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Health and Safety Executive

Age related changes and safety critical work

Identification of tools and a review of the literature

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Age related changes and safety critical work

Identification of tools and a review of the literature

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The removal of a compulsory retirement age may have implications for health and safety at work, and as such is a cross-cutting issue for HSE. HSE is concerned that some workers may continue to perform tasks with deteriorating performance. This may be a particular issue in safety critical and major hazard industries, and could potentially lead to an increase in the risk of major incidents or injury. More generally, dutyholders may also be finding it difficult to judge whether workers have the functional capacity to work to the required level of safe performance.

This piece of work has aimed to assess existing evidence on age related changes in performance and safety critical work, identify tools that assist dutyholders to assess human function and performance and to critically consider what the findings mean in terms of the need for future work.

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EXECUTIVE SUMMARY

Background

At present there are limited data on the health and safety implications of a post 65-year-old workforce, and no knowledge regarding whether the removal of the compulsory retirement age (in October 2011) will have any implications for health and safety at work. This information is believed to be of particular significance to the safety critical and major hazard industries, where a deterioration in performance could potentially lead to an increase in the risk of major incidents or injury. More generally, dutyholders may also be finding it difficult to judge whether workers have the functional capacity to work to the required level of safe performance.

Aim

This piece of work aimed to assess existing evidence on age related changes in performance and safety critical work, identify tools that assist dutyholders to assess human function and performance and to critically consider what the findings mean in terms of the need for future work.

Findings

An assessment of the literature on age related changes in performance and safety critical work.

There is a large body of literature relating to age and performance. However, there are very few papers that cover age, changes in performance and also explicitly mention work as being safety critical. These papers are predominantly studies of pilots, an area outside of HSE's remit. However, studies of pilots have been included in this review as they provide useful insights into age, performance and safety critical work that can help to inform other areas within HSE's remit.

Papers were also included in the review if they related to age, performance and a safety critical sector (e.g. construction, nuclear, and offshore). Age and high demand jobs (those that exceed exposure safety levels or average human capabilities to meet such demands) have been studied across a range of sectors. High demand jobs include high physical, cognitive and emotional demands. The literature does not explicitly include any mention of the term 'safety critical', hence it is suggested that decreases in performance in high demand jobs are actually those most likely to be 'safety-critical'. This is because the literature suggests these jobs may result in health risks to others (e.g. colleagues and the general public).

The ability to meet the physical, mental and social demands of a job (referred to as work ability) has been studied in high demand jobs (such as fire fighters and ambulance workers). Work ability has been described in the literature as a process that changes with age, although there is evidence of substantial inter-individual variability. The literature also suggests there is an association between age, performance and shift work, although more work is needed in this area to identify the outcome in terms of accidents and injuries. There is evidence from the offshore industry that prolonged exposure to shift work is believed to increase the risk of gradual reduction in physical performance capacity. Whilst no studies have directly examined the combined effects of shift work and age on safety, older workers have been suggested to be at greater risk of injuries and accidents on night shifts.

Jobs in the aviation sector, such as air traffic control and pilots require high levels of memory, cognitive processing speed and ability to multitask / timeshare (ability to complete dual tasks as efficiently as single tasks). Whilst each of these have been found to deteriorate with age, evidence suggests that job experience, and domain specific expertise, can mitigate any age related decreases in performance. The job of a pilot is highly automated, creating opportunities for human error. Evidence in the literature indicates that it is when the task is not domain relevant (i.e. the expertise to perform it has been acquired in a specific environment, and then the environment is changed) that expertise may not be sufficient to moderate the effect of age on performance (i.e. performance may decrease).

Studies from the construction sector conclude that the increase in falls in older workers may be related to loss of control of postural stability, reduced strength and decline in balance as workers age. Jobs in the transportation sector have been found to require a range of skills and abilities, and the relationship between age and driving behaviour has been described as complex. Although age, in itself, has not been found to predict driving performance, a significant relationship has been found between perceptual and cognitive abilities and driving performance. Research with fire fighters has demonstrated that work conditions become harder to bear with increasing age, and that work is distributed to take account of this (with older workers having less exposure to certain critical tasks). This may explain the decrease in incidents of accidents in older fire fighters. Whilst most indicators of work ability in fire fighters are related to age, huge inter-individual variation in task performance has been found in this group of workers. Studies of the mining sector highlight the importance of the interaction between the worker and their physical environment, and how new technology can change the mental workload involved in a job. Evidence from this sector, as with the fire service, indicates that there may be age related inequalities in exposure to risk at work, as well as age related experience (compensatory skills) serving to mitigate any decrease in performance as individuals age. Studies in the nuclear sector have investigated the relationship between age and accidents, and concluded that older workers appear to have strategies to compensate for any reductions in their capability. The working environment in the oil and petroleum industry can put specific demands on the worker, such as stress, temperature, noise, chemicals, shift work and poor ergonomic conditions. However, mandatory health licensing offshore has been found to result in a marked 'healthy worker' selection effect, indicating that older workers are moved away from jobs where the demands exceed their capability.

Age related changes that result in decreased performance at work

The literature review identified a range of abilities that decrease with age, including physical, cognitive, perceptual and psychomotor abilities. However, findings relating to an association between age related changes, and decreases in performance, are influenced by the design of the research studies. Designs include different performance measures and samples of workers (samples which may not fully reflect the demographic composition of the workforce). Another factor influencing the findings is that many tests of performance have been carried out in simulated laboratory conditions, which do not fully represent the real world environment in which workers are required to perform.

Based on the evidence, it can be concluded that age related declines do not necessarily have a negative impact on performance at work. This is particularly so when abilities are matched to job requirements and expertise is taken into account. Strategies, skills and experience can also be utilised in order to compensate for declines in human functioning. However, it is difficult to determine the true impact of age related changes on performance at work, and the conclusions that can be drawn about age related change resulting in a decrease in performance, are limited. The findings from studies of age and performance may not be a true reflection of reality in terms of changes in performance.

Decreases in performance that are safety critical

Whilst evidence from the literature highlights how difficult it is to identify the reality in terms of the impact of age related changes on performance at work, it is even more challenging to draw conclusions regarding decreases in performance being safety critical, particularly as the literature does not use the term ‘safety critical’.

In theory, a decrease in performance in physical, cognitive or emotional ability could result in safety critical outcomes. However, in practice, evidence indicates that healthy worker and safe worker effects (where workers choose to leave jobs or are excluded due to health screening) guard against safety critical outcomes. Individuals are also able to compensate for decreases in performance using their skills, experience and expertise. Adaptations to the workplace are also effective in compensating for any decreases in performance.

Ability to meet the physical, mental and social demands of a job (work ability) is influenced by individual resources, working conditions and the surrounding society. Work ability is likely to decline more steeply in jobs with a high physical workload or lower job control. However, there is a scarcity of specific details about work ability in high demand jobs.

Evidence from the review indicates that in order for any decreases in performance to become safety critical, a number of conditions would be present, such as a high demand job, no healthy worker/safe worker selection effects, lack of expertise/experience and no workplace adaptations.

Jobs where a decrease in performance could result in major accident or injury.

Specific jobs that are mentioned in the literature, which could result in major accident or injury due to a decrease in performance, are pilots and air traffic controllers. However, the evidence from the literature review indicates that rather than focusing on specific job titles, it may be more helpful to explore the specific tasks within a job, and the way in which work is organised in order to determine whether a job has safety critical implications. This is suggested as certain jobs (such as fire fighters) involve a range of tasks, and the task a worker performs may depend upon the environment in which they are working, or the way in which work is organised (i.e. each job is context dependent). Shift work would be an example of context.

Process jobs involve turning valves, which if not positioned correctly ergonomically, could result in a worker, who has decreased physical performance, being unable to turn them. These jobs might also include tasks involving resolving visual information on displays. As age has been associated with decreases in visual performance and processing speed, it might be concluded that tasks in certain process industry jobs could potentially result in major incident, for example in ‘upset conditions’ (outside of ordinary operating conditions).

Where jobs in the petroleum industry have been studied there is evidence to suggest that speed of decision making could cause problems in ‘upset conditions’. Decision making speed is something that has been identified as declining with age, and is something that has been suggested to be particularly relevant in unfamiliar conditions.

Based on the evidence, it could be concluded that it is jobs where individuals may find themselves in upset conditions, and/or unfamiliar environments, that may result in a decrease in performance, and potentially lead to safety critical outcomes. This may be particularly so in situations where there is a high demand on the individual, they are unable to use experience or expertise in the situation, and decision-making speed has declined.

Tools that are available for dutyholders to use in order to assess decrements in human function, capabilities and performance and why they have been developed.

A total of 35 tools were identified that may be used by dutyholders to assist them in assessing decrements in human function, capabilities and performance. These tools were classified into 16 'standard' measures (as they represent the types of physical and cognitive measures used in the context of employee recruitment and monitoring) and 19 'non-standard' measures which include specific measures of work ability, worker well-being and stress, and tools that have been designed with particular populations in mind (e.g. miners, nurses, rail workers).

There is a large variation in the tools/tests that have been identified in terms of the reasons for their development (e.g. to assess risk, to screen individuals, to assess or evaluate cognitive demand, test working memory, measure processing speed, examine physical fitness/ability etc). There is also variability in how feasible it would be for them to be used by a dutyholder, as some require administration by a health professional and others are designed for self-completion. The tools measure a range of constructs and capacities (e.g. injury, job retention, well-being, work functioning, sleepiness, workload, cognitive function, intelligence etc). They vary in the context in which they are used (e.g. for specific jobs such as nurses, miners and drivers), and also in the extent of their use. The Work Ability Index (WAI)[1] was identified as a tool that has had extensive use across many occupational groups and in several countries, and this is currently undergoing further development (as the Work Ability Survey - Revised)[2].

Determining the extent to which these tools are useful for dutyholders would require further evaluation.

Consideration of what the findings mean in terms of the need for future work.

Evidence in the literature recommends that further research is required on the performance of older workers. It is suggested in the literature that, for some occupations, there is a need to establish minimum standards for work ability capacity e.g. fire fighters. A move towards thinking about age in terms of 'diversity in work ability' as opposed to a chronological age cut off is also advocated in the literature.

Evidence suggests that there is a need for more longitudinal studies of age related changes in performance (following the same individuals). This would enable a better understanding of how factors, such as processing speed, change over time. This is in line with the recommendation in the literature, that further work is required in order to develop a better understanding of the variables that mediate the relationship between age and performance. However, this work would necessitate a long-term research project, which would be both time consuming and costly. Before a decision about this could be made, the costs and benefits associated with longitudinal studies should be identified and considered. As there is a scarcity of information in the literature regarding the performance of workers in high demand jobs, and evidence indicates a need to explore the extent to which safe worker and healthy worker effects guard against safety critical outcomes, the literature suggests that further research is also required in these areas.

Before a decision can be made regarding whether development of a tool is an appropriate way forwards, further evidence would need to be collected. Future research in relation to tools might involve collecting any evidence relating to existing evaluation of the tools and, based on the

[1] *See http://taen.org.uk/uploads/resources/Briefing_on_Work_Ability_web.pdf*
[2] *See http://owwac.com.au/files/slides/1105_B_D1_Taylor.pdf*

outcome from this, considering further evaluation of some tools, such as the Work Ability Index (as evidence suggests this is the most widely used) and/or investigation of associated measures that are currently being developed (e.g. Work Ability Survey-Revised).

