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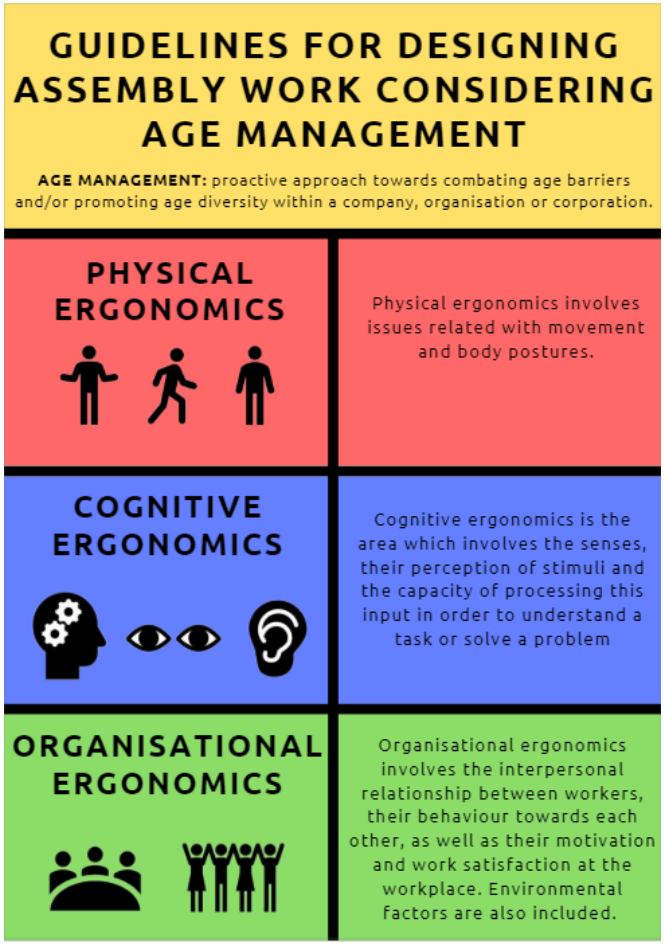

Guidelines for designing assembly work considering age management

An ergonomics approach to an ageing Europe

Master's thesis in Production Engineering

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Gothenburg, Sweden 2019

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Abstract

The European population is ageing. Indeed, this demographic change is considered one of the biggest challenges that Europe will face in the coming years. It represents an economic and social challenge for industrial companies: on the one hand, keeping workers longer, on the other hand, ensuring their health and safety. The outcome of this thesis is a guideline that provides recommendations for designing assembly work and workplaces which consider age management. It is the result of an extensive literature study which includes the three main dimensions of the field of ergonomics: physical, cognitive and organisational ergonomics. Moreover, these findings were corroborated by an interview with an ergonomist working at a production site. In addition, a survey was carried out to evaluate whether age management is an issue that is being considered in the Swedish manufacturing sector or not, and the current state of age management within production sites. The data collected has been mapped to compose the guidelines and was classified into four different groups: workstation and task design, equipment, psychosocial aspects and work environment. The findings of this research provide a valuable basis for designing workplaces considering age management. On the other hand, the results of the survey reveal a need of implementing age management measures within the design of workplaces. This guideline will be a potential tool for achieving this purpose.

Keywords: Age management, ergonomics, workplace, guideline.

Acknowledgments

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Glossary

ABBREVIATION

PCC – Population Concept Context

KPI – Key Performance Indicator

MSD – Musculoskeletal Disorder

RQ1, RQ2 – Research Question 1,2

SME – Small and Medium-sized Enterprise

DEFINITIONS

Age management: proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation

Guideline: compilation of recommendations regarding workplace design.

Ergonomics: field which evaluates the interaction of humans and other parts of the system, pursuing the human wellbeing and system performance.

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1. INTRODUCTION

1.1. BACKGROUND

The European population is ageing. Indeed, this demographic change is so urgent that it is considered one of the biggest challenges that Europe will have to face in the coming years (Kalwij & Vermeulen, 2008). As can be seen in Figure 1, there has been a shift in the population; while the population aged between 15 and 50 years old has decreased, the percentage corresponding 50 years or above has increased. It seems that this trend will continue during the coming years.

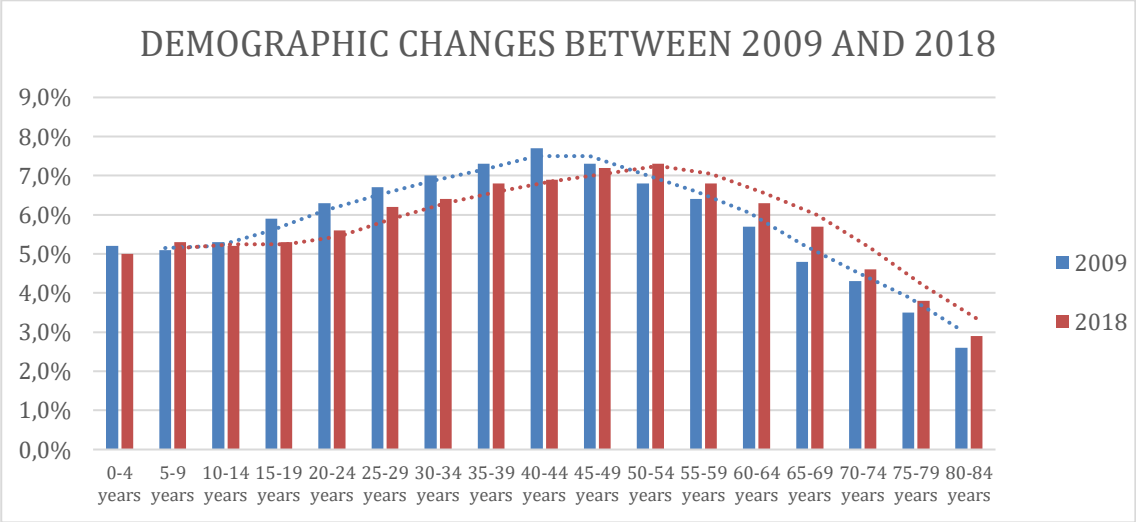

Figure 1: The demographic change in Europe between 2009 and 2018. Data source: (Eurostat Statistics Explained, 2018)

According to Eurostat, within the EU member countries 19.4% of the total population is aged 65 or above, while the percentage of people within the working age range was 64.9% in 2017. 13% of this last group is between the ages of 55 and 64 years. (Eurostat Statistics Explained, 2018). Therefore, the industry needs to take action towards designing workplaces considering this increasing proportion of the workforce.

This represents a social and economic challenge for companies. Even though, at first sight, this could be seen as a trade-off, the reality is that it is possible to match both (Morschhäuser & Sochert, 2006). On the other hand, it is a question of social sustainability. As workers age, the severity of the injures caused at workplaces is bigger (McMahan & Sturz, 2010), therefore any changes within the workplace to ensure their health and safety will enhance their quality of life at work.

Specifically, in this study, this challenge will be addressed within the production sector, more specifically in assembly work. Due to the physical dimension that characterises the work done in a production line, this challenge is even more important within this sector. However, physical condition is not the only parameter that changes with age. Cognitive ability and organisational

aspects should be considered when evaluating how age should influence the workplace design. Therefore, these three parameters will be included in the present project.

1.2.PURPOSE

This master thesis aims to analyse and give valuable recommendations for designing workplaces that can be used by all the workers, independently of their age. Its purpose to research about the physiological and psychological changes caused by age. Specifically, these changes will be evaluated from the perspective of workers aged 55 years old or above. The purpose will be also evaluating how the main physical, cognitive and psychological changes will influence the workplace design.

Afterwards, all the information will be mapped in order to set recommendations regarding the design of an appropriate and accessible workplace. This information mapping will lead to the final outcome of this master thesis: a guideline. This guideline will provide recommendations for designing workplaces considering age management. It is important at this point to clarify that, assuming that learning capacity is affected by age, the preferable solution is redesigning the workplace instead of redesigning the job (Nagamachi, M., 2000) This means that all the recommendations included in this guideline will be focused on designing workplaces.

1.3. SCOPE AND DELIMITATIONS

There are many possible approaches that might be used for solving the issue of age management, and other topics might have an impact. For instance, there is research that establishes a relationship between these demographic changes and automation or other technological advances (Acemoglu & Restrepo, 2018). However, as mentioned earlier, due to the limited time of a Master Thesis, only an ergonomic perspective will be considered. This will focus the direction of this research and establish objectives feasible to complete within the duration of the project that corresponds to 20 weeks.

Regarding the population that will be investigated, the project will be focused on workers age 55 or above, as mentioned previously. Moreover, the changes caused by age will be only analysed until 65 years old, which corresponds to the retirement age in the European Union. Moreover, the collected data belongs to Swedish primary sources, because of two main reasons: information availability and to avoid possible outliers.

This study is unable to encompass the entire range of working environments, that could be positively influenced by an ergonomic guideline. Therefore, it will focus on work done in a production line, even though there are other sectors where an ergonomic guideline would be useful. For instance, mining due to the physically demanding dimension of the work done (Kowalski-Trakofler, 2005).

Moreover, this work done within a production environment will be assembly work. The main reason is because assembly work is one of the tasks that demand abilities that diminishes with age such as lifting heavy parts or repetitive activities (Stedmon et al., 2012)

Finally, the results will be applicable to European countries. Due to the different levels of maturity of each country within this demographic change (Stedmon et al., 2012), by reducing the scope to Europe, the results will be more reliable.

1.4. RESEARCH QUESTIONS

This study will be driven by two main research questions:

> *RQ1: How do physiological and psychological changes caused by age affect the work done in a production line?*

This first question aims to evaluate the physical and psychological changes caused by age. More specifically, analysis will be done within a production line context and will be focus on differentiating these changes for an age range of 55 or above years old.

> *RQ2: How might these factors lead to a specific design of a workplace considering age management?*

This second question is focused on the application of the first question's results in workplace design. Essentially, this question aims to establish a relationship between physiological and psychological changes caused by age and workplace design within the same context and population defined in the scope of the project.

Moreover, the outcome of this project can be considered as a product with potential users. The product will be the Guidelines, and the potential users will be determinate within the Stakeholder Analysis. Therefore, an analysis of the feasibility of this product in the sector will be made.

1.5. OUTLINE OF THE THESIS

This study starts with a theoretical framework, where ergonomics and its main dimensions will be defined. Moreover, the relationship between ergonomics, age management and sustainability will be established. Lastly, key terms regarding this study will be defined.

Consecutively, the methodology of this research will be defined, focusing mainly on the literature study which will be the core of the findings. Afterwards, the findings of the literature study, interview and survey will be analysed. Within the discussion section, the most relevant findings will be addressed. Finally, conclusions of the present master thesis will be given.

2. METHODOLOGY

This project is driven by two research questions and one goal of which is to produce a guideline that provides valuable resource for achieving age-considerate workplaces. As mentioned in the introduction (see section 1.2), there is an aim and a purpose for this project. As it can be seen in Figure 2, the purpose is investigating about physiological and psychological changes caused by age and their impact in workplace's design; while the aim is giving valuable recommendations about how designing workplaces considering age management. While the purpose is related with RQ1 and RQ2, the aim is linked to the final outcome: a guideline. Moreover, the feasibility of this guidelines as a product will be evaluated with the purpose of analysing the current state of the question, and if the recommendations done are already implemented or should be valuable for a company.

The research will be mainly driven by a "Literature Study", which will be the primary source of information. The interviews will act as a reinforcement for the findings derived from this literature study. Moreover, a survey among the potential users of the guidelines will be carried out. These potential users are ergonomists at production sites (see stakeholder analysis in section 2.2). The results of the survey analysis will provide the information necessary for performing the feasibility analysis. All this information is visualized in Figure 2.

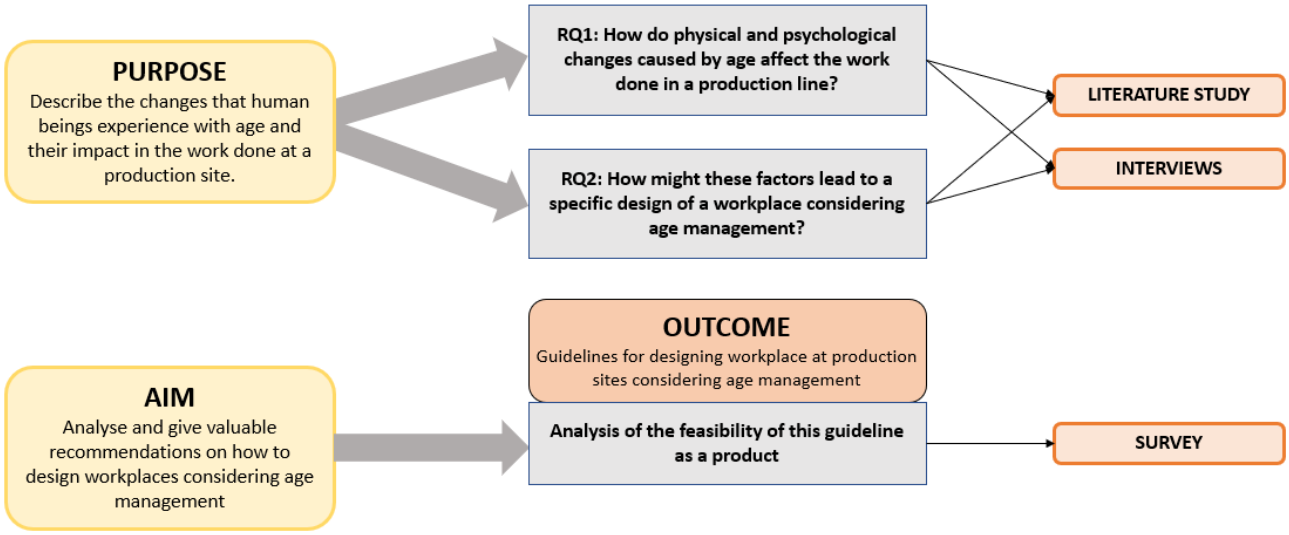

Figure 2: Interconnection between Purpose, Aim and Outcome, the research questions and the methods proposed.

To perform research, it is necessary to define a research strategy. In this case, a mixed method research has been the strategy chosen. This method consists on integrating qualitative and quantitative methods (Denscombe, 2014). In this case, two qualitative and a semi-quantitative method will be used: a literature study, interviews and a survey.

2.1. LITERATURE STUDY

As mentioned before the literature study will be the basis of this study. It will provide an insight of how this question has been addressed in past research, and if there is any guideline already that has approached the problem. Secondly, physical and cognitive condition of mature workers will be analysed. Lastly, how do these changes impact the design of workplaces will be evaluated.

According to Munn et al. (2018) a scoping review would be a good option for the cases where the main purpose of the literature study is mapping and discussion of specific characteristics or concepts, disregarding the achievement of actual results by finding out evidences. Above a systematic review, its purpose is mapping information by scoping a body of literature (Munn et al., 2018). Therefore, in this case, this type of methodology would be the one that fits better.

2.1.1. Inclusion criteria for keywords

Following the process described by Peters et al. (2015) for performing a scoping review, according to the research questions, the PCC (Participants, Concept, Context) framework will be the stipulated.

2.1.1.1. Types of participants

The population studied in the literature review would be the so-called "mature workers". Within this study, all the references to "mature workers" will include operators of an assembly line at a production facility aged between 55-65 years old.

2.1.1.2. Concept

Regarding the concept, the principal focus of this research will be physiological and psychological condition of the workers. This includes physical aspects, cognitive aspects as well as psychosocial factors, including work environment and workers and employer's interaction relationship. Moreover, within the concept it should be also included the workplace design, and consequently ergonomics, as the approach used. In other words, this study consists on studying physiological and psychological changes within workers due to age, and how these changes should be considered in order to design an ergonomic-friendly workplace for mature workers.

2.1.1.3. Context

Geographical factors are not significant in this literature review. However, the scope will be limited to Europe. Sex or other demographic and cultural factors will be disregarded, because the information that they would provide would not be relevant in this specific project.

The context of this study will be defined by a specific workplace: a production line. Specifically, this study will focus on assembly task, because within the production industry, it is the most common activity for humans (Stedmon et al., 2012)

Therefore, with all this data it is possible to extract and chart the results and the keywords that might be crucial for finding valuable literature resources. The inclusion criteria for keywords that will be used for the searching are summed up in Table 1.

Table 1: Keywords collection for Literature Searching

	MAIN CONCEPT	**ALTERNATIVE KEYWORDS**
PARTICIPANTS	Mature workers (55-65 years)	Aging/Elderly/Ageing AND population/workforce Older/Old/Senior AND Workers/Operators Age management
CONCEPT	Physiological and psychological changes	Physiological/Psychological AND changes/effects Mental Condition/Health/Ageing Physical/Cognitive Ageing Physiology Psychology/Perception/Attitudes
	Workplace design	Work design
CONTEXT	Production line	Assembly line/work Facility/Factory Production System
	Ergonomics	Ergonomics

2.1.2. Logic and method for papers inclusion

In Figure 3 a flowchart with the logic and methodology for including or excluding the papers. Each of the steps is commented bellow.

