of reduced light levels on mobility in persons with age-related macular degeneration and how performance relates to measures of visual sensory and perceptual function.	Mobility performance of a sample of adults with age-related macular degeneration (ARMD) was adversely affected by reducing light levels from photopic to mesopic. On average subjects made twice as many errors and took approximately 50% longer to complete the mobility course under mesopic conditions.	Hallway of rehabilitation centre and outdoor course	Lighting levels	Adults with vision impairments	Outcome 1

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Mobility & Wayfinding							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Wright et al., 1999)	UK	How does illuminance and its distribution affect wayfinding of people with impaired vision.	The mean speed of participants under Photoluminescent lighting was significantly lower than all other types (Normal, Electroluminescent, LED wayfinding and Incandescent wayfinding). The walking speed in the corridor was significantly higher in normal lighting and in LED wayfinding. Then came electroluminescent and miniature incandescent lighting settings. For all routes, the vision impaired subjects generally perform relatively better under the Electroluminescent and LED systems than under the other systems. Then is the Normal system. The Phosphorescent system is the one causing people with vision impairments to be the slowest relative to normally sighted people for most sections of the route. In the question: How difficult did you find it to see where you were going, the Phosphorescent system is scored worse than all other systems, and the Overhead emergency lighting scores worse than the other powered emergency lighting systems. The participants found the Incandescent wayfinding, the LED wayfinding and	Lab-Controlled	Various lighting systems	Adults with vision impairments	Outcomes 1,4

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			the Normal systems to be the most comfortable and the Phosphorescent system to be worst (too dim). The normal subjects had comparable opinions.				
(G. K. Cook et al., 1999)	UK	How does illuminance and its distribution affect wayfinding of people with impaired vision.	In the corridor, the enhanced overhead emergency lighting system received the highest score according to subjects' views, followed by LED wayfinding and emergency lighting combined. The speed in the corridor was greater with enhanced overhead emergency lighting system followed by the LED and emergency combined. In both cases the simple emergency lighting had the lowest score. For the whole course, the walking speeds of vision impaired people under powered emergency escape route lighting conditions are generally about 55-85% of the speed of the normally sighted. The higher illuminance produced by the enhanced overhead emergency lighting system gave greater assistance to the vision impaired than to the normally sighted people. Both the normally sighted and vision impaired subjects placed the basic overhead lighting system last in terms of their subjective opinions.	Lab-Controlled	Various lighting systems	Adults with vision impairments	Outcome 1,4

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Mobility & Postural Control							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Mariana G. Figueiro et al., 2011)	USA	Investigation of whether low-level illumination from conventional night-lights together with laser lines that demarcated a pathway should provide older adults with perceptual cues about the horizontal walking plane, and therefore, improve gait measures in two populations of older adults, those with high and low falls risks.	All older adults walked slower in dim light similar to that experienced by older adults when navigating in their bedrooms at night (than with bright lights). The addition of laser lines to the dim light from night lights provided participants with High Risk of Falls with perceptual cues about the walking plane resulting in a significant increase in Velocity and a significant reduction in Step Length variability; therefore, dim light enhanced by visual perceptual cues was effective for improving postural stability and control in older adults with increased risk for falls. Participants were significantly faster under ambient illumination than under night lights alone, but not under pathway plus night lights.	Lab-Controlled	Various lighting systems	Healthy older people	Outcomes 1,5

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Object Detection & Recognition							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Cornelissen et al., 1995)	The Netherlands	Relationship between the illumination level and the ability of vision impaired subjects to detect and recognize objects in a realistic visual environment.	Some subjects could not tolerate the higher light levels. Despite the fact that the objects were fairly large and could all be recognized by normal subjects at low light levels (< 1 Ix), for most subjects with vision impairments, performance improved with increased light level and kept improving when lighting levels were moderate to high.	Lab-Controlled	Lighting levels	Adults with vision impairments	Outcomes 1,6

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Colour Discrimination							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Cheng et al., 2016)	China	Investigation of the lighting levels and CCT preferred by older adults.	Older adults that participated felt more comfortable with low CCT even though they performed better under higher CCT. Their performance increased with increased illuminance.	Lab-Controlled	Lighting levels & CCT	Healthy adults	Outcome 2,7

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Mobility & Foot Placing							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Alexander, 2013)	Canada	Investigation of how changes in ambient light affect the control of foot placement onto stationary and moving targets in older adults with AMD.	Accuracy and precision of stepping to a series of stationary targets while walking were reduced for older adults with AMD compared to normally sighted controls. Reduced lighting (sudden reduction), exacerbated the control of foot placement in those with AMD, but not controls. The ability of older adults with AMD to process motion cues in bright, and for the most part dim light, was sufficient for stepping to stationary and moving targets while walking.	Lab-Controlled	Lighting settings	Older people with vision impairments	Outcome 1

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No Specific Task							
Authors & Year of publication	**Nationality**	**Research Question / Issue**	**Main Findings**	**Setting**	**Intervention**	**Participants**	**Outcome**
(Sinoo et al., 2011)	The Netherlands	Comparison of the vertical and horizontal illuminances in nursing homes to levels set by other relevant studies.	The lighting levels measured in nursing homes' spaces (including corridors) were much lower than the levels recommended by other studies.	Community dwelling	Lighting levels	Older people in community dwelling	Outcome 2

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