Evidence from the literature review has provided a number of criteria against which tools could be assessed. For example, the findings suggest that any tool to assess human performance needs to include a measure that identifies whether the conditions and environment in which the individual is working are familiar to them (i.e. are domain specific) or whether they are new and novel (in the latter case, this would point to potential for a safety critical situation to occur). Other factors that tools could be assessed against (although this list is not intended to be exhaustive) include the extent to which they incorporate an assessment of:

Emotional demands;
Expertise;
Experience;
Fatigue;
Occupation;
Mental / cognitive demands;
Physical demands (strength, muscle effort, lifting etc);
Task demands;
Time on task / task duration;
Work related psychological complaints;
Work organisation (shift work, role conflicts, control, fear of failure, lack of recognition);
Work situation / environment (stressful situations, temperature, new technology).

Whilst there are some sectors that already have assessments of human function and performance (e.g. the aviation and fire sectors, mining, driving), there is variation in the type of assessment being used and also gaps in terms of which sectors are covered. Based on this evidence, it is suggested that future work could include speaking to dutyholders and industry representatives in order to identify what they are doing to address human function and performance.

The scope of this work did not cover exploring how standard risk assessments might be used by dutyholders to assess human function and performance. However, some of the tools that were identified were developed to assess risk. These included assessing risk of fatigue, of stress, of risks specifically associated with driving such as fatigue, distraction and pressure, and management of employee risk through the full employment cycle (including using demographics, environmental and medical information to assess risk as part of the 2cRisk tool[3]). Based on this evidence, a potential avenue for future work might be to evaluate how this group of tools could be used to assess whether performance is safety critical, and possibly also to extend this to look at how other types of standard risk assessment processes might be used.

Conclusions and key messages

Whilst the literature covers a wide range of human function and performance that can deteriorate with an increase in age, limited conclusions can be drawn regarding age related changes, decreases in performance and their impact at work. This is due to the differences in study designs used in the research on age and performance, and also the age related inequality in exposure to risk at work (due to the influence of healthy worker and safe worker effects).

Evidence from this review suggests that the introduction of any special measures (or tools) to address workers performance may only be required if the job poses specific demands (i.e.

[3] *See http://www.2cRisk.com.au/solutionoverview.php*

specific mental, physical or psychosocial task characteristics). Where the specific demands of a job are not preventable (e.g. with ergonomic measures) and the demands may exceed exposure safety levels of average human capacities to meet the demands required of the job, then more knowledge is needed in order to develop solutions to keeping workers safe and healthy (both themselves and others).

It would be a mistake to assume that the relationship between age and performance is simple and straightforward. Hence, it can be concluded that developing a tool, for dutyholders to use, that can generically (across multiple sectors and different jobs) assess decrements in human function, capabilities and performance, is a challenging task. It is a task that should only be undertaken once further work has been carried out. However, following further work, development of a tool (or refinement of existing tools) is something that HSE may wish to consider.

The key messages from this work are reported in Section 5.

1 INTRODUCTION

From the first of October 2011, there will no longer be a default retirement age (DRA) of 65. The Employment Equality (Repeal of Retirement Age) Regulations 2011 came in to effect on 6th April 2011. These regulations will have an impact on the age profile of the British workforce, as workers may now theoretically carry on working for as long as they wish.

The removal of a compulsory retirement age may have implications for health and safety at work, and as such is a cross-cutting issue for HSE. HSE is concerned that some workers may continue to perform tasks with deteriorating performance. This may be a particular issue in safety critical and major hazard industries, and could potentially lead to an increase in the risk of major incidents or injury.

HSE believe that it could be difficult for dutyholders to judge whether workers still have the functional capacity to work to the required level of safe performance. This study is intended to consider sources of appropriate advice and/or tools which will enable dutyholders to assess the function and performance of their workers.

At present there is no data on the health and safety implications of a post 65 year old workforce. As a starting point in beginning to address these questions, HSE have comissioned HSL to undertake an initial study. This will collect evidence to fill one gap in knowledge, and will enable HSE to scope out future studies that need to be carried out relating to the health and safety implications of an ageing workforce.

In this initial study, HSE have asked HSL to draw together what is already known about age-related decreases in performance in safety critical work. and identify what tools already exist (or are being developed) to assist duty holders to assess human function and performance. This will include identifying why the tools have been developed.

1.1 RESEARCH AIMS AND QUESTIONS

The aims are:

1. To identify tools that exist (or are being developed) to assist dutyholders to assess human function and performance (and identify why they have been developed).

2. To carry out a literature review in order to assess existing evidence on age related changes in performance and safety critical work.

3. To critically consider what the findings mean in terms of the need for future work (e.g. producing advice or tools for dutyholders).

The research will answer the following five questions:

1. What tools are available for dutyholders to use in order to assess decrements in human function, capabilities and performance? Why have these tools been developed?

2. Which age related changes result in decreased performance at work?

3. Which decreases in performance are safety critical? (i.e. could result in major accidents or injury, beyond the individual worker)?

4. In which jobs could a decrease in performance result in major accident or injury (beyond the individual worker)?

5. What future work may need to be carried out based on the findings from the systematic literature review and the range of existing assessment tools that have been identified?

2 METHOD

The research was divided into two parts. Part one identifed a sampe of the tools that currently exist (or are being developed) to assist dutyholders to assess human function and performance (and identify why they have been developed). Part two was a literature review to identify what is currently known about age related performance in safety critical jobs.

2.1 IDENTIFICATION OF TOOLS

In order to identify relevant tools, both existing and those under development, a flexible search strategy was used. This involved searching scientific journals, key web sites, contacting key individuals by email or phone, in a way that may identify one avenue of enquiry from another, and obtain a lead about a potentially relevant tool from any available source.

2.1.1 Contact with Key Organisations/People and Website searches

Individuals within the following organisations were contacted by phone/email/in person:

- HSL Human Sciences Unit
- Health and Safety Executive, UK
- The Age and Employment Network
- Institute of Occupational Medicine
- Royal National Institute for the Blind
- National Institute for Occupational Safety and Health
- British Occupational Health Research Foundation
- Chartered Institute of Personnel and Development
- Institute of Employment Studies
- Royal Society for the Prevention of Accidents
- Transport Research Laboratory
- Employers Forum on Age
- Loughborough University, 'Working Late' Programme of Research
- Monash University, Australia
- University of Strathclyde, Employability Centre for Lifelong Learning within the School of Education
- Human Factors/Ergonomics related consultancies (e.g. David Hitchcock Ltd., Optimal Performance Ltd.)
- Glasgow Caledonian University, Institute of Applied Health Research, 'Later Life' Research Group
- Institute of Naval Medicine
- Ministry of Defence
- Work Safe Australia
- University of Amsterdam, Coronel Institute of Occupational Health.

Searches were conducted on websites from all the above organisations. Searches were also conducted on websites relating to the following: ESF Age Network, National Health Service, UK; Medical Research Council; Health and Safety Canada, Department of Work and Pensions, UK; Occupational Safety and Health Europe, Ageing at Work, European Research Area in Ageing, Rail Safety and Standards Board; FireService UK.

2.1.2 Scientific Journal and Database Search

The following scientific journals and databases were searched via the HSE Information Centre:

- Web of Science
- Medline
- PsycInfo
- Embase
- Google Scholar
- Ergonomics
- Work and Stress
- Applied Ergonomics
- Ergonomics in Design
- International Journal of Injury control and safety promotion
- Human Factors
- International Journal of Industrial Ergonomics
- Human Factors in Manufacturing Systems

The following search terms were used in conjunction with the terms **age or ageing or older workers or old age:** work ability; testing/test and decline; testing/test and deterioration; evaluation and ability; assessment tools; ability and tools; capacity and tools; assessment tools and ability; assessment tools and capacity; ability and measurement; ability and assessment; capacity and measurement; capacity and assessment; function and assessment; function and measurement; performance and assessment; performance and measurement.

The search terms 'work' and 'change'; 'work'; 'change'; 'work' and 'safety'; 'safety' were also included with all the above terms.

2.2 LITERATURE SEARCH

The original aim was to undertake a rapid evidence assessment (REA). However, this approach was adapted in light of emerging findings and discussions with HSE.

A systematic and explicit method was used in order to identify, and select the literature. Search terms and selection criteria (inclusion and exclusion criteria) were developed in collaboration with the HSE customer. Appraisal of the quality of the papers was deemed to be less important than how relevant the information they contained would be in helping to answer HSE's research questions. Hence, no quality rating was undertaken.

Literature was identified via a series of searches undertaken by the HSE search team, and was carried out on terms (a specific list of key words), using an AND/OR search method. The key words used to identify literature on age and performance, along with those to capture safety critical work are included in Appendix 1, along with a list of the electronic databases that were searched, and the number of results that were obtained.

2.2.1 Selection of studies

The review focused on scientific literature that was published in peer reviewed journals, reported in the English language only. No time limitation was imposed on the literature, as initial search results found few recent papers that were of relevance.

In order to be included in the systematic review, a paper had to meet the following criteria:

- Relate to research in a sector identified as 'safety critical' as discussed and agreed with HSE. These included the following sectors:

  - Ambulance service;
  - Aviation;
  - Construction;
  - Driving;
  - Fire;
  - Mining;
  - Nuclear;
  - Offshore;
  - Oil and Petroleum;
  - Police;
- Specify a decrease in performance due to age;
- Include findings that refer to the decrease in performance being safety critical (i.e. resulting in major accident or injury beyond the individual worker).

The initial search results, consisting of a list of paper titles and abstracts, were screened against the inclusion / exclusion criteria. In order to ensure this selection was valid, a second reviewer screened a random sample of the papers. A list of potential papers to include in the review was then developed and discussed with HSE.

Following discussion with HSE, it was agreed to modify the criteria in order to extend the number of papers included in the review, as the majority did not explicitly specify a decrease in performance as being 'safety critical'. Hence, if a paper focused on age and performance, and referred to a sector that was considered to be safety critical, it was included in the review.

Additional papers were also included in the review if they were identified as being helpful in providing context, the most up to date information on age and performance at work, and in answering the research questions.

2.2.2 Data extraction and appraisal of the quality of the literature

A data extraction tool was developed in order to facilitate the systematic management of the data from the selected papers. Data that was extracted from the studies is listed in Appendix 2. Full data extraction was undertaken for the 27 papers identified in the initial selection.

Aviation papers were treated separately according to whether they were studies of flying performance in pilots (which is a part of the sector not within HSE's remit) or whether they related to the part of the Aviation sector which is on the ground, such as air traffic control.

Data was extracted from eleven aviation sector papers that studied pilots. An overview of them has been included as part of this review, as they add value to this current piece of work. Findings from studies of pilots are useful in informing future work on performance in safety critical sectors. The job of a pilot is one that is highly automated and involves high cognitive demands. Hence, insights obtained from studies of pilots can provide helpful information on safety critical performance and age in other sectors that have similar demands.

This current review defines performance in terms of three key aspects, operational performance (e.g. communication of tasks), operational errors or accidents and cognitive ability.