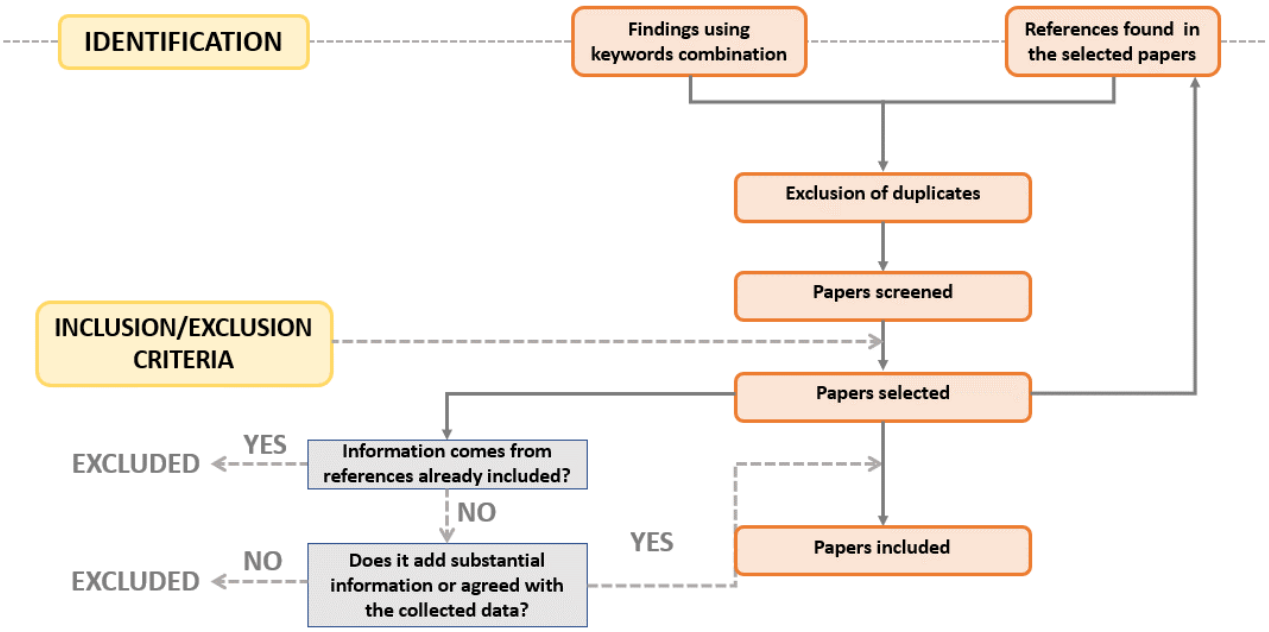

Figure 3: Flowchart of the methodology followed for classify papers in exclude or include

Identification of papers

For performing the first search of papers, different combinations of the keywords included in Table 1 will be search. For doing so, commands AND and OR will be used. In order to be more effective, several words within one of the areas of the framework will be included with the command OR in between, in combination with another set of keywords of a different framework. For instance, a possible search string could be:

"Age Management" AND ("Psychology" OR "perception" OR "attitudes")

This way, the search will provide a paper that contains two of the areas of the framework, which, as is explained in the sub-section: Inclusion/Exclusion criteria, is a requirement for being included within the Literature Study.

Exclusion of duplicates

To avoid any double consideration of the same paper, a step for excluding duplicates is added between the first searching classification and the inclusion/exclusion criteria.

Inclusion/exclusion criteria

Keywords are a very important part of this Inclusion/Exclusion criteria. For being included in this study, the papers should include at least one keyword of two of the framework areas (Participants, Concept, Context), within the title or the abstract. This way, the likelihood of being relevant for the study increase, decreasing the number of papers that do not add any valuable information. All the criteria issues are defined in Table 2 bellow.

This project is based on an ergonomics approach of a problem: ageing workforce. Therefore, the most common searching strategy and inclusion criteria would be reducing the search to all those journals which main topic is basically ergonomics. However, within this study, other Journal fields will be considered, because age management and physiological and psychological changes due to age, is not just a question of ergonomics, and by excluding any other fields, the information provided would be incomplete.

Table 2: Inclusion/Exclusion Criteria

INCLUSION CRITERIA	EXCLUSION CRITERIA
Keywords from two of the three areas of the framework PCC, at least, should be included in the title or abstract	Only keywords from one of the three areas of the framework is included within both: title and abstract.
English or Spanish language	Guidelines that approach the problem from a different perspective than ergonomics. (for instance, economy or automation of processes)
Published in scientific, peer-reviewed journals	

All the papers that meet the inclusion criteria, and overcome the exclusion criteria, will be part of the selected papers and move to the next stage.

Papers included in the study

The final step of the flowchart for the choice of the papers that will be included in the literature study will base its classification on the content of the papers selected. This means that by analysing the content of the paper itself it will be included or not in the literature study. The requirements demanded for being included are the following:

- If the information that provides comes from references that are already included, this paper should be excluded.
- If the information is not relevant for the study, this paper should be excluded.

Furthermore, within this stage, the references of the paper, despite of being included or not, will be analysed. In case there is any reference that might include relevant information of this study, it will be sent to the first stage of this flowchart, to assess the possibility of being included.

The Journals included in this study are the following:

- Journal of Education for Business
- Health Promotion Perspectives
- Professional Safety (4)
- Safety Science
- Cuaderno de Relaciones Laborales
- Scandinavian Journal of Public Health
- Procedia Engineering
- Proceedings of Human Factors and Ergonomics Society Annual Meeting
- Population and Development Review
- Ageing&Society
- Work

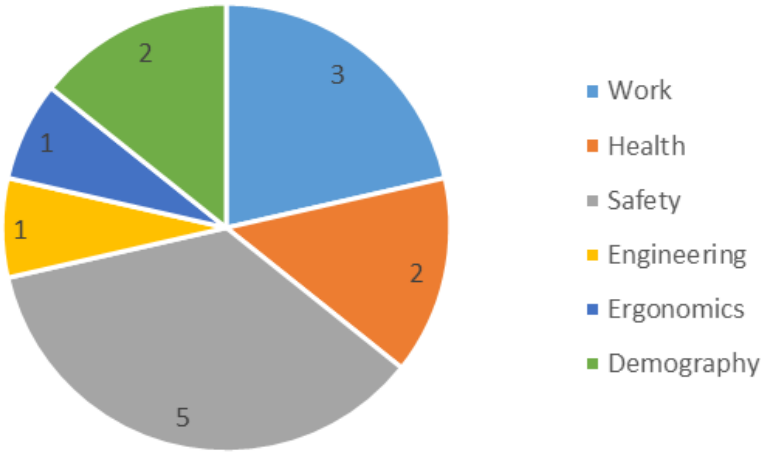

Figure 4: Proportion of Journals selected of each field

According to Figure 4, it can be seen that the vast majority of the journals belong to the safety field. However, this is coherent because if safety management is considered from a holistic perspective, its main purpose should be preventing workers to suffer injuries or any fatality, as well as mitigating any hazard or risk that they are exposed to. Therefore, ergonomics is aligned to this purpose, as one of its goals is to prevent workers to suffer MSDs.

After all this process, it is expected that the literature included within this study will provide an extensive information regarding the topic, which will contribute positively to the development of this guideline.

2.2.STAKEHOLDER ANALYSIS

In a study like this, a stakeholder analysis is an important tool to analyse which are the actors involved in the problem and solution proposal. Moreover, it is a technique that implies the study of the interconnection between of all of these people, groups and organisations that we call stakeholders (Bryson, 2004).

The Association of Social Anthropologists (2017) lists the steps that should be followed when performing a stakeholder analysis as follows: develop a stakeholder table, locate each stakeholder according to their relation power/influence and asses their importance for the success of the project. (ASA, 2017)

2.2.1. Stakeholder Table

POSITIVE PRIMARY	POSITIVE SECONDAY
Result stakeholder - Workers at a production facility: In this specific project, it will be necessary to distinguish between workers aged 55 or above and the rest of workers. While the former group is essentially the main focus of study, the latter will be affected by the changes proposed within the production line. The changes might affect them positively or not. However, it is important to consider them as stakeholders in this study. **Result stakeholder - Ergonomics managers at the production line:** Could be considered the potential user of this Guidelines. If the Guidelines are well-done and complete, age management within the production line will be improved. **Result stakeholder - Company:** If the result is positive, it will have a positive effect in the productivity levels, in the workforce satisfaction at work, and it will contribute to overcome demographic challenges.	**Realisation stakeholder - Author.** Good result will increase her knowledge about the topic and the methodology used for doing this study. **Realisation stakeholder - Chalmers.** Good relationship with companies that could be interested in the results of this study.
NEGATIVE PRIMARY	**NEGATIVE SECONDARY**
Result stakeholder – Company: If, according to the recommendations included in the Guidelines, investment should be done. This could be considered a negative impact.	

2.2.2. Interest and influence of each of the stakeholders listed above.

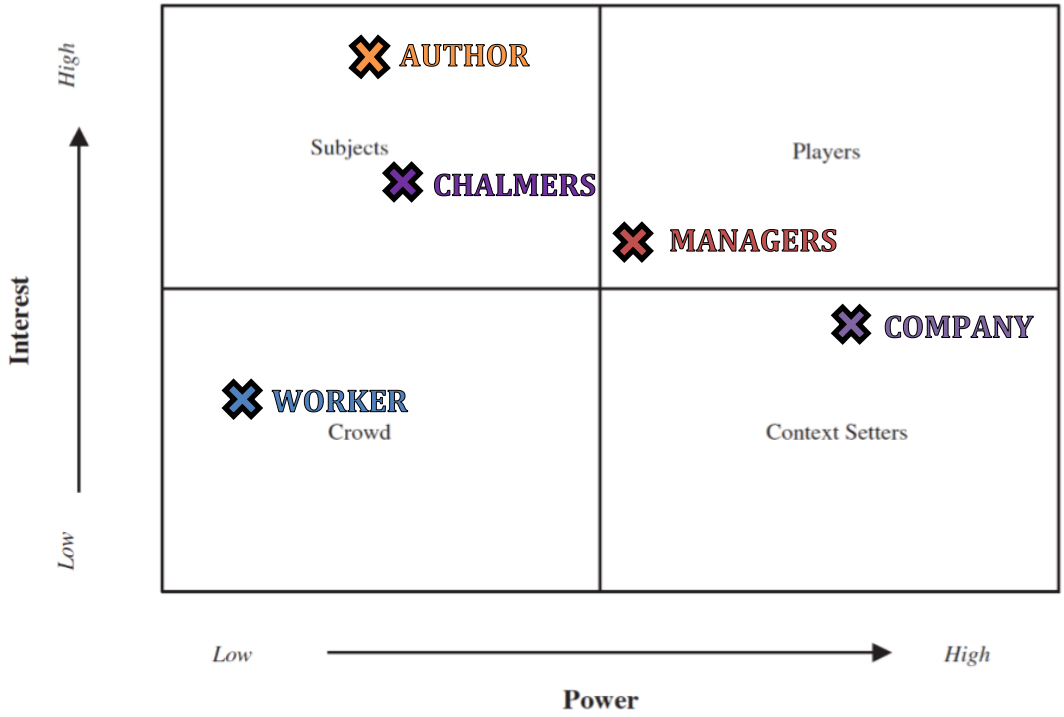

Figure 5: Interest versus Power. Image adapted from source: (Bryson, 2004)

2.2.3. Assessment of the importance of key stakeholders for project success.

Essentially this project aims to face the challenge that a demographic shift taking place in Europe implies. Therefore, companies should be benefited in knowing which the recommendations are for achieving an appropriate inclusive age management. However, this interest would not be direct. These changes will be remit of the ergonomics managers within the production line. They would be the potential users of the guidelines and meeting their expectations would be crucial for the project success. Mainly, the changes done would impact the work done by the workers. Even though their influence in the process is low, the Guideline should be totally focused on them.

Workers can be considered the stakeholders that might benefit of this project for meeting their needs, interests and expectations. The main reason is that one of the main purposes of this guidelines would be to ensure the best workplace design and work environment that could be achieved considering the changes that workers suffer with age.

However, going back to ergonomists within companies, this will be the players of the project, as well as the potential users. Therefore, for this Guidelines to be successful it would be necessary to meet the expectations of this stakeholders and consider their current work.

All these recommendations might interfere with already existing projects or policies, and all of this should be evaluated by the ergonomics department of each company. However, these issues will affect more the implementation of the guidelines than its drafting.

2.3. QUALITATIVE DATA COLLECTION

As mentioned before, the result of the literature study has been corroborated with two interviews:

- An ergonomist at a Swedish production site where assembly work is performed: his interview gave some insight regarding the topic from the perspective of the shop floor. Its perspective was very useful to complete the findings achieved in the literature study. Moreover, he gave some information of the expectations and the current limitations in age management strategies within facilities that were useful for the development of the survey questions. The interview was conducted face-to-face at the production site. The interview guide used is included in Appendix A.
- A specialist in inclusive design: her perspectives of inclusive design and language brought to the project an appropriate use of the inclusive language throughout all the study. The interview was via a phone call. However, the search for the appropriate terms used in this study required an iterative process, which involves also mails for contrasting expressions.

Both interviews were conducted in English and were recorded and transcribed. The answers of the interview with the ergonomist at a production site were key input for the development of the questions included in the survey.

2.4.SEMI-QUANTITATIVE DATA COLLECTION

The semi-quantitative data collection consisted of a survey. The respondents of the survey were chosen based on the stakeholder analysis performed (see Section 2.2). A stakeholder is meant to be a person or group of people who hold the power for impacting a company, project or issue, in one way or the other (Bryson, 2004). This stakeholder analysis has been performed based on the steps listed by the Association of Social Anthropologists: stakeholder table, Interest and influence of each of the stakeholders listed in the table and assessment of the importance of key stakeholders for project success (ASA, 2017). The survey questions are included in Appendix B.

The survey was conducted in English and was sent via Google Forms, and published in social media (LinkedIn). The method used for this survey was a web-based questionnaire. Within the survey three types of questions were included: single answer questions, multiple answer questions and open questions. Due to the presence of this last type of question, this survey provides qualitative data as well as quantitative. Even though there is a larger weight content of quantitative data in this survey, this data collection has been defined as semi-quantitative.

For the purpose of achieving valuable information, the respondents have been reduced to those ergonomists working at production sites in Sweden. Due to the contact network available for spreading the survey, the likelihood of achieving a much larger percentage of answers of Swedish ergonomists than other nationalities was high. Therefore, the nationality of the respondents was reduced to Swedish to achieve more coherent and relevant information. Even though this implies

that the analysis will lead to results that are mainly applied in Sweden, the quality of the data will be better and more reliable.

There were 11 respondents but only 8 of them were ergonomists within a production site working in Sweden. Even though it was a small-scale survey, the sample can be considered as representative, because it includes a cross-section of the population and tries to avoid outliers (Denscombe, 2014)

2.5. ETHICAL CONSIDERATIONS

As Denscombe (2014) argues, considering the ethical issues of a research is not an option it is an essential requirement for performing a good study. Within this study, several issues should be addressed from the perspective of ethics.

Firstly, inclusive language has being a challenge during the whole development of the project. It is important in a project like this, where there is a component of inclusion regarding age, to consider carefully the language used so as not to alienate the users of the work system. The language used has been analysed in a comprehensive manner, bringing in opinions of a specialist and pursuing a way of writing and speaking which boosts respect and rejects any form of age discrimination.

Secondly, when carrying out both, the interviews and the survey, the anonymity of the answers of the respondents has been respected. In the case where any personal information has been asked, the question was voluntary, and the survey provided information regarding the privacy policy of the survey host, that are compromised to treat the data in a safety and confidential way and will not use the information provided for any other purposed than the specified. All the information provided within the interviews has been managed ensuring confidentiality and stored with all the security provided by Chalmers University of Technology. Moreover, the interviews were recorded with the consent of the interviewees and without any other purpose than to support data fidelity when writing this report.

3. THEORETICAL FRAMEWORK

3.1. ERGONOMICS

According to the International Ergonomics Association (2019), the main focus of ergonomics/human factors is evaluating the interactions between human and system. Its purpose is a symbiosis between human wellbeing and system performance (IEA, 2019). Therefore, it can be said that ergonomics has benefits for both, economic and social performance (Dul&Weerdmeester, 2008).

Within the production field, this scientific discipline promotes a workplace design that decreases the risk of suffering injures or pain, ensures comfort and safety at the workplace and reduces the causes of demotivation (Berlin&Adams, 2017). Moreover, it can be considered a proactive strategy for cost saving in the long run (Berlin&Adams, 2017). Considering these two statements, ergonomics can be considered an approach that contributes to the sustainability of the company within two dimensions, social and economic.

3.2. ASPECTS OF ERGONOMICS

Three dimensions can be distinguished within the ergonomics discipline: physical, cognitive and organisational ergonomics. (IEA, 2019)

3.2.1. Physical ergonomics

Physical ergonomics refers to that part of the ergonomics field which includes movement and body postures. This movement includes the study of muscles, ligaments and joints, which compose the musculoskeletal system. The Musculoskeletal system main functions are ensuring stability, protection and movement (Whitfield, 2009). However, the energy created for making this movement should also be considered, thus the cardiovascular system should also be included within this section (Dul & Weerdmeester, 2008).

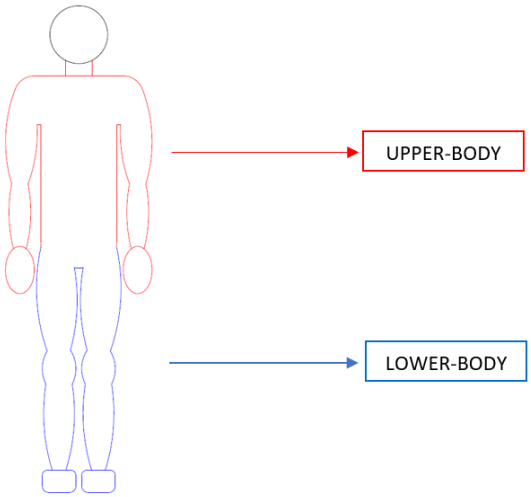

Figure 6: Designation of two main parts in the body: upper-body and lower-body

According to Figure 6, in this study the musculoskeletal system will be divided into two differentiated parts: upper-body and lower-body. The classification of the different parts of the body according to this designation is the following:

UPPER BODY	**LOWER BODY**
Neck	Legs
Trunk	Feet
Arms	Gluteus
Hands	

The cardiovascular system is responsible of supplying oxygen and nutrients. Therefore, its function is crucial for sustaining life. This system is composed of arteries, capillaries and veins, which carry the blood to all the parts of the body. If functioning correctly, all the parts of the body receive the quantity of oxygen and nutrients necessary for maintaining the person healthy and able to work appropriately without any disturbances (Talbot, 2017). The physical effect that the cardiovascular capacity of a worker has regarding his or her work performance in a production line, is the ability to perform physical exercise. According to Biron et al. (2014), physical exercise involves the use of approximately 60% of maximal oxygen uptake and an elevation of the heart rate. Therefore, aerobic activity, would be classified within this type of physical activity and involves the movement of the large muscular groups (Biron et al., 2014). Thus, when a situation requires aerobic activity, there would be an action of the cardiovascular system, conditioning the performance to the capacity owned by the worker.