3 RESULTS

3.1 WHAT TOOLS ARE AVAILABLE FOR DUTYHOLDERS TO USE IN ORDER TO ASSESS DECREMENTS IN HUMAN FUNCTION, CAPABILITIES AND PERFORMANCE? WHY HAVE THESE TOOLS BEEN DEVELOPED?

Using the search strategy (outlined in Section 2.1), a total of 35 tools or tests were identified which may assist dutyholders to assess decrements in human function, capabilities and performance. A total of 19 of these tools have been classified here as ‘non-standard’ measures (Appendix 3, Table 1). They were designed to measure work ability, worker well-being or stress, or, were designed with a particular population in mind (miners, drivers, rail workers, nurses, older workers, the general public, claimants of Employment and Support Allowance). The remaining 16 tests/scales represent a small sample of ‘standard’ psychometric or physical tests/scales that have been used in the context of employee recruitment, monitoring of personnel and age research on workers with safety critical tasks as part of their work (Appendix 3, Table 2).

There is a large variation in the tools/tests that have been identified. The tools/tests vary in terms of the reasons for their development, their feasability of use for the dutyholder, the constructs/capacities they measure, the extent of intervention they require by a health professional, the context in which they are used, and the extent of their use.

The inclusion of tools in this report does not imply any endorsement of their use on the part of the Health and Safety Laboratory.

3.1.1 Tools that have been developed that may help the dutyholder to assess decrements in human function and performance

3.1.1.1 Non-standard measures

Table 1 (Appendix 3) lists measures that may assist the dutyholder to assess decrements in human function and performance. There are numerous reasons for the development of these measures, which include:

(i) Promoting and maintaining the ability of older employees (Work Ability Index; Tuomi *et al*., 1998);

(ii) Providing information and support regarding worker well-being or stress (Workplace Well-being Tool, Department of Work and Pensions, 2011a; HSE’s Management Standards for Work-related Stress, Mellor *et al.*, 2011);

(iii) Helping disabled or disadvantaged people enter the labour market (Ability Match, Haines *et al*., 2003);

(iv) Assessing claimants of Employment and Support Allowance (The Work Capability Assessment, Department of Work and Pensions, 2011b);

(v) Screening for diminished capabilities in driving (Automated Psychophysical Test; McKnight and McKnight, 1994);

(vi) Risk assessment of all workers (2cRisk; 2cRisk, 2011) or fleet drivers (Driver Profiler 20:20; Royal Society for the Prevention of Accidents, 2011);

(vii) To give specific populations (miners, office workers, nurses, health workers, rail workers, the elderly public) the means to identify various health related conditions and interventions. These include:

a. Eyes Right (Royal National Institute for the Blind, 2011);

b. Age Awareness Training for Miners (National Institute for Occupational Safety and Health, 2008);

c. Work Instability Scale for Rheumatoid Arthritis (Carew, 2010);

d. Office Work Screen for Office based workers (Gilworth *et al.*, 2008);

e. Nurse Work Instability Scale for nurses (Gilworth *et al*., 2007);

f. Nurses Work Functioning Questionnaire (Gartner *et al*., 2011);

g. Australia's Health Assessment for rail workers (National Transport Commission, 2011);

h. Fatigue and Risk Index (Qinetiq, 2006);

i. National Health Service's Screening and Testing timeline (National Health Service, 2011);

j. Train driver mental workload assessment (Rail Safety and Standards Board, 2004).

The tool that has received significant use across a large variety of occupational groups and in numerous countries is the Work Ability Index (WAI). The WAI is an instrument originally developed in the 1980's by the Finnish Institute of Occupational Health (Tuomi *et al*., 1998). According to Finnish researchers Ilmarinen and Tuomi (2004), work ability is defined as "*how good is the worker at present, in the near future, and how able is he/she to do his/her work with respect to the work demands, health and mental resources*". Thus, the work ability of employees is the inter-relationship between the work capacity of the worker and the work he or she does (TAEN, 2008). The index is determined on the basis of answers to a series of questions which take acccount of the demands of work, the worker's health and mental resources (See Table 1, Appendix 3 for further information on the seven items tested in the WAI). The worker completes the questionnaire before an interview with an occupational health professional who rates the responses according to a set of instructions.

An interactive online resource is available to the general public on the website of the National Health Service (NHS). The NHS host a range of online tools which are aimed at providing health information and enabling self-assessments relating to their own health and well-being (e.g. well-being self-assessment, fitness self-assessment, BMI healthy weight calculator, back pain guide). This includes an interactive 'Screening and Testing timeline' with a guide to screening and tests recommended during various life stages, classified under '0-16 years', '17-29 years, '30-64 years' and '65+ years'. Information in the '65 years +' category includes guidance and support regarding diabetic retinopathy, blood pressure, height and weight, lungs and airways, cholestorol, heart disease, osteoporosis and glaucoma (National Health Service, 2011).
There are also numerous tools available for companies to monitor sickness absence in the workplace that may be relevant to this work (Institute of Occupational Medicine, 2006).

3.1.1.2 Standard Psychometric Tests/Scales

For many occupations, applicants must pass a series of physical/cognitive/medical tests. The 16 tests/scales listed in Appendix 3 (Table 2) represent a very small sample of 'standard' cognitive and physical measures that have been used in the context of employee recruitment, age research related to pilots/firefighters and monitoring of personnel throughout their working lives.

This sample of tests/scales were originally developed for numerous reasons. These include measures of: daytime sleepiness (i.e. Epworth Sleepiness Scale; Johns, 1991); the physical fitness of firefighters (i.e. European Fitness to Dive Standards; EDTC, 2003); operator workload (i.e. Multi-Attribute Task Battery; Comstock and Arnegard, 1992; The National Aeronautics and Space Administration Task Load Index; Hart and Stavenland, 1988); working memory (Sentence span test; Morrow *et al.*, 2003 Sternberg Memory Search Task; Sternberg, 1975); processing speed (Letter comparison and pattern comparison tasks; Morrow *et al*., 2003); perceptual organisation (Weschsler Adult Intelligence Scale Block Design test; Weschsler, 1981), the processing required for mental rotation (Planikin rotation task; Tsang and Voss, 1996); musculoskeletal problems (The Nordic Musculoskeletal questionnaire; Kuorinka *et al.*, 1987); motor skills (Finger Tapping Test); visual search (Bourdon-type letter cancellation test); field of view (Useful Field of View Assessment; Ball and Owlsley, 1993) and fitness to perform specific operations relevant to the Royal Air Force (Operational Fitness Test; Richmond *et al*., 2008).

Numerous other tests used in the context of employee recruitment and monitoring, which are not listed here, include cognitive tests of spatial awareness, numerical abilities, logical thinking and verbal reasoning, medical/physical tests including tests of visual acuity, colour vision, hearing, lung function and physical stamina.

Firefighters, train drivers and members of the Royal Air Force, for example, must pass 'fitness to work tests' at point of entry. At recruitment stage in the UK Fire Service, applicants are required to pass a series of tests including tests of vision, hearing, lung function and physical stamina. There are also 6 national firefighter physical tests which applicants must undertake as part of the selection process. These involve a ladder climb to test confidence of working at height, casualty evacution and ladder lift tests to assess upper and lower body strength, an enclosed space test to assess confidence and agility in enclosed spaces, equipment assembly to test manual dexterity and 'equipment carry' to assess aerobic fitness (Fireservice, 2011).

Several occupational groups undergo periodic testing throughout employment (e.g. pilots, train drivers). For example within the Royal Air Force, fitness testing is carried out at point of entry and annually during employment to ensure unacceptable risks of injury are managed (Richmond *et al.*, 2008). For train drivers in the UK, medical examinations are required prior to employment, every 5 years for staff aged up to 55 years, every 2 years for staff aged between 56 and 62 years (inclusive) and every year for staff aged 63 years and over (Rail Safety and Standards Board, 2008).

3.1.1.3 Tools in development

There are currently a number of tools that have been identified as being 'in development' for dutyholders to use in order to assess decrements in human function, capabilities and performance.

A programme of work at Loughborough University (Work Package 4 of the EPSRC – New Dynamics of Ageing "Working Late": Strategies) has an overall aim of enhancing productivity and health environments for the older workforce. This work in progress involves the design of a web-based tool entitled Organiser for Working Late (OWL). This tool is being developed due to recognition of the importance of the role of good design and ergonomics in encouraging healthy working. The intention is to design the tool to act as a resource to encourage and empower all workers to think about their bodies through the course of their working lives, and to consider any interventions that may help them to improve their own health and productivity/safety. This will be achieved by highlighting the benefits of healthy working, through better, more intelligent workplace design. The intention is to design the tool so that it could be used across all of industry. The tool will include short checklists, tool-box talks, video case studies giving workers useful ideas about changes they could make within their working environment (Gyi, 2011; Loughborough University, 2011).

Work is underway to move away from the original WAI and develop a new measure of work ability. According to Professor Phillip Taylor of Monash University in Australia, two factors have motivated the development of a new measure of work ability, namely the advancement of a holistic model of work ability by the Finnish Institute of Occupational Health and secondly, the limitations of the WAI (Taylor *et al.,* 2011). Poor discrimination among participants using the WAI was cited by Taylor *et al.* as one of the tool's limitations. The theoretical model of the new measure of work ability, entitled the Work Ability Survey Revised (WAS-R) has three components, work demands, organisational capacity and personal capacity. The work demands measure includes measures of physical demands, cognitive demands, role complexity and pace of work. Organisational capacity includes measures relating to training and workplace environment and personal capacity includes measures of physical health, psychological well-being, work/life balance, work schedule and job insecurity. The tool is currently being revised and refined.

A number of tests/tools are in the process of development at the Coronel Institute of Occupational Health at the University of Amsterdam (Sluiter, 2011). A combination of health and performance tests to assess work ability for specific high demand jobs (e.g. medical specialists, firefighters) and tests designed to monitor certain aspects of performance in construction workers are being designed.

3.2 LITERATURE REVIEW: OVERVIEW OF PAPERS AND CONTEXT

The search of the electronic databases resulted in approximately 300 citations. The sifting/ screening of these citations against the inclusion / exclusion criteria, and after removing duplicate records, resulted in 92 papers being considered for inclusion and discussion with the HSE customer. In collaboration with the HSE customer 27 papers were included in the review.

These papers covered a range of sectors and jobs (See Appendix 4 and 5). The sectors included aviation, chemical, construction, emergency services (fire), road transport (driving), mining, and oil and petroleum. The jobs within these included, air traffic controllers, drivers, fire fighters, miners, oil field workers, petroleum operatives and pilots. A range of performance measures were used in the studies, such as accidents, errors, cognitive processing speed, communication accuracy, decision making, learning speed, multi-tasking / time sharing ability, perceptual and psychomotor abilities, reaction times and work ability.

Literature on the aviation sector has been split into two parts. Studies that cover pilots and performance related to flying aircraft (i.e. performance whilst in the air) have been reported in Section 3.3. This is because this part of the sector is outside of HSE's inspection and enforcement remit. However, information from the papers has been included in this report because there is a large body of literature on age and performance in pilots, which provides useful insights into age, decreases in performance and safety critical outcomes, which could inform other sectors that are within HSE's remit.

Sixteen additional papers have been included in the review (Appendix 6). Thirteen relevant papers were identified when the search results were revisited. In addition to these, two further papers were identified from HSL knowledge of recent work undertaken with respect to age and the workplace (Williams, Bell and Daniels, 2007 and Yeomans, 2010), and one construction ‘information paper’ was sourced from contacts within HSE (Leavis, Gibb and Bust, 2008).

A number of these additional papers were sector specific. Two studies investigating age and performance in the construction industry, addressed injuries and fatalities (Choi, 2009) and the effect of muscle fatigue on performance (Mahta and Agnew 2008). Two studies that have addressed age and injury in the nuclear industry are Ringenbach and Jacobs, (1995) and Findley and Bennett, (2002). The transportation sector (defined as air, rail, highways and maritime operations) was the subject of a paper by Popkin, Morrow, Domenico and Howarth (2008), with airport apron controllers being studied by Muller, Petru and Angerer (2011).

There were also a number of additional non-sector specific papers. These included studies of age and shift work (Duffy, 2003; Folkard, 2008; Bohle, Pitts and Quinlain, 2010) and studies covering work ability (Kloimuller, Karazman and Geissler, 2000, Silverstein, 2008, Bohle, Pitts and Quinlain, 2010). In addition, Charness (2008) reviewed the content of a Human Factors publication and identified the major theoretical and practical contributions that have been made to ageing and human performance. He found that those articles that were cited the most, deal primarily with age and driving.

It is important to be aware that the definition of age and ‘older worker’, along with the categories of age groups used within studies, varies greatly. Definitions of age were discussed by Ng and Feldman (2008). They noted that whilst age is most often defined in terms of chronological age, it could also be defined as the employee’s subjective age (individual’s self-perception of age), the employee’s social age (others’ perception of the employee’s age) and the employee’s relative age (the degree to which the individual is older than others in the work group). Hence, to some extent, what ‘old’ means depends on the demographic profiles of an organisation or an occupation. Another definition of ‘older worker’ often used in the literature is any one aged 40 or above (in line with the United States age discrimination in employment act 1967). If the age of the workforce is taken to be between 16 and 65, 40 would seem to be an acceptable cut of point at which to distinguish between younger and older workers. Overall it could be concluded that the term ‘older worker’ is ill defined (Bohle, Pitts and Quinlain, 2010) and studies use a variety of ages within this definition. However the World Health Organisation (WHO) defines workers aged 55 and over as ‘older workers’.

This current review extends the depth of focus of some parts of Yeomans’ (2010) review of the ageing literature, in that it concentrates on age and performance in safety critical sectors / high demand jobs (as opposed to the workplace more generally). However, it has found some themes in common with the Yeomans’ review, such as shift work, driving, accidents, cognitive performance and specific aspects of performance such as visual acuity and attention. The key points from the Yeomans’ review are included here as they provide important context within which to begin to present and discuss age, performance and safety critical work.

3.2.1 Yeomans (2010) An update on the literature on age and employment

Yeomans (2010) carried out a wide-ranging review of age and work, which looked at the evidence for age-related effects on employment. This encompassed findings from Silverstein’s (2008) review of the literature on ageing and work, which covered physical and cognitive decline, safety performance and work ability. Yeomans concluded that there is little evidence that chronological age is a strong determinant of health, cognitive or physical abilities, sickness absence, work related injuries or productivity. In addition, where there is evidence of age related declines, these do not generally have an adverse affect on performance. When abilities are matched to job requirements, and expertise is taken in to account, little difference has been found between the performance of older and younger workers. Where mixed results between age and performance have been found, this may be due to differences in the nature of the job (e.g. shift work was found to have a negative effect on work ability, particularly for women), and the measures of performance that have been used (e.g. output indices, performance ratings, accuracy rates, etc). Two other explanations for why associations between age and performance have not been found are suggested. Firstly, most jobs do not require individuals to work at full capacity, and strategies, skills and experience can be utilised in order to compensate for declines in human functioning. Secondly, there are large variations between the functional capacities of individuals who have the same chronological age (i.e. inter-individual variations). Another explanation may relate to the 'healthy worker effect', where those who are unable to do the work leave, retire or transfer to lighter duties (select their work to match their capability as they age), meaning that studies contain unrepresentative samples of workers and hence may underestimate the effect of age on work.

Whilst there is evidence that cognitive performance does not generally decline until after the age of 70, Yeomans (2010) found laboratory studies that indicate some specific cognitive abilities do decline with age. These cognitive abilities include working memory, reasoning, attention and processing speed. However, the limitations of laboratory tests should be noted. For example, they are artificial, may lead to high anxiety and low motivation and hence, diminished performance of physical and cognitive capacity.

Yeomans found that working memory deficits were more pronounced when individuals were required to process new or complex information, or when faced with unfamiliar contexts. Attention and perception are more likely to decline in circumstances where attention is divided. Older workers have also been found to have more difficulties than younger ones when working under severe time constraints and pressures. Fluid cognitive ability, such as abstract problem solving, are those that rely on processing speed, spatial functions and connecting new pieces of information together. These have been found to deteriorate with increasing age, from around the age of 20 onwards. In contrast, crystallised abilities that are automatic, knowledge based, and demand little effort have been found to increase with age and experience (Silverstein, 2008). Having said this, it should be noted that performance of tasks might not be affected by declines in cognitive ability, due to individuals' abilities to compensate with their experience, education, high motivation, better judgement and job knowledge. For example, an individual could reduce the cognitive demands required for novel problem solving via using their experience and knowledge.

In instances where experience and expertise do not play a major part in work tasks, and a job places high demands on the worker, Yeomans (2010) points out that some evidence has been found for performance deteriorating with an increase in age. For example, performance has been shown to decrease more quickly in jobs with high physical workload and lower job control (e.g. Costa and Sartori, 2007). Hence, performance might be expected to diminish with age, only in those jobs where capacities decrease with age, and experience provides little advantage. However, the relationship between performance and age is expected to be positive in areas where capacities are maintained with age and experience enhances performance (Silverstein, 2008).

In terms of physical strength and endurance, there is also little evidence that any declines in these will adversely affect performance. This may be because few jobs demand long periods of high aerobic and muscular strength. As with cognitive abilities, physical capacity varies greatly between individuals. Working environments and the way in which work is organised can be adapted to compensate for any physical decline. They can also be adjusted to compensate for declines in visual and auditory acuity, which evidence clearly demonstrates do deteriorate with age.

Yeomans (2010) also concluded that older workers can adapt to change and are quite capable of learning and performing new skills. Whilst speed of learning does tend to slow with age, this can be overcome with additional time, tailored support, training and education. She found little conclusive evidence that there is any increased risk of occupational accidents in older workers than in younger workers, and suggests that occupation is the key factor contributing to risk of workplace injury. Any inconsistencies in the relationship between age and accidents are suggested to be due to differences in industry, type of job, job tenure and a healthy worker effect.

Silverstein (2008) suggests that laboratory based studies may find physical and cognitive declines, that are not replicated in real work situations, possibly because people are able to select work to match their capabilities as they age. Individual differences are a key factor that researchers use in explaining inconsistencies in age and performance studies (Silverstein 2008). For example, studies of fire fighters have found more than six fold differences in performance both between and within age groups (Sluiter, 2006). Ng and Feldman (2008) carried out a meta-analysis and looked at 10 dimensions of job performance in 380 empirical studies of age and performance. They found that age was largely unrelated to performance. It was only minimally related to core task performance, and slightly negatively related to performance in training.

Yeomans (2010) reported that whilst driving ability has been found to reduce with age, the variation in findings from driving studies, indicate that the relationship between age, cognitive declines and driving tasks is not straightforward. Driving is a complex task that involves several cognitive demands, such as quick responses and processing of visual cues. It can involve high traffic situations, unfamiliar routes or working in poor conditions. She notes that driving has been the focus of a number of studies, and ability to drive has been found to decline due to factors such as distraction. Whilst a significant association between reaction time and age was found for drivers performing a mental calculation in a simulator, the same study found large individual differences in reaction time in the older (61-64) age group (Makishita and Matsunaga, 2008). Age has been significantly related to deteriorations in speed and accuracy in performing complex tasks, with drivers aged 65 or older having slower response times when compared to those under 50 (Popkin *et al*., 2008). However, other studies have found no age related performance deficits in performing cognitive tests whilst driving (Horrey *et al*., 2009).

3.2.2 Context, background and findings from the sectors

This section begins with finding from papers that are not sector specific, but which focus on high demand jobs in general, on work ability and shift work. It is then sub-divided according to sectors / specific jobs, starting with air traffic control and ending with oil and petroleum.

3.2.2.1 High demand jobs, work ability and shift work

3.2.2.1.1 High demand jobs

Age and high demand jobs have been studied across a range of different sectors (Tobia, 2005; Costa & Satori 2007; Sluiter, 2006). High demand or high risk jobs are those that include ‘specific job demands’. Sluiter (2006) defines these as jobs that exceed exposure safety levels or average human capabilities to meet such demands, leading to an increased risk of work related health problems. She reports that these demands cannot be eliminated with ergonomic measures and can be classified in to physical, mental or psychosocial job characteristics. Work often involves a combination of these demands. Physical demands include: energetic (aerobic or anaerobic), and biomechanical (static and dynamic demands on the musculoskeletal system). Mental demands include: concentration, memory, decision making, and attention. Psychosocial demands include emotion, autonomy, time pressure, irregular working hours, and the appraisal of extreme environments. In Sluiter's opinion, high demand jobs involve potential public health implications because of the health risks that workers may impose upon others (e.g. colleagues and public) during the course of their work.

3.2.2.1.2 Work ability

Work ability (ability to meet the physical, mental and social demands of a job) is a dynamic process that changes throughout life, and is the result of an interaction between individual resources, working conditions and the surrounding society (e.g. Bohle, Pitts and Quinlain, 2010; Tobia, 2005; Costa & Satori, 2007). Silverstein (2008) refers to a conceptual model of work ability developed by Ilmarinen *et al*., (2001). The critical work ability factors include health status and physical impairment, the physical and cognitive demands of work, the psychosocial work environment, and the individual's general well being and supportive resources. Silverstein (2008) reported that scores on the work ability index have been found to predict self-report good health and physical condition after 5 years of follow up. Association between work ability scores and disability and sickness absence have also been found. Whilst an overall decrease in work ability has been found with age, there is substantial inter-individual variability in this decrease. Kloimuller *et al.*, (2000) found only a low correlation between work ability and age, although the correlation between stressors, stress symptoms and work ability was higher than expected. This paper refers to the 1993 and 1995 work of Ilmarinen, which distinguishes between three major classes of risk factors for the work ability of ageing workers.

1. Excessive high physical work demands (static muscle strength, high muscle effort, lifting and carrying, repetitive movements, bent and twisted work postures and other peak work loads).
2. Stressful or dangerous work environments/workplaces (dirty or wet work, risk of accidents, great heat or cold, quick changes of temperature).
3. Poor organisation of work (role conflicts, control, fear of failure, lack of recognition and esteem at work).

Bohle *et al*., (2010) refer to earlier work by Tuomi (2001) and list the key factors that predict work ability as:

1. Work demands and the physical environment, including negative factors (associated with reduced work ability) such as poor work postures and excessive mental workload, and positive factors (associated with improved work ability) such as use of knowledge.
2. Work organisation and the work community (the psychosocial work environment), including negative factors such as poor management and lack of autonomy, and a positive factor, utilisation of work experience.
3. Health and functional capacity, including negative factors such as obesity, and positive factors such as physical exercise outside work.
4. Maintenance of work-related skills, including a negative factor, job retraining and positive factors such as opportunities for development and influence at work.