3.2.2. Cognitive Ergonomics

Cognitive ergonomics is the area which involves the senses, their perception of the stimuli and the capacity of processing this data in order to understand a task or solve a problem (Berlin&Adams, 2017)

Figure 7 shows the progress of cognition (Dul & Weerdmeester, 2008). There are five stages, where cognitive ergonomics is involved: information display, senses, information processing, controls and operation. Senses and information processing will condition how the information display should be design and the controls, for, lastly perform the operation or task required. Thus, if cognition is defined as the combination of the senses, sensory stimulation, and the information processing step which involves attention, perception memory and interpretation (Berlin&Adams, 2017), any change in the cognitive abilities of the worker, it should be counteract by an appropriate design of the display or the controls within the production workplace.

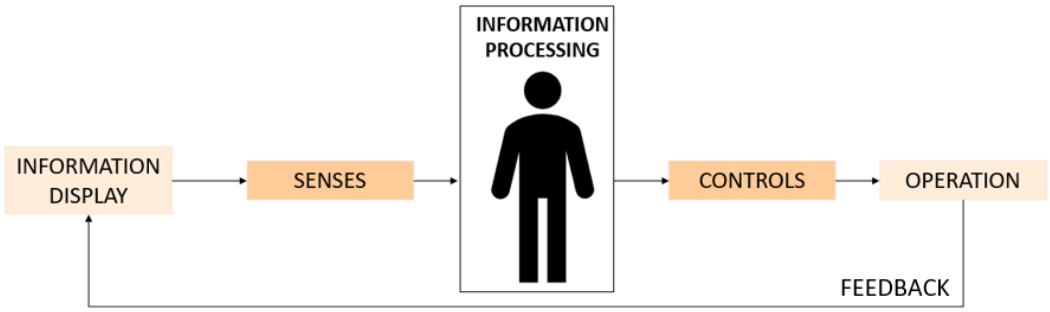

Figure 7: Flowchart of the perception, information processing and action progress. Image adapted by the author from source: (Dul & Weerdmeester, 2008)

For analysing how cognitive issues change because of age, and how the workplace should be design in accordance, three main aspects will be evaluated: vision, hearing and cognitive processes. The latter is dedicated to everything that has to do with information processing. As haptics has to do with the right part of Figure 7, controls, it is included, in case there is any relevant finding, within physical ergonomics.

3.2.3. Organisational ergonomics

Organisational ergonomics involves the interpersonal relationship between workers, their behaviour towards each other, as well as their motivation and work satisfactions at the workplace.

Figure 8 presents a diagram classifying the different parts that should be considered within the Organisational Aspect of ergonomics. Work environmental factors are included under Organisational ergonomics in this thesis, as they are not dependent on the individual, but are conditions of the workplace offered by companies. Therefore, first, in Figure 8, there is work environment factors which covers six parameters: thermal climate, air quality, radiation, lighting, sound and vibration (Berlin&Adams, 2017). Secondly, psychosocial factors involves all relationships between workers and employers, as well as motivation factors and work satisfaction.

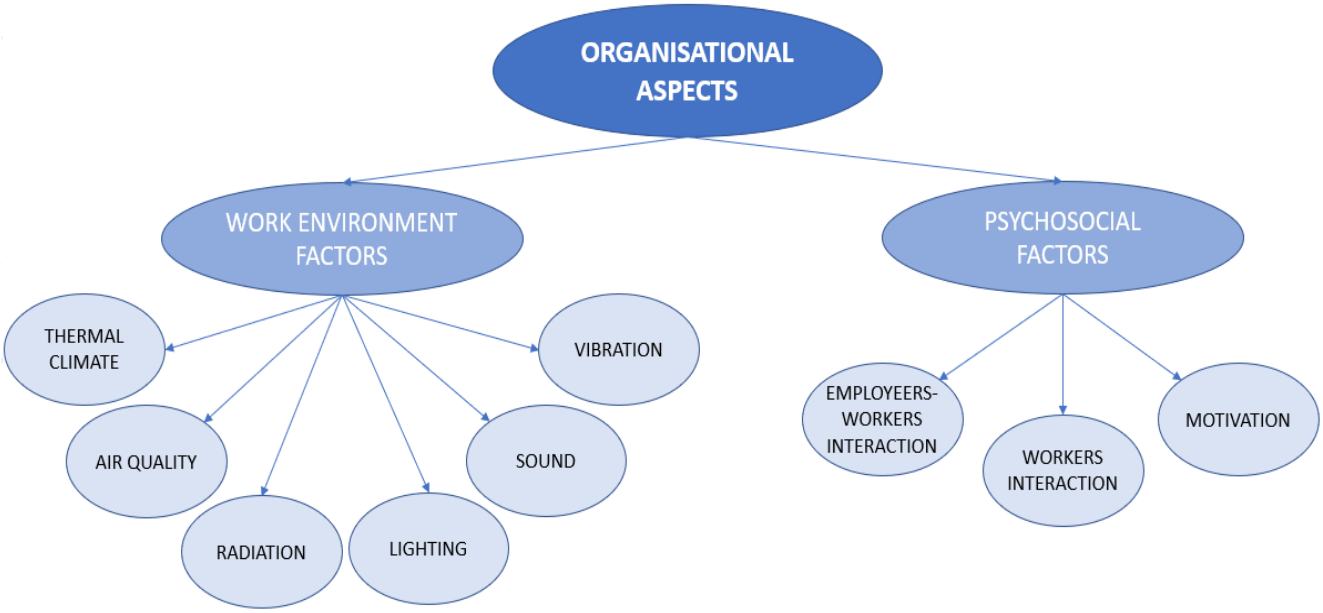

Figure 8: Diagram of the different parts that are included within Organisational Ergonomics

3.3.AGE MANAGEMENT AND ERGONOMICS

Age management is a proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation. It consists of initiatives that consider the needs of each individual, due to age, and incorporates measures for their inclusion within the group, exploiting each one's strength and compensating each weakness.

According to Witkowski&Bartosz (2017), it is an approach that does not focus in a group of people, but on workers of different ages, and involves all the activities that aims to exploit the human resources that a company have, considering their needs and expectations. Age management should not be considered an activity, but a long-term strategy that aims to present a more attractive working scenario where an active and satisfying labour career can be performed (Witkowski&Bartosz, 2017)

Within the field of ergonomics, it is possible to re-design the work done at production sites, to make it safer and healthier, not only for mature workers, but also for all the workers. This is the so-called: universal design or inclusive design. Universal design is defined as:

> "*Universal design is a process that enables and empowers a diverse population by improving human performance, health and wellness, and social participation*"
> (Steinfeld et al., 2012)

Essentially, it implies the pursuit of a healthier, safer and age-friendlier workplace, as well as a continuous improvement, considering the needs of all the population. According to this definition,

the recommendations given in this project to design workplaces considering age management, will not be aimed at universal design because other incapacities such as colour blindness or physical disabilities are not included in the analysis. Only effects of age will be considered within the analysis and will determine the recommendations in workplace design. Therefore, in this project the guidelines recommendations proposed cannot be established as pursuing a universal design but an age-inclusive design.

3.3.1. Sustainability and ergonomics

Sustainable development is defined as:

> "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*."
> (WCED, 1987)

The three dimensions of sustainability can be seen in Figure 9:

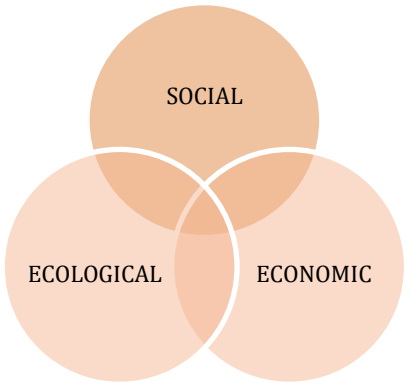

Figure 9: Three dimensions of sustainability. Adapted by the authour from source: (Sutherland et al., 2016)

This project is focused on contributing to solve one of the challenges that are active now in the context of social sustainability: aging populations (Berlin&Adams, 2017). Meyer et al. (2015) highlights the potential that ergonomics, as a discipline, has providing information and principles to achieve a more socially sustainable workplace.

However, this is not just a question of social sustainability, but also a question of economic growth. If the population is ageing, it is crucial for employers to follow a strategy to attract younger workers and to keep mature workers at workplaces. And this might only be possible if workplaces provide a good environment for healthy and safety development. Moreover, maintaining mature workers at work, without considering their needs and expectations might lead to a decrease in their performance, for physiological or psychological reasons. To measure this performance of workers, the most spread KPI is productivity, term that will be mention during this project several times. To achieve sustainability, solutions concerning the welfare of the people working at the production site should be completed with economic and performance indicators, that evaluate if the outcome of the

facility is the required. Productivity measures the relationship between output and input, i.e. what do we achieve given the efforts made (Bellgran&Säfsten, 2010)

In other words, ergonomics and sustainability are two disciplines that aimed a more socially friendly workplace for the welfare of the workers and employers. Moreover, by approaching the problem from an ergonomics perspective, an economic growth can be achieved by maintaining or even increasing the productivity at the production site.

3.4.Other key terms

Within this section other relevant terms will be defined to ensure the complete understanding of all this master thesis.

Workplace: involves all the elements that concern the working area, not only the specific workstation where the worker is at the moment, but all the production site. Its design considers elements that will impact its correct design such as work environment factors, tasks assignation or workers-employer's interactions.

Workstation: involves just the working area where the workers is actually working in.

Physiological changes: involve all musculoskeletal system, cardiovascular system and senses changes

Psychological changes: involve cognitive processing and psychosocial changes.

Mature workers: workers which age is between 55 and 65 years old. It will be the main focus population of this study. Thus, the term which defines this group of workers is important. The information and discussion provided by the specialist in inclusion interviewed has been very valuable. Three words were considered: older, mature and senior workers. The first one, older, was eliminated because it could be considered as too "hard" for this range of the population. On the other hand, senior implies experience, as well as, according to the interviewee it does not fit the range between 55 and 65 years old. Therefore, the chosen term is mature. "Mature workers" expression fulfil all the requirements. It fits the range of age predeterminate. Secondly, it is respectful and inclusive. And lastly, it does not have a negative connotation, like other expressions have, e.g. "elderly people".

4. RESULTS

4.1. FINDINGS RELATED WITH RESEARCH QUESTION 1

The first research question was articulated as:

> *How do physiological and psychological changes caused by age affect the work done in a production line?*

In order to answer this first question which main aim was to study the effects caused by age might influence the work done in a production line, the analysis has been structured in three different parts: physical, cognitive and organisational aspects. Data for this study were collected using a literature review and qualitative data collection based on an interview.

All the results have been summed up in a table included in the Appendix (See Appendix C)

4.1.1. Physical Aspects

When thinking about changes caused by age, the most obvious aspect considered is the physical one. As McMahan & Sturz (2006) argue, three main physiological changes can be distinguished: vision, hearing and musculoskeletal changes (McMahan & Sturz, 2006). However, in this study vision and hearing will be considered as cognitive factors because its main role within the human body is associated with perception and data collection (Berlin&Adams, 2017). Therefore, in this section only changes within the musculoskeletal system will be considered. Moreover, cardiovascular system changes must be also included.

Firstly, one of the most common changes caused by age is a decrease in muscular strength (McMahan&Sturz, 2006; Stedmon et al., 2012; Kowalski-Trakofler et al., 2005; Perry, 2010). The estimation is that the decline in muscular strength of a person aged between 51 and 55 years old is 20% lower than a person in his or her thirties (McMahan&Sturz, 2006). This deterioration is more significant in the lower-body (Stedmon et al, 2012).

Secondly, ageing does not only affect muscular system, but also impacts joint movement and flexibility (McMahan&Sturz, 2006; Fox et al., 2015; Kowalski-Trakofler et al., 2005; Perry, 2010) This decline is more significant in two parts of the body: the neck and the trunk. Moreover, there is also a decline in motor performance (McMahan&Sturz, 2006; Stedmon et al., 2012; Kowalski-Trakofler et al., 2005), which partly leads to a reduction of manual dexterity (Perry, 2010). Essentially, the ability to use the hands in a precise and accurate way decrease (McMahan&Sturz, 2006). Moreover, there is also a decline in tactile feedback (Perry, 2010) Within the skeletal system changes in the spine should be emphasized: loss of motion, facet joints get narrower and shock absorption is decreased (Fox et al., 2015)

Regarding the capacity to react, there is also a decline trend with age (McMahan&Sturz, 2006; Stedmon et al., 2012; Kowalski-Trakofler et al., 2005), i.e. the average reaction time increase with age (Lillo Jover & Moreira Villegas, 2009; Perry, 2010). This leads to less capacity to perform multi-tasking activities (McMahan&Struz, 2006; Perry, 2010)

Lastly, generally, cardiovascular system becomes weaker with age, which means that the aerobic capacity is decreased, leading to an increase of fatigue at work (Fox et al., 2015: Haight&Belwal, 2006; Kowalski-Trakofler et al., 2005; Perry, 2010). Moreover, this has a negative impact in the physical endurance of a worker in a production shop floor (Stedmon et al., 2012). Even though this decline is generally related with age, other factors such as the person's lifestyle might have a big impact (Fox et al., 2015).

4.1.2. Cognitive Aspects

In this section two main parts can be distinguished: senses and cognitive processes. To achieve a more structured report, the parts in which cognitive aspects have been divided are: Vision, Hearing and Cognitive Processes.

4.1.2.1. Vision

Perceptual changes related with the vision capacity are considered to be the most common and the less susceptible to vary from one person to another of the changes caused by age (Fox et al., 2015).

The most common declines with age related with the eyes are: decrease in visual acuity, range accommodation reduction, and weak depth perception (McMahan&Sturz, 2006; Stedmon et al., 2012; Lillo Jover & Moreira Villegas, 2009; Perry, 2010). Moreover, there is a decrease in the sensibility to contrasts that impact in the capacity to distinguish between several colours (among which blue and green should be noted) and the ability to separate objects or figures against a background (McMahan & Sturz, 2006; Stedmon et al., 2012; Fox et al., 2015)

Returning to the issue of colours and shapes, with age there is a reduction in the capacity of perceiving clear images without changing its colours (Lillo Jover & Moreira Villegas, 2009).

Lastly, it is important to highlight the decline in peripherical vision and in lighting changes adaptation (McMahan&Sturz, 2006; Lillo Jover & Moreira Villegas, 2009)

4.1.2.2. Hearing

Hearing losses are common within mature adults. Indeed, hearing sense decline is meant to start approximately at the age of 35 years old, and its functioning will decrease with the years continuously (McMahan&Sturz, 2006)

These hearing losses impact specially the sensibility to high-frequency and pure tones (McMahan & Sturz, 2006; Lillo Jover & Moreira Villegas, 2009; Stedmon et al., 2012; Perry, 2010). These high-frequency tones are those above 1000 Hz and are perceived as sharped (Lillo Jover & Moreira

Villegas, 2009). Moreover, this sensibility gets more severe with loud noises (McMahan & Sturz, 2006).

The ear is also responsible for maintaining balance and ensuring body equilibrium (Betman, 2017). With the years, this ability declines, thus, there is a risk of imbalance while working for mature workers (McMahan & Sturz, 2006; Perry, 2010).

Moreover, the decline of the hearing capacity is also noticed when understanding and hearing properly speech (McMahan & Sturz, 2006; Lillo Jover & Moreira Villegas, 2009; Stedmon et al., 2012) and locating sound's sources (McMahan & Sturz, 2006).

4.1.2.3. Cognitive Processes

Cognitive processes are all of the procedures that compose the total process of handling information, such as: attention, memory or perception (Berlin & Adams, 2017) Therefore, apart from the senses, these processes should be included within this section.

Within the cognitive development and more specifically within intelligence, two dimensions can be distinguished: fluid and crystallized. While fluid intelligence is the one related with the adaptation capacity to new situation, crystallized intelligence is associated with acquired capacities for managing language, numbers or problems. The major decline with age is experienced within the fluid aspect (Lillo Jover & Moreira Villegas, 2009) On the contrary, crystallized abilities commonly remain stable (Boenzi et al., 2014) This decline in the fluid aspect is the reason, for instance, for a decrease in the capacity while ageing to divide attention among different tasks, i.e. multi-tasking capacity (Stedmon et al., 2012; Boenzi et al., 2014; Perry, 2010) Essentially, and in short words, this decline in fluid intelligence is considerable within the following abilities: attention, perception, processing speed, memory and reasoning (Boenzi et al., 2014; Kowalski-Trakofler et al., 2005; Perry, 2010) This decrease cognitive abilities is related with biological age increase (Nilsson, 2016).

As was mention in the section "Physical Changes" (see section 4.1.1), and following the line of fluid intelligence, there is an increase in the reaction rate. This is not only related with the physical ability, but also influenced by the decline of the sense's capacity (Fox et al. 2015; Haight & Belwal, 2006) Therefore, the answer rate to some signals will be decreased, and the ability to react to rapid decisions will be slowed (Haight & Belwal, 2006). Moreover, this would be more critical in the case of complex tasks (Kowalski-Trakofler et al., 2005; Perry, 2010)

4.1.3. Organisational Aspect

Organisational aspect of ergonomics is related with two main issues: work environment factors and psychosocial factors. While the former is connected with physical factors related with the climate of the working space, the latter is related with the interconnection between people working at the production site, as well as motivation, work satisfaction and inclusion goals. In this section, effects caused by age will be analysed regarding these two issues.

4.1.3.1. Work Environment Factors

Within the work environment factors that impact the workers five aspects can be distinguished: thermal climate, air quality, lighting, sound, vibration and radiation (Berlin&Adams, 2017)

Beginning with thermal climate, as people age the ability to maintain a body constant temperature decline. Regarding environmental pollutants, as dust, with age its effect increases. (Stedmon et al., 2012)

Regarding lighting and sound, this two are directly linked with the information provided in the section of vision and hearing. On the other hand, vibration and radiation do not have any effect related with age, further than the actual effects that they have in all workers.

4.1.3.2. Psychosocial Factors

According to Berlin&Adams (2017), within the so-called psychological environment it is necessary to distinguish between: team working (interrelationship between the members of the group as well as their relationship with the leaders and vice versa), culture (concerning geographic, time and order priorities) and personal lifestyle. Regarding culture, age will be the main representative factor, which affects this psychosocial environment in the way that priorities are order. This means that culture will be included within the whole study, and this section will be divided into two: interrelationships between members of the group, and personal lifestyle.

Firstly, it is necessary to evaluate how do workers interact with each other while working in teams. Considering age management as the main topic here, one of the aspects that might be evaluated is how workers from different ages interact with each other. The relationship between young and mature workers is determinate by the perceptions and attitudes towards each one. The perception of the differences between each age group are bigger than they actually are (Van Dalen et al., 2010) Indeed, according to Van Dalen et al. (2010) studies, younger workers consider themselves better than mature workers, while these last agree with this statement.

To evaluate the perception that employers have of the workers, it is necessary to distinguish two types of abilities: soft, which mainly involve job performance abilities as social skills or commitment; and hard, which include the already mentioned fluid intelligence aspects as well as creativity and physical capacity to deal with workload (Van Dalen et al., 2010) While mature workers achieve better scores within soft abilities, younger clearly stand out in hard abilities (Van Dalen et al., 2010) This perception that managers have of mature workers drives their attitude to them. This attitude is considered to be one of the most important factors for extending retirement age, meaning that in the places where there is a positive attitude to mature workers inclusion within the workforce, their willingness to stay at work more time is larger (Nilsson, 2016)

The interviewee argued that the retirement age depends on how happy the workers is within the department, i.e. the social engagement on the department. Work satisfaction and the involvement of the workers by paying attention to their needs is key for promoting retirement age postponement

(Nilsson, 2016) This social engagement decreased if needs and expectations of workers are not considered (Perry, 2010)

Secondly, regarding personal lifestyle, it has a significant impact on the effects of ageing (Fox et al., 2015; Nilsson, 2016; Haight & Belwal, 2006) Factors such as regular activity and exercise moderates the decline in physical capabilities (Fox et al., 2015)

4.2. FINDINGS RELATED WITH RESEARCH QUESTION 2

This section aims to answer the RQ2 that, in short words, consist on setting the consequences in workplace design of the effects that age have within the three areas (physical, cognitive and organisational). It was articulated as:

> *How might these factors lead to a specific design of a workplace considering age management?*

It is worth mentioning that the information provided here has been organised following a structure based on proposing design recommendations to counteract the ageing effects listed in RQ1.

As mentioned in the Methodology chapter, the data for answering question 2 was collected by performing a literature study and a qualitative data collection based on and interview with an ergonomist working at a production site.

Within Appendix D a table is presented with a summary of all the information provided within this section, compared with the findings related with RQ1, and referred to all the sources consulted.

4.2.1. Physical Aspects

As mentioned before (see section 4.1.1), there is a decrease in muscular strength. In a production site, this will be translated in a decrease in the capacity for lifting heavy objects (Haight&Belwal, 2006). Mechanical assistance use, such as lifting devices, should be implemented to combat this decline (McMahan & Sturz, 2006; Kowalski-Trakofler et al., 2005). This lifting ability is also directly related with working posture workload, which means that the problem can be approached without installing extra devices or equipment, but with a re-design of the position of the working place. To avoid the two postures that are considered as the most severe and the principal cause of MSDs of mature workers: knee bend and back bend; tools, equipment and working area should be located at the height of the workers' chest (Nagamachi, 2000). Moreover, these two postures correspond to efforts in lower-body muscles, that are the most affected by muscular decline caused by age (Stedmon et al., 2012) In case this is not possible, lifting devices would be an appropriate solution. However, when possible, pursuing a strategy that implies maintaining a good working posture itself without the need of external mechanical devices, will be a more effective solution because it does not allow workers to take shortcuts. As the interviewee argues, the current problem that they are facing with lifting devices is that workers think they are strong enough to work without them until they get hurt. Then, it is might be too late.

As people age, there is a decline in motor performance that leads to several effects in the work done at a production site. This can be improved by reducing the maximum reach extension (Haight&Belwal, 2006; Kowalski-Trakofler et al, 2005) and height (under the workers' head) in workplaces (McMahan&Sturz, 2006). Moreover, in order to deal with manual dexterity, a solution could be decreasing the production flow. However, this solution might lead to a decrease in productivity (Haight&Belwal, 2006), which does not meet the requirement of maintaining effectivity at the same time as ensuring the welfare of mature workers. Essentially, motor performance affects the ability of mature workers to perform material handling activities. For instance, by ensuring that the tool edges are kept sharp it would be possible to avoid extra forces applied because of dull blades or objects (McMahan&Sturz, 2006; Perry, 2010); or avoiding the use of hands for holding the parts stable and static is facilitated by the use of clamps (McMahan&Sturz, 2006) A proactive strategy for avoiding injures when motor performance is required would be encouraging workers to stretch during the breaks and at the end of the working shift (McMahan & Sturz, 2006). Moreover, repetitive task should be, if possible, reduced (Kowalski-Trakofler et al, 2005).

Changes in the spine because of age should be combated by avoiding tasks that implies twisting the back and the neck (McMahan&Sturz, 2006; Kowalski-Trakofler et al., 2005) Moreover, to avoid intense joint movement, range of motion should be reduced to an acceptable value (Kowalski-Trakofler et al, 2005).

As the capacity of feedback of the tactile sense decrease, the textures and the shapes of the control should be distinguished easily by the workers (Kowalski-Trakofler et al., 2005).

Regarding the reduced aerobic capacity, Haight&Belwal (2006) set the threshold at the level of 14.6 kJ/min, which corresponds to approximately 210 kcal/h (Energy expenditure). In case it is not possible to decrease the aerobic capacity to this level, breaks should be increased, and the working hours reduced (Haight&Belwal, 2006).

To take consideration of the increase in reaction time with age, avoid any confusion in the design of the workplace. For instance, do not situate "stop" and "start" switches nearby (Lillo Jover & Moreira Villegas, 2009). Moreover, to deal with the fact that mature worker's capacity for performing several parallel tasks decreases, environments where multi-tasking is not required would be more appropriate for mature workers.

4.2.2. Cognitive Aspects

4.2.2.1. Vision

A decline in the ability to perceive depth because of ageing is one of the causes of falls in workplaces (Haight&Belwal, 2006; McMahan & Sturz, 2006). Therefore, color-coding should be used in stairs or ramps for prevention (McMahan & Sturz, 2006). When aging, the capacity to contrast colours decrease, thus this should be considered when deciding the colours used (Fox et al, 2015). Since the lens become more yellow with ageing, the combination between green and blue is the most difficult to discriminate (Pinheiro&Moreira da Silva, 2012). Moreover, to combat falls, the simplest solution

would be bringing the work to the ground floor, when possible. If it is not possible, in the cases there is space available, prioritise shallow-angle stairs instead of ladders (Haight&Belwal, 2006; Fox et al, 2015). Moreover, use an anti-slip flooring (Fox et al., 2015; McMahan & Sturz, 2006) and maintain it uncluttered without tripping hazards (Fox et al., 2015).

Due to the decline on the adaptation to changes in illumination, lighting should remain constant through the different areas (McMahan & Sturz, 2006; Perry, 2010) This lighting within the workplace should be strong and, if necessary, devices for Augmented Reality should be used (Nagamachi, 2000). However, it is important to mention that strategies towards increasing lighting without creating glare should be implemented, such as: avoid direct view of light source and/or avoid any reflective surfaces (Perry, 2010).

The tool that might be the most affected because of a decline in the vision are assembly instructions. The recommendations to counteract the decline of the vision ability are the following:

- Possibility to adjust lighting in the visual representation of the information. In case this information is shown in a paper, lighting with a level of illumination of more than 100 cd/m2 should be provided (Fox et al, 2015) In other words, the level of illumination should be higher that what is specified in the applicable regulation within the country involved, which, on the other hand, will not have a negative impact in the younger workers (Lillo Jover & Moreira Villegas, 2009)
- In order to promote an easier adaptation for each individual, depending on each one's needs and their vision capacity, a solution for visualizing assembly instructions could be screens that enable adjustments within the projected image (Haight&Belwal, 2006)
- Size, contrast and colours are the three parameters that should be considered when instructions are designed (Fox et al, 2015; Haight&Belwal, 2006) The combination of similar colours with similar shades should be avoided (Lillo Jover & Moreira Villegas, 2009) Moreover, the best combination would be a good contrast light-dark (Lillo Jover & Moreira Villegas, 2009) and as mention before, combination between green and blue should be avoided (Pinheiro&Moreira da Silva, 2012). Regarding the size of fonts, it should be at least 12-points big (Perry, 2010)
- Complex figures, decoration and irrelevant details should be avoided, because the capacity to distinguish sharp images decrease with age, and simple fonts should be used (Lillo Jover & Moreira Villegas, 2009; Haight&Belwal, 2006)
- Situate the screen or paper nearby the worker to facilitate the reading. Choose a location in front of the worker or at as small as possible an acute angle. This implies that the workers should be able to look at the instructions without twisting back and neck, or at least reducing this movement as much as possible (McMahan&Sturz, 2006; Kowalski-Trakofler et al., 2005)

4.2.2.2. Hearing

For addressing the issue of the hearing losses and emergency situations, one of the solutions could be providing visual signals as well as sounds (McMahan & Sturz, 2006; Lillo Jover & Moreira

Villegas, 2009; Nagamachi, 2000). Moreover, the tones intended to work as emergency sound should be characterised by low frequency (Nagamachi, 2000).

To improve noise control, two measures could be implemented: use sound-absorbent materials and avoid those objects that create echo (McMahan & Sturz, 2006). This might decrease environmental sounds, making it easier for the worker to hear speech properly.

The most proactive measure that should be implemented in the production site, that is directly related with occupational safety, is the use of the necessary hearing protection equipment (McMahan & Sturz, 2006)

Moreover, loss of hearing causes imbalances, so works that imply leaning to one side should be avoided (McMahan & Sturz, 2006). This will reduce the likelihood of falling.

4.2.2.3. Cognitive Processes

To accommodate the situation of mature workers that should face multi-tasking environment, a study of the possibility to increase the time for decision making between steps, as well as refreshers about priorities between tasks, will increase the likelihood of maintaining the pace of the production as well as ensuring quality (Haight&Belwal, 2006)

Avoid dependency on memory when performing a task. Instead, make it possible to identify an external stimulation that gives the information about, for instance, how to perform the task. This way, the worker would be using the crystallized intelligence, which is considered as a characteristic of fluid intelligence, instead of the memory. A simple application of this might be avoiding the use of abbreviations or acronyms. To achieve processes that do not require the use of the memory, feedback of the materials in use should be promoted, meaning that the equipment itself provide the clues and the information necessary to follow the process. (Lillo Jover & Moreira Villegas, 2009)

Fluid intelligence is also related with the ability to adapt to a new situation, equipment or process. To encourage an active exploration of new equipment, it is essential to be aware of two main design rules: ensure reversibility of the action and provide instructions (Lillo Jover & Moreira Villegas, 2009).

These are not the only examples of how this decline in the fluid intelligence impact mature workers performance. Moreover, there is one example that should be considered when designing workplaces: warning symbol design. Due to the difficulties with attention, language and memory, mature workers find it more difficult to understand complex symbols (Lesch et al., 2012). Lesch et al. (2012) study recommend the following:

- Simple and direct symbols.
- If the meaning is complex, add the details that provide any help to understand it.
- In the case the symbol is abstract, avoid arbitrary symbols. Abstract symbols are those one which have a remote relationship with the meaning, i.e. the information that provides is not

precise enough to establish the meaning at the first moment. Arbitrary symbols, on the other hand, are those which representation do not provide information about its meaning.
- In the case the symbol is abstract and arbitrary, provide text, facilitating the understanding.
- Train workers, both younger and mature, to facilitate understanding.

Figure 10 shows an example of comprehensibility of symbols.

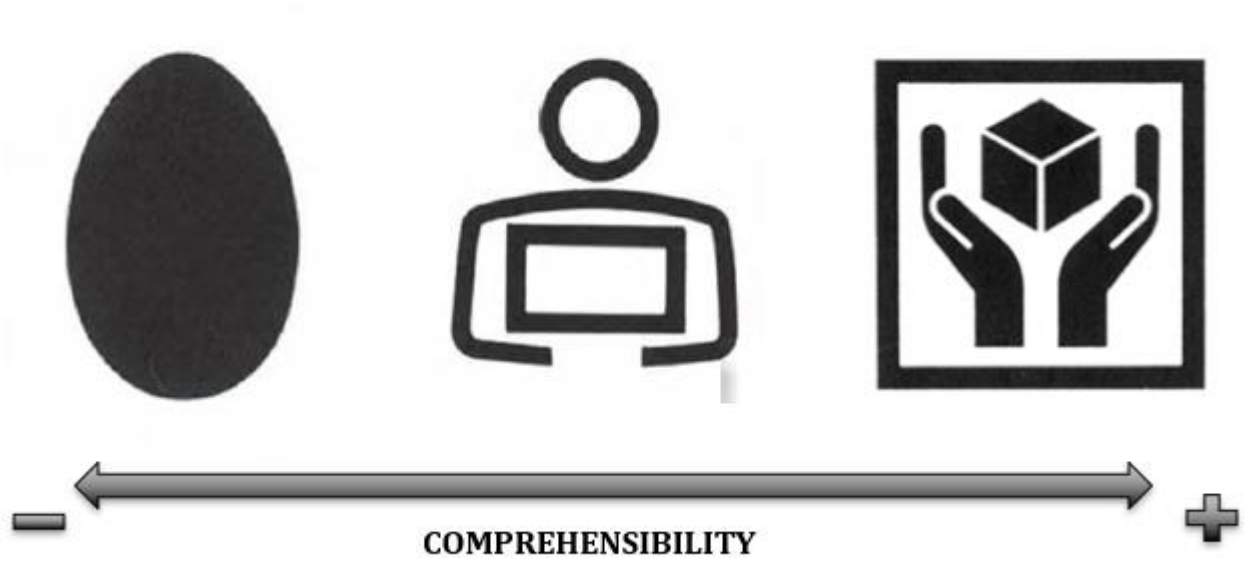

Figure 10: Example of three symbols which represents "Handle with care" and their level of comprehensibility. Modified by the author from source: (Lesch et al., 2012)

Information should be presented in a standard form, being consistent with an internal model. As far as possible, this internal model should be also consistent with the way information is presented externally (Lillo Jover & Moreira Villegas, 2009)

4.2.3. Psychosocial Aspects

4.2.3.1. Work Environment Factors

Due to ageing, mature works find it more difficult to maintain a constant temperature within their bodies. Thus, it is important to keep constant levels of humidity and heat at the facility (Stedmon et al., 2012) However, this is not only related with the climate conditions of the facility itself but also with the clothes that the workers were (Berlin&Adams, 2017). Therefore, the work uniform should be design allowing heat exchange.

Considering the higher effect that environmental pollutants have in mature workers, it is necessary to maintain the workplace clean and control the contaminants (Stedmon et al., 2012; Fox et al, 2015).

Moreover, changes that have being proposed within the cognitive area that have to do with lighting and sound, might be also included in work environment design. However, they have not been

included at this section to keep the structure of ageing effects and correspondent design recommendations that has being set at the beginning.

4.2.3.2. Psychosocial Factors

According to the interviewee, a postponement or extension of the retirement age is mostly a question of social engagement and a function of how happy and motivated the worker at the production site is, and more specifically, at the department where he or she is working. Moreover, social needs are meant to be crucial for maintaining a good physical and psychological condition (Bruggencate et al., 2018). Therefore, the psychological aspects should be considered, and the conclusions extracted from this study will have a big repercussion in a proper design that considers age management.

As mention in section 4.1.3.2. managers have in strong consideration soft abilities of mature workers, while young workers stand out in hard abilities. This match with the statement done when evaluating the effect of age in cognitive processes on how fluid intelligence is the most affected. Therefore, one of the recommendations against this trend and for the maintenance of the motivation of all workers would be evaluating the performance of each worker considering their experience within the production site and their age. This way, both age groups will see their own merits recognised. Moreover, their activities in the shop floor should be assigned depending also on these parameters. For instance, knowledge transfer tasks should be promoted from the mature to the younger workers. In addition, this knowledge transfer is considered an important satisfaction source activity (Bruggencate et al, 2018). Indeed, the recognition of the experience and knowledge of mature workers by employers leads them to consider more positively the idea of staying at the workforce for a longer time (Nilsson, 2016) This knowledge transfer is not only reduced to technical issues, but also can be used as an opportunity to adopt a proactive strategy towards correct mistakes done in the past. This means that mature workers have the experience of how bad postures and shortcuts when performing tasks at the production line can lead to injures and pain. According to interviewee words, “a good example of a bad example”.

Following the line of maintaining the motivation of the workers, there should be a way to promote and make it easier for the workers to share input and feedback of the design of the product, the workplace itself, or the organisation (Fox et al, 2015) This is the so-called: “Participatory Ergonomics”. Nagamachi (2000) argues that this participatory ergonomics could be applied by organising workshops for workers and employers learn more about ageing and its physiological and psychological effects. Moreover, there should be a feedback from workers to management and design employees (Nagamachi, 2000; Kowalski-Trakofler et al., 2005) and workers should be involved in the implementations of the measures resulted from this feedback (Bruggencate et al, 2018; Kowalski-Trakofler et al., 2005). This would be a way to use their experience in improving the work, which means that they will be credited and valued, which leads to work satisfaction and motivation (Nilsson, 2016)

An important issue that should be also addressed is respect and inclusion; each individual has his/her own needs, expectations and abilities (Kowalski-Trakofler et al., 2005; Bruggencate et al,

2018). Heterogeneous groups should be formed, in order to promote the exploitation of each one talent and understand that the differences among all the workers of different ages are considered to be larger than what actually are. (Bruggencate et al, 2018)

A healthy lifestyle and regular exercise should be promoted by the company, encouraging the workers to follow these recommendations in order to slow down ageing physical effects (Fox et al, 2015; Nilsson, 2016). Moreover, training will improve physical and cognitive abilities (Stedmon et al., 2012)

4.3. FEASIBILITY ANALYSIS OF THE PRODUCT

Considering that the outcome of this master thesis is a "product", it is important to assess the feasibility of the project itself to meet the demands of the "customers". Within this project it will be considered that the product is a "Guideline for designing assembly work considering age management", and consequently with the stakeholder analysis (see section 2.2), the customers will be "Ergonomists working at production sites where assembly work is done". Therefore, a survey has been carried out for evaluating whether age management is an issue that is being considered in the sector or not, and the current state of the question within production sites.