Their review of the nature of occupational safety and health risks faced by older workers reports that, work ability has been found to be lower in those doing physical work than those doing mental work. Work demands and the work environment have been found to have the strongest influence on work ability scores. Whilst work ability is a promising construct, it has limitations in relation to its definition, measurement and the prediction of some outcomes (Bohle *et al*., 2010). The present form of the work ability index is believed to be prone to 'ceiling effects', with the scores of many respondents clustering in the high range, at least in some populations.

Despite its limitations, the work ability construct is believed to have potential for helping to find a better accommodation between older workers and their jobs.

Bohle *et al*., (2010) also point out that the relationship between occupational safety and health and age is a complex one. The extent of decline with age depends on many factors, and some cognitive processes can increase (rather than decrease) with age. It is only when the job demands are lower than overall work capacity can older workers compensate for reduced physical or mental capacity. Across all occupations, falls from height have been found to be more prominent in workers aged over 65, and more likely to result in fatality or fracture as people age.

Work ability (WA) has been found to remain quite constant and high over the years for Italian workers, in jobs with higher mental involvement and autonomy. It significantly decreased with a steeper trend the higher the physical workload and the lower the job control, for example in nurses and manual workers (Costa and Sartori, 2007). WA was found to differ dependent upon job field, and to be lower in those fields where more psycho-physical effort was required (Tobia, 2005). However, when all job fields were taken together, work ability decreased as age increased. It is suggested that ageing has a negative influence on perceptions of work ability, and that good self-esteem and psychosocial wellbeing can positively influence the development of work ability (Tobia, 2005).

Sluiter (2006) aimed to identify if the age of the worker is an important factor in explaining diversity in work ability in high demand jobs, and to present an overview of what is known about work ability and age in high demand jobs. These jobs included Fire fighters; Ambulance workers; Police officers; medical specialists; pilots / astronauts and submarine officers. She found that currently there is no information about the performance of older workers in high demand jobs. She suggests that assessment of single demands will probably not reveal enough relevant information about WA in high demand jobs, and that there will be a call for more integrated measures. She found that specific details about WA of ageing workers in high demand jobs are scarce. Existing studies have used various methods to address the issue such as task analysis for quantifying physical work demands, observations of psychological and physiological parameters, measures of psychosocial work demands and health complaints. Functional performance is the most critical predictor of future job performance, but it has not been applied extensively in job surveillance.

3.2.2.1.3 Shift work

In their review of the evidence on the nature of occupational safety and health risks faced by older workers, Bohle, Pitts and Quinlain (2010) refer to the negative impact of shift work, and note that the critical age for increasing intolerance to night work seems to be between 45 and 50. Shift workers have been found to have lower work ability than day workers, with this effect being most pronounced in older workers. Older workers have been suggested to be at greater risk of injuries and accidents on night shifts, although this has not been proven. Despite the fact that the negative impact of shift work has been recognised for some time researchers have only recently started to examine how the effects of working hours vary with age. The impact of working hours has not yet been disentangled from ageing, lifestyle and other aspects of work. Bohle et al., (2010) conclude that more focused longitudinal and comparative studies are needed to systematically evaluate the relationships between ageing, occupational safety and health, and aspects of work organisation.

A review undertaken by Folkard (2008) found that no studies have directly examined the combined effects of shift work and age on safety. He found that although occupational injuries are less frequent in older workers, they tend to be more serious. There is reasonable evidence that injury rates are higher at night, and some evidence to suggest that older workers may be less able to maintain both their performance over the course of a night shift, and to cope with longer spans of successive night shifts. It was concluded that older workers might be at greater risk of injury and accidents on a night shift. Hence, more studies are needed to investigate the combined effects of shift work and age on injury and accidents. In her review of shift work and ageing, Duffy (2003) reports that many studies of shift work have examined the impact of night and rotating shift work on older workers. It could be anticipated that older workers might cope better with shift work than younger ones, due to their greater experience. However, several studies have found the opposite. Night and rotating shift work can result in difficulty sleeping during the daytime, leading to sleepiness on the following night shift and an increased risk of accidents at work. These problems occur because the circadian timing system promotes wakefulness during the day (when night shift workers are asleep) and sleep during the night (when the workers are awake). The general problems that shift workers experience with sleepiness at night and difficulty sleeping during the day are typically worse in older workers because the reduced ability of older people to sleep at adverse biologic times.

In their study of WA and shift work, Costa and Sartori, (2007) found that shift workers in general showed a higher percentage of poor / moderate WA than day workers. Shift workers suffered more illness at all ages. Women were found to show a higher percentage of poor / moderate WA than men at all age groups except the youngest (both for shift and non-shift workers). Female shift workers showed a much earlier decrease in work ability than men, as compared to their day working colleagues. In male shift workers, the effect of work on WA appears to be relevant only in the oldest decade. WA was found to progressively decrease, as long as the number of illnesses increased. This has a higher influence than age, although there is a significant increase in the number of illnesses with increasing age.

3.2.2.2 Air traffic control and Apron control

Two studies investigated the job of air traffic control (Becker and Broach, 2003; Becker and Milke, 1998) and one investigated the job of apron controller (Muller, Petru and Angerer, 2011). The job of apron controller (determining the taxiways for aircraft entering the apron area until they reach their parking positions and vice versa) requires particularly high levels of memory and cognitive processing speed. Muller *et al*., (2011) found no relationship between age and attention performance, and a U-shaped relationship between subjective workload and age (workload declines until the age of 35-37 years and then gradually increases). They suggest that this relationship can be explained by the effects of experience, combined with age-related declines, and recommended that the job should be designed to reduce high demands.

The job of air traffic controller (ATC) is relatively complex, the ability to handle simultaneous visual and auditory input, or to return to a task after a break to complete another task, is critical to success, and is suggested to be the sort of cognitive function most affected by age. Multitasking is perceived to be an integral and important component of the ATC specialist job. The two most important forms of multitasking, according to controllers, involve the use of auditory and visual modes to gather information simultaneously or near simultaneously, and the continuation of job activities despite having to handle frequent interruptions (Becker & Milke, 1998). Domain specific expertise such as ability to predict future events can be seen as critical for the efficient transit of an airplane through simulated airspace (Becker and Broach, 2003).

In America there is a trend towards an ageing workforce of air traffic controllers, who may be more adversely affected by shift rotation or difficult shifts. There are also changes to the Air Traffic Control working environment. Automation changes to the ATC system include newer, faster computers and interfaces being installed in ATC facilities, along with implementation of software designed to act as a decision tool to aid the ATC specialist in traffic conflict resolution.

There will also be other changes in the ATC system, and it will be necessary to understand what effect these changes will have on the job performance of ATC specialists (Becker & Milke, 1998).

The top 20 worker requirements, out of a potential list of 67, were reported in a survey (Becker & Milke, 1998). These were initially rated in order of perceived job-relatedness, and then a smaller sample of air traffic controllers rated them in terms of which requirements they believed became more important with an increase in age. This survey was part of a worker requirements study designed to improve hiring and training procedures by the American Federal Aviation Authority. The study aimed to determine those requirements that experienced workers believed were critical for successful job performance. Many of those that were rated as most important in the main survey are referred to as 'executive functions' according to the authors (e.g. prioritisation, situational awareness, planning, execution, thinking ahead, reasoning and time sharing). The importance of executive function continued as a theme when the requirements were rated according to which was most important as air controllers became older (e.g. visualisation, problem solving, recall from interruption and both long and short-term memory). It is suggested that the increase in importance of executive function with age may represent a deficiency in executive processes (the older controller has to attend to them more and perhaps involve other cognitive domains), or it may be due to a compensatory response (use of executive processes to overcome deficiencies in other areas), or to the moderating effect of experience (the controller has learned that these processes are most critical for successful work performance).

There have been no clear demonstrations that older age necessarily leads to poorer job performance in air traffic controllers. Blanket statements regarding age and performance are probably unwarranted, and it would be a mistake to assume that the age / performance correlation is simple and straightforward. It is factors other than age (but those that may be correlated with age) that are suggested to affect performance. Amongst air traffic control specialists, it is cautiously predicted that domain relevant processes, and processing, are those that are less likely to be affected by age (Becker and Milke, 1998). Experience has been found to moderate the effects of age on the performance of job relevant tasks by affecting the efficiency with which certain operations can be performed (Becker and Broach, 2003). It is not clear whether competence is moderated by experience, or whether only expertise affects performance. Whilst having on the job experience in the ATC environment appears to moderate the effects of advancing age, this benefit cannot be maintained over the life span of a controller. As age and experience are highly correlated, it is difficult to disentangle the separate effects of these two factors on performance ratings (Becker and Milke, 1998).

3.2.2.3 Construction

Leaviss, Gibb and Bust (2008) undertook analysis of UK construction statistics and found that construction workers aged 60 or over are twice as likely as workers from any other age group to suffer a fatal accident at work. Falls and trips are reported to be the primary type of accident leading to injuries amongst older construction workers. Between 1996/7 and 2004/5, a dramatic rise in the proportion of fatalities caused by falls was found in the 65 and over age group. They report that it is unclear whether this is because the survival rate from falls is lower in this age group, or because this group of construction workers suffer more falls.

Some explanation for the falls in older workers is provided by Choi (2009) who describes injuries, illness and fatalities among older workers in the US construction industry. Despite proportionately lower injury and illness, older workers are reported to generally suffer more severe accidents and injuries than younger ones. Ladders are most often involved in falls among older construction workers, which research suggests may be due to a decline in balance and coordination amongst these workers. Choi's (2009) review concludes that an increased risk of falling may be related to loss of control of postural stability, and that reduced strength affects ability to recover balance or lost footing in attempt to avoid a fall. He suggests that research is needed to refine job skills and task requirements in relation to age, so that the best ways of minimising age-related injuries can be determined. The other study of age in the construction sector investigated the effects of muscle fatigue on performance of drilling tasks (Mahta and Agnew, 2008). Shoulder fatigue was found to significantly reduce task completion times for all age groups. Whilst older study participants did not show any changes in error rates due to fatigue, younger groups did have an increase in errors when fatigued.

3.2.2.4 Driving

The relationship between age and driving behaviour is complex. A number of factors, whilst not affecting ability to work, may affect an older person's ability to drive safely (NIOSH, 2005). These include:

- Fatigue
- Medication
- Diminished vision
- Slower reaction times
- Declines in cognitive functioning
- Decrease muscle strength and range of motion
- Arthritis
- Macular degeneration

Popkin, Morrow, Domenico and Howarth (2008) carried out a review of age in the transportation sector. They used a socio-technical systems approach in order to develop a better understanding of the impact of older workers on the transportation workforce. This approach recognises the workplace as a complex system (involving interactions between people and the tools and techniques they use). It is the demands and context of the external environment that are largely responsible for driving the interaction between the social and technical systems. They report that there are around 4 million transportation workers in the United States (e.g. air traffic controllers and long haul truck drivers). It is suggested that knowledge (expertise), along with a range of common skills and abilities are needed for 15 jobs within transportation such as air, rail, highways and maritime operations. The common skills include operation and control, speaking, active listening, coordination, operation monitoring, time management, critical thinking and judgement, and decision-making. The common abilities include: control precision, far vision, oral expression, oral comprehension, near vision, reaction time, selective attention, speech clarity, depth perception, problems sensitivity, spatial orientation and time sharing. This review refers to the Llaneras et al., (1998) study of truck driver performance. Older drivers performed worse on selective attention tasks and were found to have difficulty with depth perception. It also references the study of pilots undertaken by Tsang and Voss (1996), where experience reduced the effects of age related declines in performance.