Essentially, by evaluating the current concern and further initiatives of companies which production sites are focused on assembly work, to see if effectively these guidelines might have a positive impact for the promotion of age management. At the same time, their answers will give an insight of how appealing this product could be for them.

4.3.1. Importance of retaining mature workers at production sites

Apart from the reasons stated at the beginning of this report, which comes from a first insight of the problem, the study done within this Master Thesis, have come out with different reasons that make project like this important for an industrial party.

Firstly, age related changes, both physical and mental, are in most cases inevitable. However, these changes do not imply necessarily that there is a diminish in performance at the workplace. (McMahan&Sturz, 2006; Stedmon et al., 2012). These negative effects in physiological and psychological condition might be compensated with other abilities resulted from their experience at work (Stedmon et al., 2012). These lasts are valuable assets for the company, which involves also attributes such as commitment and loyalty (McMahan&Sturz, 2006). These attributes are not possible to be substitute by a new worker when a worker go on retirement (Lillo Jover & Moreira Villegas, 2009). Moreover, Haight&Belwal (2006) argued that mature workers are better than younger ones when it comes to attributes such as reliability and consistency. Therefore, it is very important to hold mature workers by understanding their needs and recognising their experience and knowledge.

As the interviewee argued, mature workers are not only experienced from work, but also from life. As a result of this lifetime experience, abilities such as judgement and common sense are enhanced

over the years pass (Nagamachi, 2000) According to some researches, this experience lead mature workers to work in a smarter way instead of a harder way, thus compensating the different physical disadvantages experienced with age (Fox et al. 2015; Nilsson, 2016)

This need becomes more important if looking at studies which state the tendency of blue-collar workers to stay at the same position during all their working life's (Nilsson, 2016). This supports the fact that mature workers add to the company knowledge, expertise, loyalty and commitment.

Lastly, all the changes that will improve workplaces for counteracting age effects, will be at the same time positive for all the workforce (Lillo Jover & Moreira Villegas, 2009). Initiatives such as this guideline might be key for this purpose.

4.3.2. Survey results

4.3.2.1. Sample representativeness

According to two main reasons, the sample consulted can be considered representative, adding reliability to the data collected. First, the participants were reduced to: "ergonomists within a production site working in Sweden". With this constrain, the context (production site) is fixed and by specifying the country, there will be organic results. Otherwise, the likelihood of obtaining dispersed results that leads to a non-representative set of data might be larger. Secondly, the respondents belong to large enterprises, i.e. workforce larger than 250 workers. Even though this was not planned and reduces the appliance of this analysis only to larger companies, the results will be more representative.

This does not reduce the implementation of the recommendations stated in the Guidelines only to those companies that meet all these requirements, but it evaluates the current state of the question and the interest that it will create within this context.

4.3.2.2. Findings obtained from the survey

Figure 11 provides an insight of the proportion of respondents that recognise age management as an approach that is being discussed at their corresponding companies. According to it, 6 out of 8 of the respondents have recognised age management as an issue that concerns their companies. Therefore, there is a strong possibility that initiatives such as this Guidelines interest them.

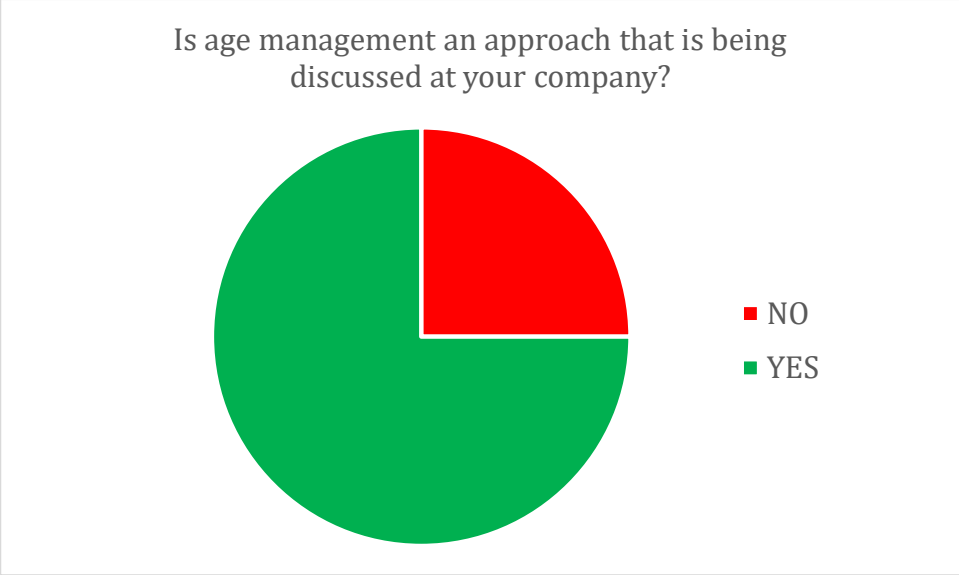

Figure 11: Graphic representing the proportion of companies that have in consideration age management.

However, when analysing actual initiatives or strategies undertaken towards implementing age management at production sites the results differ. As can be seen in Figure 12, the percentage of companies that have implemented any initiative towards achieving a better performance in age management is smaller than the ones that have not. This implies that there is a gap between intentions and actions. While 6 out of 8 of the companies are concerned about this issue, only 3 out of 8 claim they have already taken any measure to address it.

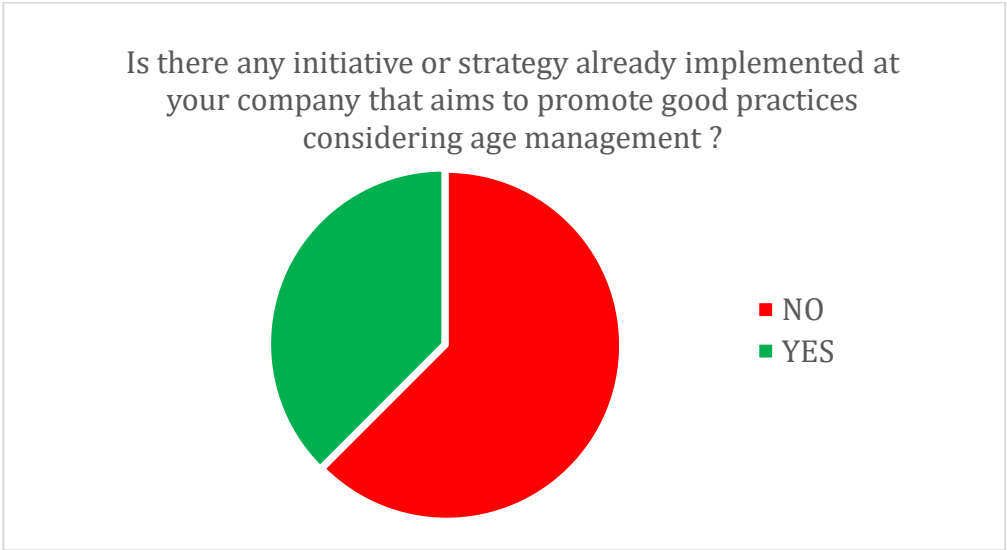

Figure 12: Graphic representing the proportion of companies that have already taken any measure to approach age management.

Recommendations done in the guidelines VS. What is currently implemented at production sites.

First of all, knowledge transfer. As already mentioned in previous sections (See section 4.2.3.2), knowledge transfer is an activity that should be promoted within the company because it creates work satisfactions at the same time it recognises the knowledge and expertise of mature workers.

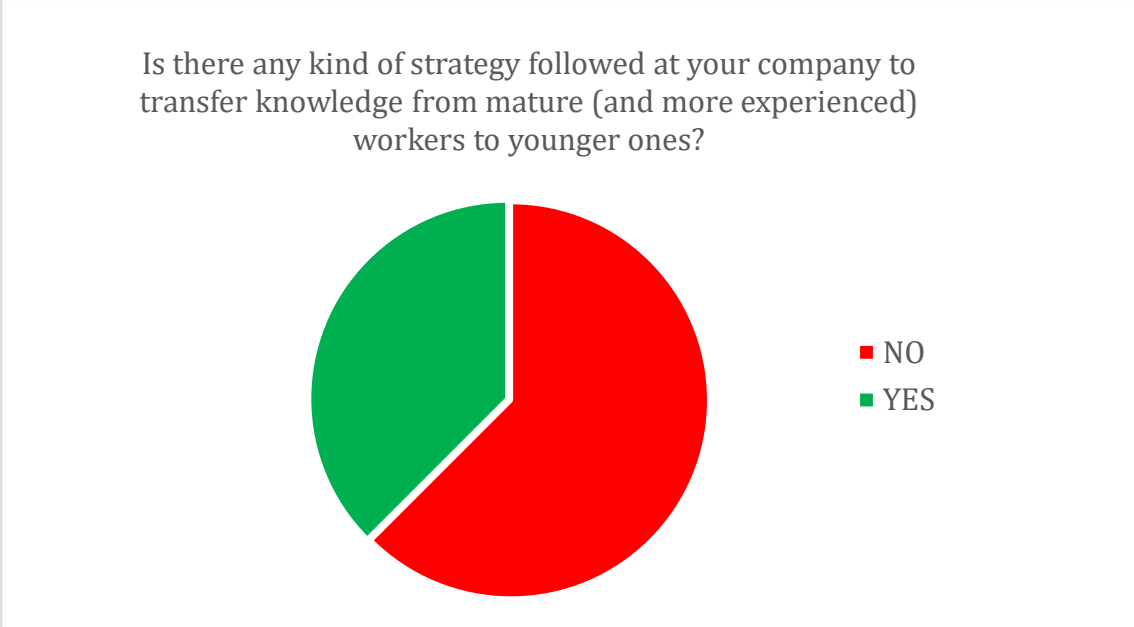

Figure 13: Graphic representing the proportion of companies that pursue knowledge transfer at production sites.

As it can be seen in Figure 13, only 6 out of 8 of the respondent's stated that there is no strategy towards transferring knowledge from mature workers to younger. This means that there is a gap between age management-considerate strategies and what is currently established.

Secondly, falls prevention signalling. As was stated previously (see section 4.2.2.1), decline in deep perception is one of the most common causes of falls at workplaces. Thus, signalling is crucial for decreasing the likelihood of this happening. Regarding this topic, the results provided by the survey show a concern about this topic, being 6 out of 8, as seen in Figure 14, of the respondents recognise that there are visual marks for indicating stairs and steps.

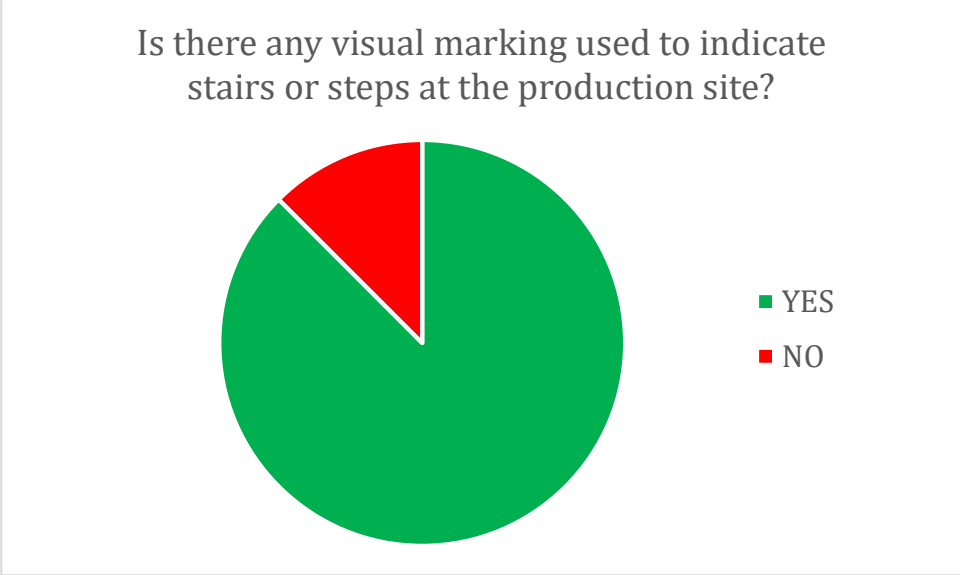

Figure 14: Graphic representing the proportion of companies that use visual marking to indicate stairs of steps at the production site.

Lastly, assembly instructions design. This is an issue that is directly related with the decline in cognitive abilities in the perception and the processing of the information. According to Figure 15, the most popular tool for showing instructions is "Paper", that is in the majority of the cases a shared tool with "Screens". Moreover, the respondent that included the option of not having instructions, also recognised the use of paper and screens. Therefore, in all the companies consulted assembly instructions are used within the process.

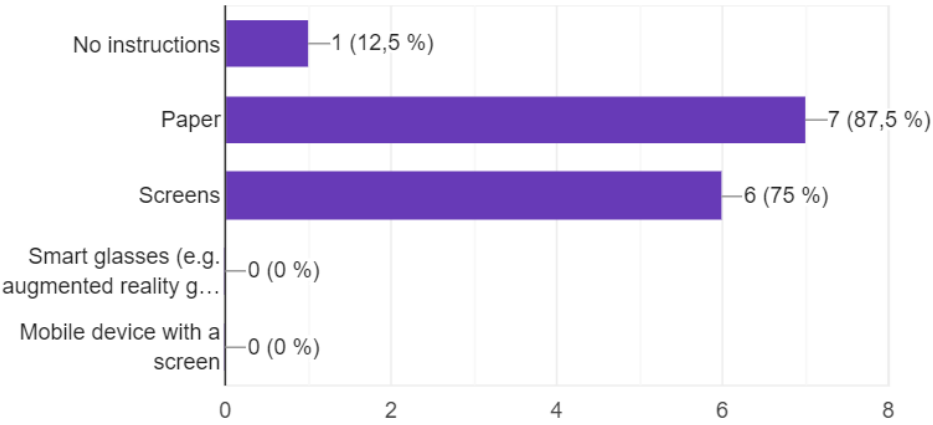

Figure 15: Collection of the different types of tools for assembly instructions display, and their use according to the respondents.

The most interesting data regarding this topic will we the extracted from the sub-section "Digital tools for assembly instructions". Size font, contrast and lighting are three important parameters when it comes to perceiving the information. Moreover, due to digital tools features, it is possible to allow the worker to adjust them to accommodate the display to their vision.

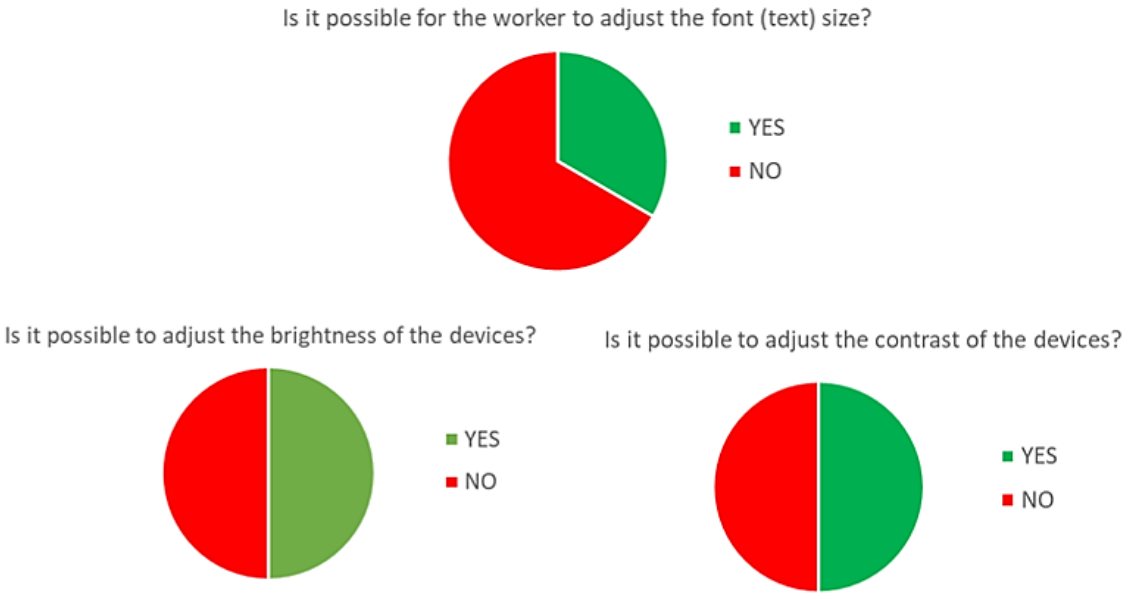

Figure 16: Record of the answers for the adjustment of the three main parameters (font size, brightness and contrast) in digital assembly instructions.

According to Figure 16, adjustment of contrast and brightness is possible for the 50% of the respondents, while the font size adjustment is only available in one third. This means that the features that a digital tool provides is not been exploited. Digital tools provide the potential to achieve a less cognitive stress and workload by adjusting the display to the needs of each worker.

Ergonomics dimensions' importance for the respondents

Lastly, the questionnaire also wonders which were the most important dimensions of ergonomics that should be most interesting to evaluate in a guideline as this. The answers to these questions are represented in Figure 17. Analysing the three dimensions, it is rather clear that physical ergonomics is the considered the most important. Cognitive ergonomics importance seems to be more dependent on the product assembled or the company consulted. However, the majority gives an importance of 2 to having guidance for age management in cognitive ergonomics. Regarding the third, organisational, there is a slightly advantage of the third stage of importance. Moreover, is worth to highlight that none of the respondents gave a 5 (Less important) to any of the dimensions. Regarding the open question, which follows the question explained above, one of the respondents stated:

"Focus on all three areas (physical, cognitive and organisational) are important!"

This statement is the pursued with this project. Therefore, these guidelines are a potential tool for a complete age management-considerate design.

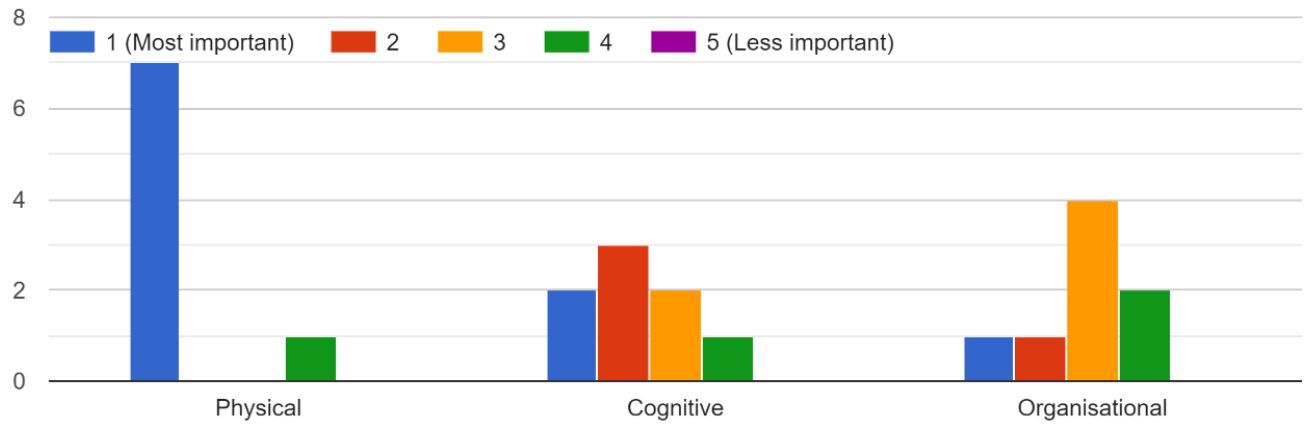

Figure 17: Representation of the answers to question: "If a guideline for "age management ergonomics" applied to production sites were to be created, which area(s) would you consider the most crucial to receive guidance in?"

4.3.2.3. Conclusions of this survey

From the first two statistics represented and analysed in the previous section it seems that there is a mismatch between the concern and the action yet. Thus, this guideline might be a potential tool to address this problem and overcome the existing gap for the implementation of actual measures to achieve a better age management performance.

There are recommendations done in the guideline that are not being implemented at production sites. This might happen because there is no concern yet of the importance of this measures for adopting an age management-considerate strategy. If this is the reason, the possibility of having all this information mapped in the same document, in a structured way, will be useful for any industrial party. Moreover, it brings recommendations of how digital tools could be used in a way that decrease the cognitive workload of workers. This is something, that according to the figures, is not yet achieved completely, and means that the exploitation of the features that digital tools offer to a better performance at workplaces is not attained.

On the other hand, even though there was a clear majority that gives the larger importance to guidance in the physical dimension of ergonomics, there is a tendency to believe that all the dimensions are important. Therefore, these guidelines, which considers the three of them, could be appealing to ergonomists working at production sites, as a potential tool for achieving a more age friendly workplaces design.

5. DISCUSSION

The main goal of this project was to address one of the major challenges within social sustainability that Europe is been facing and will face during the next years an ageing population. This chapter includes a discussion of the findings presented in the previous chapter. It also includes a reflexion of several issues that the author found interesting to be discussed.

Moreover, the limitations of this study will be discussed, and recommendations for further research will be done.

Main findings of this research

Comparing these recommendations with general ergonomic recommendations for designing workplaces, there are not large differences. Mostly, all recommendations are a bit more restrictive than regular recommendations. However, this restriction is larger or lower depending on the dimension analysed.

Particularly, when analysing the specific design that considers age management with regard to issues related with vision and cognitive processes the recommendations are more restrictive than other general ergonomic recommendations. The senses, in particular vision, decline significantly in the period studied, between 55 and 65 years old (Stedmon et al., 2012), therefore the recommendations are more extensive. Regarding the cognitive processes, and more specifically the fluid intelligence aspect, as mentioned throughout this research, there is a gradual decline which starts also in the early adulthood, around 30 years old (Lillo Jover & Moreira Villegas, 2009). Considering this issue, there are also recommendations added within these guidelines that might not be included in regular ergonomic regulations.

On the other hand, regarding the physical aspect of the findings of this research, the differences between this guideline, and those ones that embrace all workers, without a focus on age management, are not as large as the ones done within cognitive ergonomics. This matches with the fact that ergonomics is a proactive approach, which considers the possible injures and avoid them from the beginning. Thus, the measures recommended to avoid MSDs are practically the same in both cases. However, with willingness of adopting a proactive strategy towards avoiding severe injuries in the case of mature workers, more restrictive thresholds regarding movements and tasks that concern joints or muscle strength have been included in these guidelines.

In addition, there is one aspect that must not be neglected, psychosocial factors. The concern about psychosocial factors as the source of motivation and work satisfaction is essential for keeping workers at production sites for a longer period of time. As Herzberg argues, besides meeting hygiene factors (those ones related with salary, working conditions and interpersonal relationships), to achieve job satisfactions, and consequently motivation, it is necessary to pursue: achievement, recognition, responsibility and progression (Naoum, 2011). Therefore, initiatives

towards inclusion and age effects deceleration are essential to achieve workers' satisfactions, independently of their age.

Regarding the findings of the survey done to ergonomists as potential users of the guidelines, it was revealing that even though the majority of the respondents agree on the concern about age management and its repercussion at the production sites, there was a minority of them that recognised that there were not any strategies or initiatives towards addressing this issue. Therefore, these guidelines might be a potential tool for overcoming this gap and implement measures towards a more age management-considerate performance.

Comparative between different authors

There are no contradictions between authors. Moreover, the questionnaires related with problems and solutions made at a production line, done to an ergonomist within a multinational company, have provided information that matches perfectly with the finding of the literature study. Even though the papers consulted belongs to journals within different knowledge fields, all of them agree in all the statements, without any contradiction.

Several guidelines for designing workplaces which consider age as a factor that impact in its design have been found. However, none of them were focused on production lines. Therefore, it differs on what is being proposed in this project in the focus. While the focus of a Guideline which is aimed to be applied in an office environment, would be more focussed on enhancing the software of their computers, to lead with issues caused by age, within a production site there is a physical component that impact in all the other aspects of work.

External devices VS Strategic design

It is commonly known that one of the challenges that imply the implementation of ergonomics within a production site is achieving the actual involvement of the workers. In the case of mechanical (external) devices, this involvement becomes even more difficult. According to the words of the ergonomist interviewed within this project, younger workers tend to think that "they are supermen", thus they can work without the use of all these devices. When they realise that their bodies are complaining, then is too late. Ergonomics is a proactive approach, it should not be a reactive solution.

In the case of mature workers, there are two phenomena related with the use of mechanical devices. The first one is directly related with the decline in fluid intelligence argued by different authors (Lillo Jover & Moreira Villegas, 2009; Boenzi et al., 2014; Kowalski-Trakofler et al., 2005; Perry, 2010) Due to this decline, there is an increased difficulty to adapt to new equipment. Therefore, if the use of lifting devices is implemented in a workplace for the first time, mature workers will probably not use them. Secondly, according to the interviewee, "*The humans tend to take short cuts, the only way to make sure that people works correctly is increasing the knowledge and the engagement*". Translating this to the specific case of mature workers, due to their experience, taking shortcuts will be even more common, because they know better the work than a younger and less experienced worker. When it comes to mechanical devices, they will not use them because they will

find a way to do it in a shorter time. However, this shortcut might not be the healthier path. The challenge for the ergonomist and workplace designer might be achieving them to do the work in a healthy and effective way. Furthermore, when knowledge and engagement strategies do not work, or do not provide good enough solutions, a re-design of the position of the working area, following the principles of: reducing maximum reaching extension and height, and maintaining the work at worker's chest height (Haight&Belwal, 2006; McMahan & Sturz, 2006; Kowalski-Trakofler et al., 2005).

In the case there is no other solution available but the use of mechanical devices, other strategies could be used. All this engagement and involvement of mature workers in following the instructions and using mechanical devices, has much to do with fluid intelligence, as mentioned before. Thus, to achieve better results the best strategy is leaving as much workload as possible to the crystallised intelligence, at the same time fluid abilities are overcome by strategies that seek to decrease the need for memory or processing skills.

Other standards

For technical support and to approach the problem with all the resources available, current standards that address the needs of mature workers within production sites were searched and consulted. A standard was found ISO/TR 22411:2008: Ergonomics data and guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of mature persons and persons with disabilities (ISO, 2008). This ISO/IEC Guide 71 is a guide for addressing accessibility in standards, involving mature persons and people with disabilities.

It is well worth to comment the fact that the standard itself groups together mature people with people with disabilities. Therefore, inclusion is not achieved. In addition, it promotes exclusion of mature people, as a group within the workforce that might be separated from the rest. Moreover, it is putting together age with disability, the recommendations done would be too restrictive for mature workers or too wide for people with disability. On the other hand, these standards are too extensive, because they involve not only the design of environments, but also of product and services. For these two reasons, the context of implementation and the fact that age is treated as a disability, this standard is not included within this research.

From the point of view of policies promoted by Europe, the existing concern regarding ageing at workplaces is being spread around all the country members of the EU and European Commission is promoting policies, with incentives and funding, to improve the current situation and ensuring an easier access for workers between 55 and 65 years old to the working life. The goal set by the EU 2020 Strategy is increase the percentage of people working at the working age (defined as 20-64 years old) from 69% to 75% (European Agency for Safety and Health at Work, 2016). This strategy is being set differently depending on the state of each country, i.e. the number of working people aged between 55 and 65 years old. This means that depending on how reinforced the system is already, more or less recommendations and duties will be set for each country.

Code of conduct – Consideration of Age Management within it.

Within the code of conduct of the company there should be an Age Management consideration focused mainly on promoting inclusion and respect of people of all the ages within the workplaces. It should not only be a question of recruiting and human resources, but also a question of how people within workplaces interact with each other in terms of respect and age-inclusion. Language and behaviour towards each other are examples of issues where respect and inclusion should be the driving forces. Regarding this issue, an extensive research should be done to understand how language expressions and vocabulary might affect the involvement of mature workers at production sites.

Limitations of this project and further research

The survey was only answered by employees at large companies, which are those ones where the workforce is more than 250 people. Therefore, it would be interesting to investigate the current state of the question and the interest shown by SMEs.

Due to scoping issues, these guidelines can only be applied for assembly tasks in production contexts. Therefore, the generalizability of the data collected in the guidelines is relatively low. Even though, it is certainly possible to extract some of the recommendations and apply them to other context besides production, the main goal was to develop a guideline for assembly task in production environment, and this has been done. Further research should be done to extend this ergonomics approach to address the issue of an aging Europe, that is not only present in production sites, but also in other sectors.

As mentioned at the introduction, other approaches as the automation of the processes to address this issue of ageing. During the research phase of this thesis, the author found out some studies about automation and workforce aging, but it was considered out of scope. Therefore, further research regarding this issue could be interesting to approach this problem.

The implementation of the recommendations done here should be customized in each company, depending on the workers, managers and the product that is being assembled. These here are just generalised recommendations that can be applied to any company, independently of the assembly work done. This is a positive thing on the one hand, because it allows any company benefit from the guidelines. But it is also a handicap, because it implies the need of a specific study of each company to see the state of the question and the changes that might be done. In other words, the need for customisation depends on which company this guideline is being used at. This level of customisation is because of several reasons: the actual state of the production line, the resources available or the level of involvement of workers and managers to deal with this situation, among others.

This involvement will be crucial for the achievement of a more age management-considerate design. This involvement, as mentioned before is not only a question of managers, but a question of workers, which will be the main affected by the implementation of new strategies. New technologies might be one of these new strategies, and their correct involvement and development at them

should be considered. Therefore, further research should be done within this topic, to improve the knowledge in this topic and to find solutions to the challenge that represents this demographic shift.

Ethical implications

Even though the ethical implications of this master thesis in general were developed at the methodology section, the implications that the guideline itself has should be also analysed. The main issue in relation with ethics is the use of inclusive and respectful language. This was the main ethical implication, and it has been fulfilled. Moreover, to ensure the reliability of the data, references to the sources consulted have been included.

6. CONCLUSION

Looking back at the research questions:

> *RQ1: How do physiological and psychological changes caused by age affect the work done in a production line?*
>
> Physical and psychological changes, which impact the work done at production sites, have been found and described in this study within the three main areas of ergonomics. All the findings related with this research question are compiled in Appendix C.
>
> *RQ2: How might these factors lead to a specific design of a workplace considering age management?*
>
> According to the finding of the previous question, as well as the data collected by the literature study and the interview to the ergonomists, design recommendations have been found and described. All the findings related with this research question are compiled in Appendix D.

The findings of this research provide a valuable basis for designing workplaces considering age management. On the other hand, the results of the survey evidence the need of implementing age management measures within the design of workplaces. Therefore, both of the above support this guideline as a potential tool for the deployment of workplaces that allow workers to safely extend retirement age. The guideline, which is the outcome of this master thesis, can be found at Appendix E.

However, ageing is a complex issue, and affects each individual differently. Therefore, these guidelines should be considered as a set of recommendations, supported by an extensive study, which should be use as a guide for designing workplaces production sites, but that should be personalised adding the parameters of the actual workforce and work task of the workplace.

For these guidelines to be successful, there should be a synergy between managers and workers. It is important to collaborate, sharing the concern about the impact that ageing has at work. But not as a negative issue, but as an opportunity to achieve the best performance. Current thought patterns such as considering age and disability together for the design of work environment, products or services should be avoided. Respect and inclusion should be encouraged.

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APPENDIX A: INTERVIEW GUIDE

SMALL INTRODUCTION

First of all, thank you very much for having me here and for your time. I hope this conversation lead us to valuable information for both of us. Secondly, I want to ensure you that the information discuss here will be store in a secure and confidential way. Also, I would like to ask you if you allow me to record the conversation.

QUESTIONNARIE

As Potential User of the Guidelines:

1. Which are the expectations that you have if I talk about a "Guideline for designing industrial work and workplaces for inclusive age management"?
2. Already taken initiatives:
   2.1. Have Volvo already taken any initiatives to improve inclusive age management within the production line? If yes, could you tell me a bit regarding that initiatives?
   2.2. If we divide inclusive age management into three dimensions: physical, cognitive and organisational and work environment. In which of these three areas, the need of structuring and mapping all the already existing information regarding this topic is most crucial for ensuring that an inclusive age management is done effectively?
3. Are you aware of any other initiatives for compiling knowledge on age management in production? (either from the knowledge community or from competitors)

As an "age management dealer":

1. Which value-adding capacities and capabilities would you say that workers age 55 or above contribute at work.
2. In contrast to the previous question, which would you say are the main problems that you should face when the average age of the workforce increase?
3. Retirement age:
   3.1. Which is the typical retirement age in this facility? At what age you would say that workers start thinking about retirement, caused by health or motivation at work issues?
   3.2. Is there any internal regulation that establish a retirement age within the production line workers that is not the stipulated (65 years)?
   3.3. Within this topic there is any input or influence of the Union?
4. Do production employees tend to stay in assembly up to retirement age, or are there other career paths they tend to take within the company as they get older/ more experienced?
5. At the moment, are you taking any actions to transfer knowledge and experience from the older to the younger?

As an experienced ergonomist in a production facility (opinion):

1. Do you think age discrimination can lead to a lower physical strength self-consideration? In other words, is there a direct relationship between workers feeling old and feeling lower physical strength than actually have.
2. If you have to name the principal task of a worker in a production line, which would be?
3. How is the relationship between workers of different ages?
4. Would you say that the most common accident within the group of workers aged 55 or above are falls?
5. Have you performed the WAI (Work Ability Index) evaluation within the age management strategy?

APPENDIX B: SURVEY QUESTIONS

This is a survey that aims to collect some data from ergonomists working at production sites. This data will bring valuable resource to a Master Thesis carried out at Chalmers named: "Guidelines for designing assembly work considering age management"

Essentially, this Master Thesis project will: evaluate which are the main physical, cognitive and psychological characteristics affected by aged and secondly, analyse how these characteristics influence the workplace design. The final outcome will be a Guideline containing recommendations within three different areas: Physical, Cognitive and Organisational Ergonomics.

One important concept in this project will be "Age management", defined as a proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation. It consists on initiatives that consider the needs of each individual, due to age, and incorporate measures for their inclusion within the group, exploiting each one strength and compensating each weakness.

All questions marked with * are mandatory.

1. Are you an ergonomist within a production site working in Sweden?
    a) YES
    b) NO (If not the survey shows the following message:
    Thank you for your collaboration! This survey is aimed to be answered by ergonomists within a production site working in Sweden. If your profile does not match with this description, your help is really appreciated, but your answers would be out of scope, and thus cannot be included.
    And the survey directly finishes)

BACKGROUND QUESTIONS

2. What is the size of your company?
    a) Small (<50 employees)
    b) Medium (<250 employees)
    c) Big (>250 employees)
3. What kind of product(s) is assembled or manufactured at your company?
    ……..
4. Is age management an approach that is being discussed at your company?
    Age management is defined here as a proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation. It consists of initiatives that consider each individual's needs due to age, and incorporate measures for their inclusion within the group, exploiting the individual's strengths and compensating their weaknesses.
    a) YES
    b) NO
5. Is there any initiative or strategy already implemented at your company that aims to promote good practices considering age management ?
    a) YES
    b) NO
6. Within the Code of Conduct of your company, is there any section including “worker behaviour within the production site”?