Llaneras, Swezey, Brock; Rogers, and Van-Cott (1998) investigated 15 human abilities, the changes in these that occur with ageing, and the effect on truck driving performance. They suggest that there are four basic processes that are critical to many driving tasks. These are ability to see, recognise, decide and act. Deficits in these driving-related abilities may restrict or degrade performance. The perceptual ability most associated with driving is visual ability. This has 6 components (Static visual acuity, dynamic visual acuity, contrast sensitivity, useful field of view, field dependence and depth perception). Cognitive abilities that decrease with age include decision-making, selective attention, attention sharing and general information processing. These can limit driving ability if they degrade. Both perceptual and cognitive abilities tend to deteriorate with increasing age and show a relationship with driving performance (see Appendix 8). The influence of psycho-motor abilities on driving performance can be reduced by things like power steering, and automatic transmission. So they may not be as critical in influencing truck driving performance as other abilities such as decision making, perception and cognitive abilities. These psychomotor demands could be greater when driving trucks or buses. Those who drive commercially will not be able to choose when they drive (e.g. to avoid bad weather / the dark) so any deficits in abilities will be more problematic in commercial drivers. There has been little work done with commercial truck driver performance in the post 50 year old age group.

Age in itself was not found to be predictive of driving performance. There is a significant relationship between the 15 abilities and driving performance. All 6 perceptual abilities showed a negative correlation with age. Significant differences were found between the under 50 group and the 65 and over in static visual acuity, dynamic acuity, contrast sensitivity useful field of view (UFOV), field dependence and depth perception (the over 65s were significantly poorer). Whilst all 6 perceptual measures were found to significantly degrade by age 65, dynamic acuity and field dependence both degraded at age 55. Three cognitive abilities decreased with age. The exception was decision-making accuracy. However, decision making speed was negatively correlated with age.

The National Institute for Occupational Safety and Health, (2005) published a fact sheet, for use by employers and workers, to help prevent crashes. This incorporated a commentary and list of tips for employers and workers. Roadway crashes were reported to be the leading cause of occupational fatalities for older workers in the US, with deaths for work-related roadway crashes increasing steadily from around the age of 55. In contrast to this, in the general population, fatal crash involvement rates were found to decrease with age. Older drivers were more likely to have a crash at an intersection, particularly when turning across the line of traffic, and when merging or changing lanes on a freeway. The fact sheet states that the effect of many conditions on driving can be reduced or resolved with treatment for illness or other health problems. Ways of protecting older employees from death or disability due to roadway crashes are suggested to include forward thinking safety programmes, reasonable accommodations, and open lines of communication between employers and workers.

Janke (2001) evaluated non-driving tests (such as tests of visual acuity, recognition speed and reaction time) in order to select those that could be used to identify and assess drivers whose ability to drive safely is in question (classed as referrals). Overall, referrals showed a significantly worse performance, than the control group of volunteers, in most driving tasks and all driving measures. Almost all non-driving measures were significantly related to both age and group, only the Doran reaction distance and knowledge test errors were not significantly related to either. No non-driving measure was related to gender. The Snellen test is now used to screen drivers, along with the standard knowledge test. This appears to constitute the first tier battery of testing that could be administered to drivers, regardless of age. The Pelli-Robson contrast sensitivity was the most significant first tier measure in distinguishing referrals from volunteers. Previous studies have found this test to be related to prior crash experience for drivers aged 70+ and young drivers wearing contact lenses. So it is a test that could be used for all ages.

3.2.2.5 Fire

Several hundred studies have been published in the international literature about fire fighters although only one in ten report on age-relevant issues (Sluiter and Frings-Dresen, 2007). In their investigation of accident rates in fire fighters, Cloutier and Champoux (2000) note that several studies have demonstrated that work conditions become harder to bear with increasing age. These include a number of conditions that are particularly applicable to fire fighters, such as high and sustained physical workloads, rigid time constraints, demanding precision requirements, rigid operational modes and the presence of multiple constraints. They suggest that the age at which the stressors become difficult to bear is highly stressor-dependent. In studies that have examined the relationship between age and safety among fire fighters, older fire fighters named tasks requiring high aerobic capacity or significant motor co-ordination as the most demanding.

Cloutier and Champoux (2000) found that accident frequency rate significantly decreased with age (consistent with the findings from other studies, including the review by Sluiter and Frings-Dresen, 2007). They report that an age related increase in falls is reported in virtually all studies that have examined the variation of the type of accident with age. The age-related increase in accident severity may reflect an age-dependent increase in recovery time. The relationship between age and the incidence of accidents may reflect the exclusion of older workers who are no longer able to cope with certain work stressors. Fire fighters exposure to particularly demanding tasks (such as exploration or ventilation hazards) has been found to decrease with age. The authors suggest that the decreased incidence of accidents observed amongst older fire fighters may reflect their lower exposure to certain critical tasks (e.g. those associated with extinction operations). It appears that the distribution of work within fire fighting teams may take in to account the increasing difficulty older fire fighters face in performing certain tasks. They suggest that older fire fighters probably exploit their experience and know-how to develop protective individual and collective work strategies.

Sluiter and Frings-Dresen (2007) undertook a study (incorporating a systematic literature review) sponsored by the fire fighting sector, which resulted in them recommending discontinuation of the early retirement age of 55 for the future. This was because they found lack of evidence for this collective age setting, and the huge inter-individual changes in physical workload and health. Based on the findings from this study, the sector has chosen to allow the development of evidence based pre-employment medical tests and on-employment health monitoring of fire fighters. When fire fighters lose their ability to meet the work demands safely or only with restrictions, interventions or horizontal career steps will be planned in time to retain their expertise for the sector. Both pre-employment health screening, and also on-employment assessment of employees is recommended, in order to eliminate candidates whose health may hamper them from performing their jobs as safely as other employees, thereby endangering themselves or others. Sluiter and Frings-Fresen (2007) report that most indicators of work ability in fire fighters are related to age, but huge inter-individual variation between and within age groups has been found in task performance and task-related percentage of heart rate reserve. Although fire-fighters may be a healthy group of people, compared to the general population, with increasing age work-related ill health is worse, and is up to six times higher in older fire-fighters than it is in their youngest colleagues. They found that the international literature proved to be lacking in age-relevant evidence about the work-related emotional or psychological effects of fire fighting.

Sluiter and Frings-Dresen (2007) report a number of key points that are particularly pertinent to this current review: "*Jobs that pose no specific demands in terms of mental, physical or psychosocial task characteristics may not require the introduction of any special measures to keep workers on the job for longer periods. However, there are jobs where it is not possible to decrease the specific exposures to job demands. A base of knowledge is needed to prevent problems that workers face in performing any kind of heavy work. This knowledge base should be based on valid assessment techniques and be useful in creating effective measures to 1. keep workers heatlthy in their jobs, 2. increase the safety of (co) workers and 3. optimise the person-job-interaction*" (p. 1898, Sluiter and Frings-Dresen, 2007). Specific Job demands are defined as "*job demands that are not preventable with state-of-the-art (ergonomics) measures and that* *may exceed exposure safety levels or average human capacities to meet such demands on a daily basis for approximately 5 working days a week, over a period of 30 to 40 years without causing work-related health problems*". (p. 1899, Sluiter and Frings-Dresen, 2007).

3.2.2.6 Mining

Kowalski-Trakofler, Steiner, and Schwerha, (2005) discussed psychological and physical issues specific to the ageing workforce, and related this to the mining industry. They reported that there is a trend towards an ageing workforce in the mining industry. Mining is thought to be one of the most physically demanding occupations, with one of its biggest issues being the low light environment. The work environment includes unpredictable geological anomalies that can change the physical work environment within minutes. Any response to this environment requires experience, knowledge and the ability to make decisions quickly and safely. With reference to the literature this paper provides a list of age related cognitive and physical declines (see Appendix 7). The authors suggest a socio-ecological approach (to training) in order to support the older worker. This approach focuses on 1. the individual employee; 2. the physical workplace; 3. organisational dynamics and 4. the community / culture. It focuses on the interactions between humans and their environments, including the institutional and cultural context.

As new technology is designed and implemented, there can be a change in mental workload. Therefore studying technological advancements, and their application to mining before implementation, becomes critical to an ageing workforce (Kowalski-Trakofler, *et al*., 2005). In their study of accidents in Swedish iron-ore miners, Laflamme; Menckel and Lundholm (1996) found that whilst older workers have the capacity to reduce difficulties in meeting job demands, through acquired experience and more efficient utilisation of their personal resources, it is only under particular (unspecified by the authors) conditions that they can rely on compensatory skills. They found that aggregated age related accident rates were generally lower in older age categories. They suggest that this may be due to inequalities in risk exposure e.g. better employment conditions for older workers mean they are exposed to less risk, or because they use compensatory skills. However, injuries tended to be more severe in older age groups.

3.2.2.7 Nuclear

The relationship between age and injuries of workers has been studied in nuclear power plants (Findley and Bennett, 2002; Ringenbach and Jacobs, 1995). Older workers did not have a greater number of injuries than younger workers. However, once injured older workers took more time to recover (Ringenbach and Jacobs, 1995) and whilst injury rates remained relatively stable after the age of 30, the average cost associated with injury per employee increased with age, with those aged 50 and older having the highest average costs in terms of compensation (Findley and Bennett, 2002). Older workers were more likely than younger ones to believe that the organisation supported a safe work environment. They also appeared to compensate for their reduced physical capability by being more aware of, and more sensitive to, safety in the workplace. It is suggested that they are more cautious on the job, due to fear of injury. The authors note that injuries can be the result of job complexity and new performance requirements. They advocate that it is important to obtain a greater understanding of the relationship between age, work environment and accidents (Ringenbach and Jacobs, 1995).

3.2.2.8 Oil and Petroleum

The modal age of workers in the US petroleum industry is increasing, and this trend is likely to continue (Attwood, 2005). The average age of offshore employees in Norway increased rapidly between 1992 and 2002, and it is suggested that this "ageing may conflict with the requirements of a robust emergency preparedness organisation" (Bjerkebaek, 2002).

Health and work ability are important factors for occupational safety in the oil industry (Bresic, 2007). External stressors such as high and low temperatures, humidity, or dry air, chemical evaporations, noise and poor ergonomic conditions are easy to identify, mitigate or eliminate (partly or fully). However, psychosocial stressors are more difficult to discover and define. Workers on oil fields, drilling rigs & other oil production workplaces are exposed to various chemical hazards, fire, explosion etc therefore are at high risk of accidents. Stress at work can reduce safety and increase chances of occupational injury of workers working on oil platforms. Most workers in Bresic's (2007) study believed they were exposed to stress but the perception of specific stressors depended on the workplace environment (between offices, laboratories and the oil platform). Fear from chemical hazards was greatest in the laboratory and field workers. Work overload and overtime & shift work, night shifts and 24 hour time on duty were more often perceived as stressful by the oil field workers than the other 2 groups. Stressors perceived by oil field workers indicate more difficult work conditions and stressful working schedules. Poor communication with colleagues and conflicts were not perceived to be a stressor in field workers but were stressors for laboratory workers. After adjusting for age, a significant difference in work ability scores was found between the workplace groups (which could be due to the different conditions at work).