Company Code of Conduct: a written document where a company sets principles that its employees are committed to follow.

a) YES
b) NO
c) We do not have a Code of Conduct within my company

7. If you answered YES to the previous question: Does the worker behaviour code in any way concern age management?
   a) YES
   b) NO
8. If you have answered YES to the previous question, please provide any examples of how:
   ……..
9. Which ergonomics problems do you commonly deal with concerning older workers at your production site?
   In this project, we consider as "older workers" those workers whose age is 55 years old or above.
   ……..
10. Is there any kind of strategy followed at your company to transfer knowledge from older (and more experienced) workers to younger ones?
    a) YES
    b) NO
11. If you answered YES to the previous question, please provide any examples of how:
    ……..

GUIDANCE PREFERENCES WITHIN THE THREE AREAS OF ERGONOMICS

Physical ergonomics: the area which includes everything that has to do with movement and body postures.
Cognitive Ergonomics: involves the senses, their capacity for perceiving stimuli and the ability to process the information collected to understand a task and solve problems.
Organisational ergonomics: involves the interpersonal relationships between employees, their behaviour towards each other, as well as conditions for appropriate motivation for each individual within the workplace.

12. If a guideline for "age management ergonomics" applied to production sites were to be created, which area(s) would you consider the most crucial to receive guidance in?

	1 (Most important)	2	3	4	5 (Less important)
Physical					
Cognitive					
Organisational					

Please feel free to comment on any topic or any specific focus that you would like to see included in a guideline for age management-considerate design of assembly work:
……..

WORK CATEGORIZATION

13. Please, rate the following activity-characteristics depending on how commonly they occur in the assembly work done at the production site of your company.

	1(Very seldom)	2	3	4	5(Very often)
Aerobic activity					
Heavy lifting					
Rapid decision-making activities					
Multi-tasking activities					
Postures that require muscular strength					
Manual skills					

14. Do you use any kind of visual aids, such as colour coding, for marking equipment and tools at the shop floor?
    a) YES
    b) NO
15. If you answered YES to the previous question: Could you describe these visual aids?
    ……..
16. Is there any visual marking used to indicate stairs or steps at the production site?
    a) YES
    b) NO
17. If you answered YES to the previous question: Could you indicate the type and colour of this visual marking?
    ……..
18. How are assembly instructions presented at the production site?
    - No instructions
    - Paper
    - Screens
    - Smart glasses (e.g. augmented reality glasses)
    - Mobile device with a screen
    - Other
19. Does your company provide one or more digital tools in production?
    a) YES
    b) NO (If the answer is no, the survey comes to the end)

DIGITAL TOOLS FOOR ASSEMBLY INSTRUCTIONS

20. Is it possible for the worker to adjust the font (text) size?
    a) YES
    b) NO
21. Which colours are used in the assembly instructions?
    If possible, specify background and foreground colours.
    ……..
22. Is it possible to adjust the brightness of the devices?
    a) YES
    b) NO
23. Is it possible to adjust the contrast of the devices?
    a) YES
    b) NO

END OF THE SURVEY

Thank you very much for your collaboration!

If you are interested in the results of this Master thesis, please provide us your email address and a link to the report will be sent to you when the project is finished:
We want to ensure you that the personal data provided in this question has the only purpose of contacting you for sending the final result of this Master Thesis. Moreover, this information will be treated confidentially and the survey itself will stay anonymous, even if you provide your email address which will be stored separately.
……

If you have any additional comments or feedback, please feel free to leave them in the following text box:
……

APPENDIX C: RQ1 SUMMARY TABLE

PHYSICAL		
	Decrease in muscular strength	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
	Decrease in joint movement and flexibility	(McMahan&Sturz, 2006)
		(Fox et al., 2015)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
	Decline in motor performace (reduction of manual dexterity)	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
	Tactile feedback decline	(Perry, 2010)
	Changes in the spine	(Fox et al., 2015)
	Decrease in the capacity of reaction (Less multi-tasking capacity)	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Lillo Jover & Moreira Villegas, 2009)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
	Weak cardiovascular system capacity (Fatigue)	(Fox et al., 2015)
		(Haight & Belwal, 2006)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
COGNITIVE		
VISION	Decrease in: visual acuity, range accommodation and depth perception	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Lillo Jover & Moreira Villegas, 2009)
		(Perry, 2010)
	Decrease in contrast sensiblity	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Fox et al., 2015)
	Difficulty to perceive clear and colourful images	(Lillo Jover & Moreira Villegas, 2009)
	Decline in peripherical vision and adaptation for lighting changes	(McMahan&Sturz, 2006)
		(Lillo Jover & Moreira Villegas, 2009)
HEARING	Sensibility to high-frequency and pure tones (1000Hz or above). Specially severe with loud noises	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Lillo Jover & Moreira Villegas, 2009)
		(Perry, 2010)
	Increased risk of imbalance	(McMahan&Sturz, 2006)
		(Perry, 2010)

	Decrease capacity for understanding and hearing properly speech	(McMahan&Sturz, 2006)
		(Stedmon et al., 2012)
		(Lillo Jover & Moreira Villegas, 2009)
	Decreased capacity for locating sound sources	(McMahan&Sturz, 2006)
COGNITIVE PROCESSES	Decline in fluid intelligence abilities (attention, perception, processing speed, memory and reasoning)	(Lillo Jover & Moreira Villegas, 2009)
		(Boenzi et al., 2014)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
	Increased in the reaction time (more critical in complex task performance)	(Fox et al., 2015)
		(Haight & Belwal, 2006)
		(Kowalski-Trakofler et al., 2005)
		(Perry, 2010)
WORK ENVIRONMENT		
WORK ENVIRONMENT FACTORS	Thermal climate: reduced ability to keep a constant body temperature	(Stedmon et al., 2012)
	Air quality: sensibility to environmental pollutants (as dust) increase	(Stedmon et al., 2012)
PSYCHOSOCIAL ASPECTS	Perception of the differences between each age group are bigger than they actually are	(Van Dalen et al., 2010)
	Motivation of mature workers decreased when are compared with younger workers	(Bakotić et al., 2018)
	Social engagement is key for keeping motivation among mature workers	(Perry, 2010)
	Employeers perception of mature workers is good at soft abilities	(Van Dalen et al., 2010)
	Personal lifestyle impacts significally on ageing effects	(Fox et al., 2015)
		(Nilsson, 2016)
		(Haight & Belwal, 2006)
	Regular activity and execise moderates the decline in physical capabilities	(Fox et al., 2015)

APPENDIX D: RQ2 SUMMARY TABLE

ASPECT	EFFECT CAUSED BY AGE	DESIGN CONSEQUENCE AT WORKPLACE	REFERENCE (OF THIRD COLUMN)
PHYSICAL			
	Decrease in muscular strength	Use of mechanical lifting devices	(McMahan & Sturz, 2006) ; (Kowalski-Trakofler et al., 2005)
		Position of equipment and working area: worker's chest height	(Nagamachi, 2000)
	Decrease in joint movement and flexibility, decline in motor performance (reduction of manual dexterity)	Reduce maximum reaching extension and height	(Haight&Belwal, 2006); (McMahan & Sturz, 2006); (Kowalski-Trakofler et al., 2005)
		Keep edge's tools sharp	(McMahan & Sturz, 2006) ; (Perry, 2010)
		Use clamps to hold parts	(McMahan & Sturz, 2006)
		Encourage workers to stretch	(McMahan & Sturz, 2006)
		Avoid repetitive tasks, if possible	(Kowalski-Trakofler, 2005)
	Tactile feedback decline	Use textures and shapes that can be distinguised for the controls	(Kowalski-Trakofler, 2005)
	Changes in the spine	Avoid tasks that implies twisting back or neck	(McMahan & Sturz, 2006); (Kowalski-Trakofler et al., 2005)
	Decrease in the capacity of reaction (Less multi-tasking capacity)	Avoid any confusion at the workplace design	(Lillo Jover & Moreira Villegas, 2009)
		Avoid, as far as possible, multi-tasking environments	-
	Weak cardiovascular system capacity (Fatigue)	Do not exceed the threshold at the level of 14.6 KJ/min	(Haight&Belwal, 2006)
		If that is not possible: increase breaks and reduce working hours	(Haight&Belwal, 2006)
COGNITIVE			
VISION	Decrease in: visual acuity, range accommodation and depth perception	Avoid falls: color-coding at stairs or ramps, keep work at ground floor, anti-slip flooring and without tripping hazards	(Haight&Belwal, 2006); (McMahan & Sturz, 2006); (Pinheiro & Moreira da Silva, 2012); (Fox et al., 2015)
		Instructions: no decoration, simple fonts, good lighting	(Haight&Belwal, 2006); (Lillo Jover & Moreira Villegas, 2009)

	Decrease in contrast sensiblity and difficulty to perceive clear and colourful images	Use light-dark contrast	(Lillo Jover & Moreira Villegas, 2009)
		Avoid green-blue combinations	(Pinheiro & Moreira da Silva, 2012)
		Digital device that allows asjustment: contrast and lighting	(Haight&Belwal, 2006)
		Implement strategies to avoid glare	(Perry, 2010)
	Decline in peripherical vision and adaptation for lighting changes	Ligthing should remain constant through facility areas	(McMahan & Sturz, 2006) ; (Perry, 2010)
		Small angle of vision for instructions	-
HEARING	Sensibility to high-frequency and pure tones (1000Hz or above). Specially severe with loud noises	Use low frequency tones	(Nagamachi, 2000)
	Increased risk of imbalance	Avoid workers that imply leaning to one side	(McMahan & Sturz, 2006)
	Decrease capacity for understanding and hearing properly speech	Decrease environmental sound by noise control: sound-absorbent materials and avoid objects that create echo	(McMahan & Sturz, 2006)
	Decreased capacity for locating sound sources	Provide visual signals as well as sound signals	(McMahan & Sturz, 2006); (Lillo Jover & Moreira Villegas, 2009); (Nagamachi, 2000)
COGNITIVE PROCESSES	Decline in fluid intelligence abilities (attention, perception, processing speed, memory and reasoning)	Provide external information instead of requiring the use of memory	(Lillo Jover & Moreira Villegas, 2009)
		Warning symbol design	(Lesch et al., 2012)
		Information provided in a standard form	(Lillo Jover & Moreira Villegas, 2009)
		Encourage active exploration of new equipment	(Lillo Jover & Moreira Villegas, 2009)
WORK ENVIRONMENT			
WORK ENVIRONMENT FACTORS	Thermal climate: reduced ability to keep a constant body temperature	Keep levels of humidity and heat constant at the facility	(Stedmon et al, 2012)
	Air quality: sensibility to environmental pollutants (as dust) increase	Maintain workplace clean	(Stedmon et al, 2012); (Fox et al., 2015)
		Control of contaminants	(Stedmon et al, 2012); (Fox et al., 2015)
PSYCHOSOCIAL ASPECTS	Perception of the differences between each age group are bigger than they actually are	Heterogeneous groups formation. Respect and inclusion at work.	(Bruggencate et al, 2018); (Kowalski-Trakofler et al., 2005)
	Social engagement is key for keeping motivation among mature workers		

	Motivation of mature workers decreased when are compared with younger workers	Different performance evaluation and tasks designation. Increase activities such as knowledge transfer.	(Bruggencate et al, 2018)
	Employeers perception of mature workers is good at soft abilities	Chose a strategy based on:"Participatory ergonomics"	(Nagamachi, 2000); (Kowalski-Trakofler et al., 2005); (Bruggencate et al., 2018)
	Personal lifestyle impacts significally on ageing effects	Promote a healthy lifestyle and regular exercise	(Fox et al., 2015); (Nilsson, 2016)
	Regular activity and execise moderates the decline in physical capabilities		

APPENDIX E: GUIDELINE FOR DESIGNING ASSEMBLY WORK CONSIDERING AGE MANAGEMENT

This is the outcome of this master thesis. All the information collected for answering both research questions has been compiled in this guideline for designing assembly work considering age management.

GUIDELINES FOR DESIGNING ASSEMBLY WORK CONSIDERING AGE MANAGEMENT

AGE MANAGEMENT: proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation.

PHYSICAL ERGONOMICS

Physical ergonomics involves issues related with movement and body postures.

COGNITIVE ERGONOMICS

Cognitive ergonomics is the area which involves the senses, their perception of stimuli and the capacity of processing this input in order to understand a task or solve a problem

ORGANISATIONAL ERGONOMICS

Organisational ergonomics involves the interpersonal relationship between workers, their behaviour towards each other, as well as their motivation and work satisfaction at the workplace. Environmental factors are also included.

INTRODUCTION

The European population is ageing. Indeed, this demographic change is so urgent that it is considered one of the biggest challenges that Europe will have to face in the coming years **[6]**. While the population aged between 15 and 50 years old has decreased, the percentage corresponding 50 years or above has increase. It seems that this trend will continue during the coming years **[3]**.

This represents a social and economic challenge for industrial companies. On the one hand, economically, corporate leaders should find the formula for keeping workers longer, to overcome the shortage of new workers and to leverage the mature workers' value-adding experience, at the same time as productivity levels are maintained and increased. Even though, at first sight, this adaptation could be seen as a trade-off, the reality is that it is possible to match both **[11].** On the other hand, it is a question of social sustainability. As workers age, the severity of the injures caused at workplaces is greater **[10]**, therefore any changes within the workplace to ensure their health and safety will enhance their quality of life at work.

This guideline is the result of an extensive study that includes the three main parameters or dimensions within the field or ergonomics: physical, cognitive and organisational ergonomics. Within this analysis, physiological and psychological changes caused by age have being evaluated from the perspective of workers aged 55 years old or above. On the basis of these effects, recommendations regarding the design of assembly work and workplaces should be followed to achieve a proper age management within the facility.

Age management is defined here as a proactive approach towards combating age barriers and/or promoting age diversity within a company, organisation or corporation. It consists of initiatives that consider each individual's needs due to advancement of age, and incorporates measures for their inclusion within the group, exploiting the individual's strengths and compensating their weaknesses.

Regarding the design of this guidelines, it is worth mentioning that each of the dimensions is displayed in a colour:

- Physical: Red
- Cognitive: Blue
- Organisational: Green

The structure of this guidelines is the following: firstly, a portfolio where the recommendations are mapped in a schematic way; secondly, each of the recommendations made are presented with the corresponding explanation, including the references consulted. At the very end of this guideline, there is a list of all the references consulted for the completion of this document.

Below, is a table of the content included in this guideline. Four main parts can be distinguished:

- Work Station and Task Design
- Equipment
- Psychosocial Aspects
- Work Environment

CONTENTS

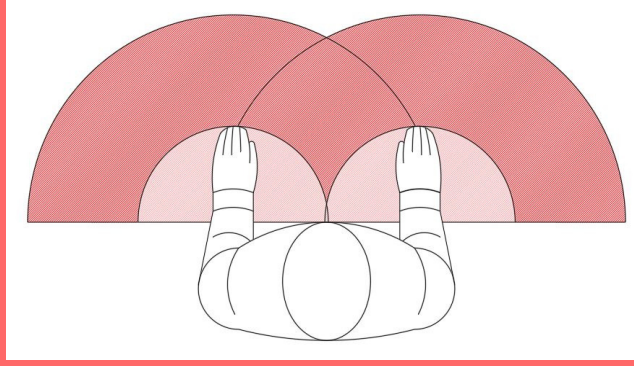
WORK STATION AND TASK DESIGN

To achieve more age-friendly workplaces, workstation and task design should consider physiological ageing effects experienced by workers. Both issues are directly connected: workplace design impacts task design and vice versa.

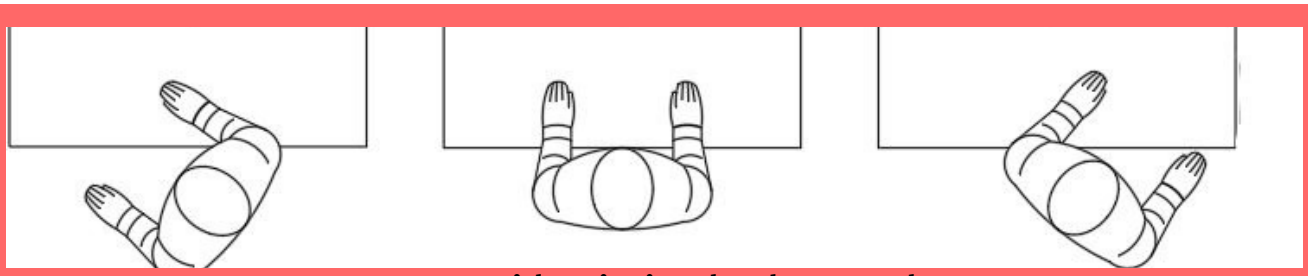
POSTURE

PAGE 5

- Reduce maximum reaching extension and work height.
- Avoid back or neck twisting.
- Encourage stretching.
- Avoid any situation that requires leaning to one side.
- Ideal position of working area: worker's chest height



Reaching extension restriction: Reduce movements within the red area



Avoid twisting back or neck

TASK DESIGN

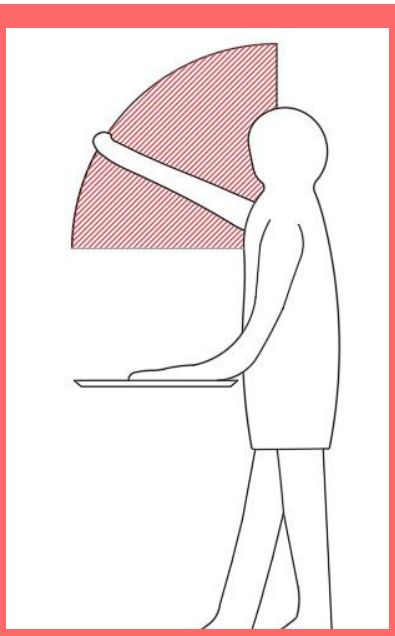
PAGE 5

- Avoid tasks that require repetition
- Avoid multi-tasking environments

ACTIVITY LEVEL

PAGE 6

- Energy expenditure threshold: 14.6 KJ/min
- If this limit is overcome: increase breaks and reduce working hours



Height restriction: Avoid movements within the red area

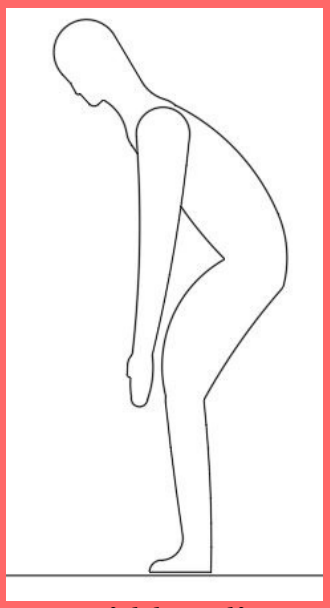
FALLS PREVENTION

PAGE 6

- Use colour-coding at stairs or ramps
- If possible, organise work without changing floor levels
- Use anti-slip flooring
- Eliminate tripping hazards

EQUIPMENT

Several physical and cognitive abilities decrease with age, as mentioned before. Equipment at workplaces could be used for overcoming this decline. This strategy might lead to a better age management performance. Moreover, the design of this equipment should consider the decline of these abilities.

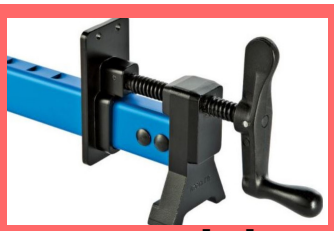


Avoid bending knees and back

ADDRESSING DECLINING MUSCULAR STRENGTH

- Use mechanical devices to compensate for hand strength or lifting ability
- Ideal position of equipment: worker's chest height

PAGE 6



CLAMP. [17]

- Keep tool edges sharp
- Use clamps to hold parts

PAGE 7

ADDRESSING DECLINING MANUAL DEXTERITY

CONTROLS

- The position of the controls should avoid any confusion. (E.g. do not situate together "stop" and "start" buttons)
- Use textures and shapes for the controls that can be easily distinguished

PAGE 7

WARNING SYMBOL DESIGN

PAGE 7

- Use simple and direct symbols (Pictograms)
- If the meaning is complex, add the necessary details.
- If the symbol is abstract, avoid arbitrary/non-intuitive symbols
- If the symbol is abstract and arbitrary, provide text to facilitate the understanding.
- Train all the workers to facilitate the understanding.

ASSEMBLY INSTRUCTIONS

IF DISPLAYED ON DIGITAL DEVICES

- Allow adjustment of contrast and lighting.
- Allow type size (text) adjustment.

PAGE 8

DESIGN

PAGE 7

- Avoid excessive decoration
- Use simple and big enough text fonts
- Information should be provided in a standardised form

COLOUR

PAGE 8

- Avoid green-blue combinations
- Increase light-dark contrast

LIGHTING

PAGE 8

- Implement strategies to avoid glare
- Provide good lighting

POSITION

PAGE 8

- Implement strategies to avoid glare
- The position of instructions should be within the workers' viewing area.

PSYCHOSOCIAL ASPECTS

Motivation and work satisfaction at the workplace are keys for decreasing the likelihood of an early retirement. To achieve both, there are two main issues that should be pursued by managers and designers: inclusion and age effects deceleration.

INITIATIVES TOWARDS INCLUSION

- Encourage active exploration of new equipment.**PAGE 8**
- Promote age-heterogeneous groups. **PAGE 8**
- Implement a system of task designation and performance evaluation that considers age management. **PAGE 9**
- Chose a strategy based on: "Participatory ergonomics" **PAGE 9**

INITIATIVES TOWARDS AGE EFFECTS DECELERATION

- Promote a healthy lifestyle and regular exercise **PAGE 9**
- Train workers on good working habits. **PAGE 9**
- Leverage the knowledge and example of older, and more experienced workers, to encourage good working habits. **PAGE 9**

WORK ENVIRONMENT

Optimal conditions at the workplace should be pursued for ensuring a proper mental and physical work development. Therefore, work environment factors will be key within a design that considers age management.

NOISE

Decrease environmental sound by noise control:

- Use sound-absorbent material
- Avoid objects that create echo

PAGE 9

LIGHTING

Maintain lighting constant through facility areas

PAGE 10

THERMAL CLIMATE

Keep the levels of humidity and heat constant

PAGE 9

AIR QUALITY

- Maintain cleanliness, specifically of workplaces
- Make contaminants controls periodically

PAGE 10

SAFETY

- Use low-frequency tones for alarms and alerts
- Provide visual signals as well as sound signals
- Provide external information to avoid the use of short-term memory

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GUIDELINES FOR DESIGNING ASSEMBLY WORK CONSIDERING AGE MANAGEMENT

This is the second part of the Guideline. Here the reader can find the explanation of all the recommendations made previously, as well as the references of the sources consulted for developing this Guideline.

WORKSTATION AND TASK DESIGN

To achieve more age-friendly workplaces, workstation and task design should consider physiological ageing effects experienced by workers. Both issues are directly connected: workplace design impact task design and vice versa. This section is divided in four parts: posture, activity level, task design and falls prevention.

POSTURE

Within this sub-section, workplace design recommendations for achieving a good posture, to avoid MSDs, will be given.

- ☐ **Reduce maximum reaching extension.** Avoid movements that require extending the elbows. In case this is not possible, reduce the distance. **[5, 7, 10]**
- ☐ **Reduce maximum reaching work height.** Avoid movements that require raising the worker's arm above the chest. This means that the angle the arm forms relative to the (horizontal) ground should not be larger than 0º. **[5, 7, 10]**
- ☐ **Avoid back or neck twisting.** Instead, promote strategies that allow the worker to have all the necessary equipment within the working area that does not require twisting. To avoid intense joint movement, the range of motion should be reduced to an acceptable value **[7, 10]**
- ☐ **Encourage stretching.** A proactive strategy for avoiding injures when motor performance is required would be encouraging workers to stretch during the breaks and at the end of the working shift. **[10]**
- ☐ **Avoid any situation that requires leaning to one side.** Due to a decrease in capacity for maintaining balance, the design of the workplace should avoid any situation that could lead the worker to lean to one side. **[10]**
- ☐ **Ideal working area position should be at worker's chest height.** This is directly linked with the reduction of the maximum reaching height, but this recommendation is more conservative. It concerns all the working area and specifies that the working area should not be neither below nor above the worker's chest. **[12]**

TASK DESIGN

This sub-section will involve recommendations specifically focused on the design of the tasks.

- ☐ **Avoid tasks that require repetition.** Therefore, when designing tasks that imply repetition some strategies to avoid negative effects could be adding rotations or little breaks. **[7]**
- ☐ **Avoid multi-tasking environments.** Due to a decrease in the capacity to react (not only in a cognitive way, but also physically), there is a decrease in multi-tasking capacity. **[7, 10, 14, 16]** To accommodate the situation in case multi-tasking is not possible to avoid, a study of the possibility for increasing the time for decision making between steps, as well as reminders about priorities between tasks, will increase the likelihood of maintaining the pace of the production as well as ensuring quality **[5]**

ACTIVITY LEVEL

Activity level involves the aerobic activity. This is related with the capacity of the cardiovascular system (which is responsible for supplying oxygen and nutrients) which decreases with age.

- ☐ **Set an energy expenditure threshold.** This energy threshold, according to some authors, should be around 14.6 KJ/min (Approx. 210 kcal/h). If the task requires overcoming this limit, breaks should be increased or working hours reduced. **[5]**

FALLS PREVENTION

Considering falls as one of the most common accidents within older workers **[4]**, workplace design should consider any measure that reduces the likelihood of this event.

- ☐ **Use colour-coding at stairs or ramps.** As the decline to perceive depth because of ageing is one of the cause of falls in workplaces, color-coding should be used. When deciding the colours, if fluorescent, consider strategies to situate the light in order to avoid glare, the effect of which becomes more intense with age. **[5, 10]**
- ☐ **If it is possible, organise work without changing floor levels.** In other words, avoid the use of stairs and ramps, as far as possible. In the case this is not possible, prioritise shallow-angle stairs instead of ladders. **[4, 5]**
- ☐ **Use anti-slip flooring.** Implement anti-slip flooring at the shop floor. **[4, 10]**
- ☐ **Avoid tripping hazards.** Maintain the workplace free of any obstacle that might lead to a fall. **[4]**

EQUIPMENT

Several physical and cognitive abilities decrease with age, as mentioned before. Equipment at workplaces could be used for the sake of overcoming this decline. This strategy might lead to a better age management performance. Moreover, the design of equipment should consider the decline of these abilities. Within this section several issues will be considered: equipment and strategies addressing declining muscular strength, manual dexterity and controls; warning signals and design of assembly instructions.

ADDRESSING DECLINING MUSCULAR STRENGTH

Due to muscular strength decline, two main solutions below might be considered. Moreover, all solutions that do not involve the use of external devices is preferable. Therefore, when possible to implement, the second strategy would be the best.

- ☐ **Use mechanical devices to compensate for hand strength or lifting ability**. This type of equipment will allow the worker to, for instance, lift heavy objects, without harm. Moreover, this type of devices will reduce the occurrence of two postures that are the major cause of MSDs of older wokers: knee bend and back bend **[7, 10, 12]**
- ☐ **Ideal position of equipment: worker's chest height**. To avoid the use of mechanical devices, that workers tend to not use, an option could be finding strategies which maintain the work at the worker's chest height. **[12]**

ADDRESSING DECLINING MANUAL DEXTERITY

Due to manual dexterity decrease, strategies towards improving the precision of the equipment itself and of the work by using devices should be promoted.

- ☐ **Keep tool edges sharp.** To avoid any extra forces, and improve accuracy, the maintenance of tool edges is very important. Periodical revisions of the tools might be done to ensure that this is done. **[10, 14]**
- ☐ **Use clamps to hold parts.** The use of this kind of equipment allow a better handling of the parts, consequently making the operation that might be done easier **[10]**

CONTROLS

The decrease of the tactile sense, as well as the decline in cognitive processes, imply a specific design of controls within the workplace.

- ☐ **Avoid confusion in the position of the controls at the workplace.** This confusion will lead to an even higher reaction time that with age will increase considerably. For instance, in case there are two buttons, for start, and for stop, do not situate both together. **[9]**
- ☐ **Use textures and shapes for the controls that can be easily distinguished.** Due to a decrease in the ability to distinguish textures and surfaces, distinct textures and shape should be used for controls **[7]**

WARNING SYMBOL DESIGN

Due to the decline of vision, safety might be compromised, which directly impact warning symbol design. **[8]**

- ☐ Use simple and direct symbols (Pictograms). Avoid any unnecessary complexity.
- ☐ If the meaning is complex, add the details necessary to understand it.
- ☐ If the symbol is abstract, avoid arbitrary/non-intuitive symbols.
    - Abstract symbol: has a remote relationship with the actual meaning of the symbol.
    - Arbitrary/non-intuitive symbol: its representation and design do not provide information about its meaning.
- ☐ If the symbol is abstract and arbitrary, provide text to facilitate the understanding.
- ☐ Train all the workers to facilitate the understanding.

ASSEMBLY INSTRUCTIONS

With the trend that the industry is experiencing to customize products, work at an assembly line is intensified, making instructions very important. Due to vision decline caused by age, several issues should be considered regarding assembly instructions: design, colour, position and lighting.

A. DESIGN

- ☐ **Avoid excessive or unnecessary decoration**. Complex figures, decoration and irrelevant details should be avoided because the capacity to distinguish sharp images decreases with age **[5, 9]**
- ☐ **Use simple fonts for text.** Simple fonts are easier to recognise by older workers **[5, 9]**
- ☐ **Use big enough text font size.** The font size should be at least 12 points **[14]**
- ☐ **Information should be provided in a standardised form.** All instructions should be designed following an established pattern. This will provide consistency to the instructions, avoiding confusion. **[9]**

B. COLOUR

- ☐ **Avoid green-blue combinations.** These two colours are the most difficult to discriminate with age. Instead, black tones with white background are recommended. **[15]**
- ☐ **Increase light-dark contrast**. **[9]**

C. POSITION

- ☐ **Implement strategies to avoid glare.** As mentioned before, a higher sensibility to glare is caused by ageing. Therefore, the position of the assembly instructions should be strategic. **[14]**
- ☐ **The position of instructions should be within the workers' viewing area**. Situate the screen or paper nearby the worker to facilitate the reading. Choose a location in front of the worker or within the workers' viewing are. This implies that the workers should be able to look at the instructions without twisting their back and neck, or at least reducing this movement as much as possible. **[7, 10]**

D. LIGHTING

- ☐ **Implement strategies to avoid glare.** Same as above **[14]**
- ☐ **Provide good lighting.** There are two different lightings that should be considered when designing workplaces: work environment lighting and assembly instructions lighting. This refers to the last one and enhances the importance of providing a good lighting for: obtaining a more comfortable view and avoiding any mistakes caused by lack of sight **[5, 9]** Lighting with a level of illumination of more than 100 cd/m2 should be provided **[4]**

FOR ASSEMBLY INSTRUCTIONS DISPLAYED ON DIGITAL DEVICES. If the assembly instructions are displayed in a digital device, two more aspects should be considered:

- **Allow adjustment of contrast and lighting.** One of the advantages that provides the use of digital devices, provide apart from flexibility and reliability, is the possibility to adjust the instructions to the necessities of each worker. Thus, this advantage should be leveraged, and the software display should allow the worker to adjust the information presentation to her or his own needs. **[5]**
- **Allow type size (text) adjustment.** For the same reasons detailed above. **[5]**

PSYCHOSOCIAL ASPECTS

Motivation and work satisfaction at the workplace are keys for decreasing the likelihood of an early retirement. To achieve both, there are two main issues that should be pursued by managers and designers: inclusion and deceleration of age effects on workers.

INITIATIVES TOWARDS INCLUSION

To achieve inclusion two things should be considered: keep every worker up to date with new equipment, techniques or any other changes and respect of each ones' needs, skills, expectations and experiences.

- ☐ **Encourage active exploration of new equipment.** Due to a decrease in fluid intelligence **[1, 7, 9, 14]**, the ability to adapt to new equipment decreases. Thus, to promote the active exploration of new equipment two main rules should be implemented: reversibility of the action should be ensured, and instructions provided. **[9]**
- ☐ **Promote age-heterogeneous groups.** The recognition of each ones' needs, expectations and talents will improve respect and inclusion at the workplace. By organising heterogenous groups, a larger benefit of each ones' skills and talents will be promoted. **[2, 7]**

- ☐ **Implement a system of task designation and performance evaluation that considers age management.** Essentially activities in the shop floor should be assigned depending on the following parameters: age (and the physical and physiological effects that it has on humans) and experience within the production site. The recognition of workers' expertise and skills developed during the years, motivates the workers. Thus, for instance, knowledge transfer activities should be promoted. **[2]**
- ☐ **Chose a strategy based on: "Participatory ergonomics".** To maintain worker's motivation, there should be a way to share input and feedback of the design of the product, the workplace itself, or the organisation **[4]** Participatory ergonomics should be a good strategy. Workshops for workers and employers to learn more about ageing and its effects, feedback between workers, management and designers and the involvement of workers within the implementation of the measures of this feedback **[2, 7, 12]**

INITIATIVES TOWARDS DECELERATION OF AGE EFFECTS ON WORKERS

Age effects can be decelerated. Three main strategies are outlined below:

- ☐ **Promote a healthy lifestyle and regular exercise.** Encourage the workers to follow these recommendations in order to slow down physical ageing effects **[4, 13]**
- ☐ **Train workers on good working habits.** Training will improve physical and cognitive abilities **[16]**
- ☐ **Leverage the knowledge and example of older, and more experienced workers, to encourage good working habits.** As mentioned before, facilitate knowledge transfer **[2]**. In this case, this knowledge transfer should be about good working habits.

WORK ENVIRONMENT

Optimal conditions at the workplace should be pursued for ensuring a proper mental and physical work development. Therefore, work environment factors are key within a design that considers age management.

NOISE

Apply noise control to decrease environmental noise **[10]**:

- ☐ Use sound-absorbent materials.
- ☐ Avoid objects that create echo. This fact is not only related to the object itself, but also its position within the workplace.

THERMAL CLIMATE

Thermal climate corresponds to a parameter that not only involves temperature. In short words, it has to do with comfort. As humans age, their capacity to adapt to changes in climate conditions decrease.

- ☐ **Keep the levels of humidity and heat constant at the facility.** This is not only a question of the climate situation of the facility itself but also of workers' clothes that should allow heat transfer. **[16]**

AIR QUALITY

Air quality issue involves the concern regarding the limits of air pollutants within the facility **[4, 16]**

- ☐ **Maintain cleanliness, specifically of workplaces.** The effect that dust has on people becomes even more negative over the life-span.
- ☐ **Make contaminants controls periodically.** The same way that dust impact increases with age, so do the effects of all other contaminants.

LIGHTING

Work environment consequences of decreased vision from a cognitive perspective are considered within this section.

- ☐ **Maintain lighting constant through all the facility areas.** Because of vision ageing, the difficulty to adapt to different lights increases. The lighting within the workplace should be strong and, if necessary, devices for Augmented Reality should be used to overcome the decline of vision. **[10, 12, 14]**

SAFETY

There is cognitive decline with age. This decline has a direct impact on the facility safety. This impact is significant in hearing and cognitive processes. The latter is related with the decrease in fluid intelligence, that is related to the capacity to adapt to new situations (Abilities included within this fluid capacity or intelligence: attention, perception, processing speed, memory and reasoning) **[1, 7, 9, 14]**

- ☐ **Use low frequency tones for emergency and safety sound signals.** Later in the life-pan, humans experience a sensibility loss to high-frequency and pure tones. **[12]**
- ☐ **Provide visual signals as well as sound signals**. This decreases the likelihood of not noticing that something is happening. **[9, 10, 12]**
- ☐ **Provide external information for avoiding the use of short-term memory**. A simple application of this might be avoiding the use of abbreviations or acronyms. Moreover, feedback of the materials in use should be implemented, meaning that the equipment itself provides the clues and the information necessary to follow the process. **[9, 10]**