Bjerkebaek (2002) suggested that mandatory health licensing and special working conditions offshore probably result in a marked 'healthy worker' selection effect. Employees aged 60 or over showed a 50% rise in loss of license than younger age groups. Mandatory licensing is required to work offshore due to 'emergency preparedness' reasons, yet physicians claim that licenses are mainly revoked based on reduced work ability in the offshore environment. Age related health problems are a major contributor to loss of license and early exit from offshore employment. Prolonged exposure to shifts is believed to increase the risk of gradual reduction in physical performance capacity. Although loss of license represents one of the major career end points for offshore workers, there is no systematic knowledge or statistical information as to which health problems are the most important in reducing work ability for the ageing offshore worker.

Attwood (2005) described the physical, physiological and psychological changes that take place with age, using examples from the petroleum workplace. He notes that many jobs in the process industry require the operation of valves, which if not optimally located and oriented, require force to operate them. This may cause issues for older individuals who have reduced force capability. Manual material handling tasks require strength and high energy levels expended over long periods of time, which is an ability that reduces with age. Older workers may experience difficulties hearing high frequencies and have reduced ability to resolve visual information. If displays are confusing, it will take longer for older process workers to decode / process them, which could cause problems in 'upset conditions' due to slower decision-making responses.

Shahani (1997) found a negative relationship between accidents and age in an oil company, and little evidence of progressive selection (i.e. that age of workers influenced which type of job they did). Accident frequency was found to differ, dependent upon job, although there was little difference in the proportion of major (severe) accidents across different job groups. High and low risk jobs did not greatly differ in proportion of severe accidents. In addition, the relationship between age and accidents did not differ for high and low risk occupational groups. Regardless of the risk of occupational groups, the youngest group had the highest frequency of accidents, and accidents for all age groups increased for high risk jobs. He notes that past research has generally ignored the situation or job context when examining the relationship between industrial accidents and age.

3.3 AVIATION SECTOR: BACKGROUND AND FINDINGS

3.3.1 Background

Responsibility for health and safety in the aviation sector is distributed between authorities. The Civil Aviation Authority (CAA) has a general duty for the health and safety of crew members of UK operators whilst on aircraft. The CAA is responsible for advising the Secretary of State on the safeguarding of the health of persons on board aircraft as set out in the Civil Aviation Act 2006. The Act includes a general duty of organising, carrying out and encouraging measures for safeguarding the health of people onboard aircraft. This includes both crew members and passengers. Local Authorities are generally responsible for the health and safety of employees and members of the public in airports, in shops, restaurants or other retail outlets; common parts of the airport for example check-in halls; offices; and car parking facilities within the airport. The Health and Safety Executive is responsible for the health and safety of employees and members of the public in all areas not mentioned above, for example work on or around an aircraft on the ground, workshops within the airport and air traffic control.

3.3.2 Overview of papers

Thirteen papers studied age and decrease in performance in the Aviation Sector. Two of these papers related to Air Traffic Control (ATC) which is part of the sector that is within HSE's remit (see Section 3.2), whilst the other eleven were studies of pilots and are included here in this section (see Appendix 4 for a summary of these papers).

Pilots represent a population of workers who are selected according to specific psychomotor and medical criteria, and who have very specific expert training. Experts, such as pilots, may compensate for any age related deterioration in cognitive and psychomotor performance with more skills and efficient management strategies (Pelegrin, Maho and Amalberti, 1995).

In a review of older pilots' cognition and flight performance, the job is reported to be highly automated (Hardy and Parasuraman 1997). This is suggested to put high cognitive demands on pilots when flying, thus creating opportunities for human error. How age and expertise interact is an issue that has been examined extensively in the cognitive ageing literature. However in studies of pilots, flight expertise or experience and pilot age are often confounded, making comparisons between younger and older pilot performance difficult to interpret. It is suggested that studies do not find a relationship between age-related cognitive decline and job performance because simple static measures of cognitive functioning obtained in laboratory tests, may not be representative of the more complex and dynamic cognitive processes required in real-world tasks. (Hardy and Parasuraman 1997. pg 314)

Many of the studies on pilots are from the United States, where there is a regulation, commonly referred to as the 'Age 60 rule'. This mandates that commercial airline pilots (such as air carrier pilots) must retire at the age of 60. However, the majority of the studies included in this review either widened the scope of participants beyond commercial airline pilots, or excluded this group altogether, in order to extend the maximum age of study participants beyond the age of 60. The exceptions were one that focused on commercial pilots aged under 60 (Li *et al.*, 2002), and two that focused on data only from air carrier accidents (Li *et al.*, 2003 and 2006).

Four of the studies used a comparative research design that compared the performance of pilots with that of non-pilots. They did this across a range of age groups, from the age of 20 up to age 79 (Morrow *et al.*, 2003, Tsang and Voss, 1996, Vincenzi & Mouloua, 2001, Tsang, 1997). This design was selected in order to examine difference in performance due to experience and expertise, as pilots are believed to have specific areas of expertise and experience that are not present in non-pilots.

Six of the papers investigated the effect of experience and expertise on performance. Three of these focused on communication performance and working memory (Taylor 2005, Morrow, 2003 and Tsang, 1997). Two covered the cognitive skill of time-sharing (Tsang and Voss, 1996 and Vincenzi and Mouloua 2001) and one investigated crash risk (Li 2003).

3.3.2.1 Communication Performance and Working Memory

Communication is believed to be essential to air safety, and to impose heavy demands on pilots working memory (Morrow *et al*., 2003). Measures of working memory capacity and spatial ability have been found to predict communication performance (Morrow *et al*., 2003). In a study of working memory and communication task accuracy, Taylor *et al*., (2005) found that age related differences in working memory span could account for age differences in communication performance. In addition, Taylor *et al*., (2005) also found that age differences in working memory could be explained by age-related difference in processing speed and interference control.

Working memory has also been the subject of other studies (Taylor *et al*., 2001, Li *et al*., 2002 and Tsang 1997). Taylor *et al*., (2001) measured the cognitive performance of pilots at 3 points in time via a computer administered cognitive test battery. This included measures of general speed / working memory; visual associative memory; tracking; motor-coordination. They found that each age group increased its performance on the computer administered cognitive test battery. The test scores showed significant practice effects, with the exception of visual associative memory, which stopped increasing after the second test. Li *et al*., (2002) also investigated cognitive abilities (memory; concentration; mental acuity and reaction speed). They found that self-rated changes in health and cognitive abilities (particularly concentration and mental acuity) were significantly related to self-rated changes in piloting skills. Higher age was associated with less positive self-ratings on the tests, perhaps due to greater optimism at younger ages. Memory and reaction speed were the abilities that the highest percentage of pilots across the age groups rated as having declined. Tsang (1997) explored short term memory, perceptual motor speed; tracking; mental rotation; and memory. He found that age was not a good predictor of an individual's performance.

3.3.2.2 Time-sharing Skills

Pilots have been found to have specific skills in time-sharing (e.g. Tsang & Voss, 1996, Vincenzi and Mouloua, 2001). This includes two key components, firstly time sharing efficiency and secondly attention allocation control. Time-sharing efficiency is a measure that compares dual task performance with single task performance. The closer together the two measures, the greater the time-sharing efficiency is. Attention allocation control is the extent to which someone can direct their attention to different tasks according to certain task demands. Tsang and Voss (1996) found that the influence of age on time-sharing performance seemed to be moderated by experience and expertise. Likewise, Vincenzi & Mouloua, (2001) concluded that pilot performance appears to be a function of time-sharing ability, and that experience may enhance this ability as well as determine how available resources are distributed to deal with multiple tasks. According to Tsang and Voss (1996), age alone is not a definitive discriminator of an individual's time-sharing skill. They found that the influence of age on time-sharing seemed to be moderated by expertise, and concluded that, experience and expertise play a role in level of performance. Other variables, such as intelligence and perceptual motor speed, have been found to be more predictive of both single and time-sharing performance (Tsang, 1997), with pilot expertise contributing only modestly to the single task and time-shared tracking performance.

3.3.2.3 Crash risk

In studies on age and safety performance, the lack of association between pilot age, crash risk and errors has been suggested to reflect a 'healthy worker' effect, stemming from rigorous medical standards for pilots (Li, 2003), or a 'safe worker effect' resulting from rigorous selection process and certification standards for professional pilots (Li, 2006). Age and experience have both been found to effect the correct detection of automation failures (Vincenzi & Mouloua, 2001), with pilots performing better than non-pilots, and younger groups performing better than the older ones. One key finding from the studies on age and safety performance was that flight experience showed a significant protective effect against risk of crash involvement (Li *et al*., 2003).

3.3.2.4 Pilot expertise and experience

It has been suggested that, as expertise is acquired in specific environments, knowledge is most likely to influence performance on tasks that are similar to these environments, that is, where tasks and procedures are organised in terms of domain relevant goals (Morrow *et al*., 2003). Researchers have suggested that expertise should moderate age effect, when the task is domain relevant. However, whilst task domain relevance may be a necessary condition for expertise to moderate the effect of age, it does not appear to be a sufficient one (Taylor *et al*., 2005).

Expertise developed via experience and training, has been found to increase performance on domain-relevant tasks for all ages (Taylor *et al*., 2005). Pelegrin, Maho and Amalberti (1995) investigated age related performance in terms of learning to fly different / unfamiliar aircraft. Age was found to be a handicap to making the transition to a new system, older pilots needed longer to adapt and were more likely to fail the final exam. However, some older pilots performed very well which demonstrates variability between individuals. If experience on the system and task management can be transferred, it was concluded that age does not affect performance. Pilots also compensate for slow learning with better consciousness of their own possibilities.

3.4 WHICH AGE RELATED CHANGES RESULT IN DECREASED PERFORMANCE AT WORK?

Findings from this review indicate that the relationship between age and decreased performance at work is not simple, nor is it straightforward. Performance has been distinguished from competence and defined as 'what a person can do under actual conditions' as opposed to under ideal conditions (Becker and Milke, 1998). What a person can actually do is influenced by a range of variables which are external to their competence, such as memory, attention, motivation and task familiarity, to name just a few.

Whilst a range of cognitive and physical functions have been found to decline with age, these have not generally been found to result in decreased performance at work. Individuals have been found to compensate for age related changes via use of expertise and domain specific experience. Decreases in performance have been suggested to be due to a combination of age and other factors, such as the nature of the job (e.g. if the work organisation involves shift work, an older worker may have more difficulty maintaining their performance at work).

3.5 WHICH DECREASES IN PERFORMANCE ARE SAFETY-CRITICAL (I.E. COULD RESULT IN MAJOR ACCIDENTS OR INJURY, BEYOND THE INDIVIDUAL WORKER)?

The majority of the papers in the review discuss decreases in performance in relationship to the safety of an individual, as opposed to having safety implications beyond the individual. However, work carried out by Sluiter (2006) highlights that it is those aspects of performance required by high demand jobs that may result in safety critical outcomes if they decrease. These are jobs that include high physical, mental/cognitive or psychosocial job characteristics. For example, decreases in memory or decision making speed could lead to safety critical outcomes, particularly under conditions that are unfamiliar.

3.6 IN WHICH JOBS COULD A DECREASE IN PERFORMANCE RESULT IN MAJOR ACCIDENT OR INJURY (BEYOND THE INDIVIDUAL WORKER)?

High demand, or high risk jobs, (such as fire fighters, ambulance workers, police officers and pilots) are defined as those that exceed exposure safety levels or average human capabilities to meet the job demands. Work often involves a combination of demands. Hence, it is suggested that it is the specific combination of demands required by a job that make it safety critical, as opposed to the job 'title'.

The literature indicates that as workers age, there is an element of 'healthy worker' selection in terms of the jobs they participate in. For example, older fire fighters are likely to move to less demanding duties, and offshore workers are likely to lose their licence to work due to health reasons.

Work ability is the ability to meet the physical, mental and social demands of a job. A range of risk factors can influence work ability, such as excessively high physical demands (such as experienced by fire fighters), excessive mental workload (such as those experienced by pilots), stressful or dangerous work environments, work organisation (e.g. shift work and technological advances). There is some evidence that older shift workers are at greater risk of injury or accidents at work and this could have implications beyond the individual worker. In addition to these, work ability can be affected by an individual's health and functional capacity and maintenance of their work related skills.

Age related changes in visual ability in commercial drivers and pilots may lead to loss of work ability (and consequent safety critical outcomes). Technological advances can increase mental workload (e.g. in pilots and miners) and in industries where components are being increasingly miniaturised (such as the electronics industry), changes in visual ability could affect work ability especially if the work demands include good colour perception (Goedhard, 2000 as cited in Cox *et al.*, 2000).

3.7 STRENGTHS AND LIMITATIONS OF THE RESEARCH

The tools/tests documented in this report are a sample of what was found using the search strategy outlined in Section 2.1. This is not intended to be a comprehensive or exhaustive list of tools / tests. Some lines of enquiry relating to identification of tools had not come to fruition in the time available for this research. The inclusion of tools/tests in this report does not imply any endorsement on the part of the HSL.

The findings from the literature review contribute to knowledge regarding age related decreases in performance and safety critical work. However, the quality of the literature review is proportionate to the quality of the studies upon which it is based.

Explicit methods were used in order to identify, and select the literature, which helps to reduce bias in terms of which studies were included. It also results in greater clarity regarding how conclusions have been reached. Adoption of this approach means that the review will be replicable, and able to be updated in the future.

The exclusion of grey literature (such as conference proceedings and technical reports) from the review may mean that potentially relevant research, not published in peer review journals, has been omitted.

There was limited literature that discussed decreases in performance that are safety critical (i.e. could result in major accidents/injury beyond the individual worker). The majority of the papers discussed decreases in performance in relationship to the safety of an individual.

4 SUGGESTIONS FOR FUTURE WORK

4.1 WHAT FUTURE WORK MAY NEED TO BE CARRIED OUT BASED ON THE FINDINGS FROM THE SYSTEMATIC LITERATURE REVIEW AND THE RANGE OF EXISTING ASSESSMENT TOOLS THAT HAVE BEEN IDENTIFIED?

4.1.1 Suggestions for Future Work based on findings from the Literature Review

The studies included in the literature review identified a number of potential avenues for future work. These are presented by sector.

4.1.1.1 General / cross sector

Williams *et al*. (2007) concluded that age needs to be incorporated into process safety and reliability assessments, and that these assessments need to become an integral part of modern hazard management, production safety and reliability improvement processes. Tobia (2005) believes that future work should evaluate the need to introduce ergonomic measures to support work ability e.g. solutions to reduce muscular exertion and effort, and a bigger attention to awkward postures. Sluiter (2006) suggests that there is a need for valid assessment techniques that can be applied during simulated or real task environments throughout the career. She believes that relevant physical and psychological parameters could be monitored, along with objective criteria for the safe and sufficient execution of tasks. In addition, that functional testing and job-specific work ability indices should be developed. Based on the findings from her review of high demand jobs, she makes the case for ‘diversity in work ability rather than a chronological age cut-off’. Hence, she advocates that future work should include moving from ‘no-diversity thinking’ to ‘diversity thinking’ regarding functional age and high-risk jobs.

Ng and Feldman (2008) found that little attention has been paid to variables that mediate the relationship between age and performance. For example, variables such as job complexity can influence the extent to which specific skills, required by a job, are associated with age-related performance. By measuring the mediating variables researchers can begin to explain why age matters to job performance. For the future, they suggest that new approaches are needed in order to study the relationship between age and performance. Designs should incorporate longitudinal studies and the use of performance measures from different sources and of different types. For example, if losses in self-efficacy influence a decline in performance with age, then multiple measures of this variable will need to be obtained. In future, researchers should also consider alternative ways of measuring age (e.g. this could be subjective age i.e. how old people feel, or age in relation to others in the same work environment). As the age-performance relationship has been found to vary across the socio-demographic characteristics of a sample (e.g. race education, job level, job complexity, job tenure and organisation tenure), Ng and Feldman (2008) advocate that studies should control for the effect of these characteristics, and that the findings are interpreted in light of them.

4.1.1.2 Aviation (pilots and air traffic controllers)

Work is needed to determine whether the benefit of experience on performance is maintained over the lifespan, and beyond 40 years of age (Becker & Broach 2003). Longitudinal studies are also needed in order to investigate how processing speed and control of inference change over the lifespan (Taylor *et al*., 2005).

As age related reductions in domain-general cognitive abilities may impact on performance of domain-relevant tasks, it is important to assess the degree to which working memory and related fluid abilities contribute towards performance (Taylor *et al*., 2005). It is suggested that communication tasks should be designed to reduce demands on cognitive abilities (especially working memory) and to support the use of domain knowledge. For example, air traffic control messages should be short and presented in a way that reduce the demands on working memory, and use of cognitive aids can play an important role in maintaining performance as individuals age (Morrow *et al*., 2003).

Training plays an important part in mitigating the effects of age on performance in pilots. Training should support spatial abilities (Morrow *et al*., 2003) and concentrate on improving monitoring capability, as system monitoring will become more important as technology and automation advances (Vincenzi and Mouloua, 2001). Further work is required to explore whether older pilots use different or unique sets of expertise-related skills or strategies in order to offset age-related disadvantages. Work could also focus on identifying any mental workload characteristics that influence performance potential (Hardy and Parasuraman, 1997). Interventioins to reduce stress and anxiety in pilots may help to improve cognitive abilities and piloting skills (Li *et al*., 2002).

4.1.1.3 Driving

In their review of the transportation sector, Popkin *et al*., (2008) concluded that more research, particularly longitudinal research, is required before an answer can be provided as to whether 'age is more than just a number'. Transportation is a 24/7 job that means stress from shift working should be considered in relation to other changes that occur with age. More needs to be known about the interaction between age and the effects of circadian rhythm frailty, obtaining sleep and the use of medication on performance.

4.1.1.4 Fire

Sluiter *et al*., (2007) recommend that minimal standards for work ability capacity are established at national level, and that fire fighters should be repeatedly tested throughout their careers, using the same test. Declines in performance should be monitored and interventions introduced. It is recommended that multi-modal functional tests, that closely simulate real job activities, are used in order to regularly screen fire fighters. The authors suggest that testing the combination of physical, mental and emotional demands is the most important future task facing researchers, as functional performance or functional capacity is critical to good job performance, but is seldom used as a 'medical' test in pre-employment assessments. In order to introduce functional testing of fire fighters and increase the acceptance of these 'new' kinds of medical tests in the sector, groups of fire fighters must establish criteria for 'successful' and 'unsuccessful' functional performance.

The authors draw particular attention to the importance of looking at time spent on tasks, or task duration. This is because catastrophes can occur in public health jobs for both workers and their environments when there is a problem with time or duration of task performance. They go on to suggest possible benchmarks that could be used to decide whether to start an intervention, or to allow the individual to continue working. These could be a set percentage pass rate for functional tests. They believe that it should be possible to use emotional demands, and the work-related psychological complaints associated with those, to screen out workers whose present health prevents them from performing their jobs as safely as other employees. It is believed that fatigue and psychological functioning during night hours call for more age related research.

Sluiter *et al*., (2007) suggest a number of tools that could prove useful in testing function and performance of fire fighters. In order to screen for post-traumatic stress complaints the impact of event scale (IES) could be useful (e.g. Sudin & Horowitz, 2002). Whilst. The Epworth sleepiness scale (ESS) could be used to assess too much sleepiness (e.g. Johns 1992). For those fire fighters who perform diving activities, the European fitness to dive standards (EDTC, 2003) is applied for medical testing in several countries. These standards consist of many mono-medical tests like spirometry and exercise stress testing through the cycle ergometer test. Finally the authors believe that, although initially appealing, semi-functional mono-tests, such as bicycle exercise stress testing, handgrip force push-ups have not shown good predictive values.

4.1.1.5 Mining

Kowalski *et al*., (2005) recommend that future research is required into specific mining injuries that may be age-related, and that more research is needed to determine job skills and task requirements as they relate to age. This data would be beneficial in planning interventions and ensuring healthier work environments and procedures for workers in the future. In drawing conclusions from their study of mining accidents, Laflamme *et al*., (1996) advocate that in future studies longitudinal designs and individual data on exposures are essential, also that further studies are needed to test the hypothesis that lower accident ratios found in older workers are due to inequality in exposure to risk.

4.1.1.6 Oil and Petroleum

Additional training in communication skills for workers plus preventative measures will improve health and safety in the workplace (Bresic, 2007). More knowledge is needed about the causes and symptoms related to early exit from the offshore environment, and ways of combining ageing and offshore employment need to be re-thought (Bjerkebaek, 2002).

4.1.2 Suggestions for Future Work based on Findings from the Tools Search

4.1.2.1 Evaluation of the Work Ability Index (WAI)

The WAI has had widespread use and investment in Finland and considerable use in several other countries (Ilmarinen, 2007). The Association of Finnish Pension Institutions and the Finnish Institute of Occupational Health (FIOH) has trained all their full-time occupational health professionals in the application of the index (The Age and Employment Network, 2008). There is some evidence of its use in the UK (Institute of Naval Medicine, 2011; Reilly *et al.*, 2009) but this appears to be minimal particularly in comparison to its use across mainland Europe, Australia and China (Costa *et al.*, 2005; Lin *et al*., 2006).

Future work could involve evaluation of the WAI, particularly for widespread use in the context of the UK workforce. Research by Reilly *et al.* (2009) on its usefulness in predicting and promoting continued work in staff employed by a major UK charity, concluded that a more explicit question on job satisfaction should be included in the WAI. Furthermore, in the course of this work, UK experts on ageing have commented that the WAI is a useful screening tool but that it may require modification for ease of use and may benefit from additional measures such as stress and mental workload and consideration of how to intervene for those who get low WAI scores.

Further work could also involve investigation into current attempts to revise the WAI, that is the development of the Work Ability Survey Revised (WAS-R) by Taylor *et al.* (2011).

4.1.2.2 Development of a new tool

Based on findings from the tools identified in this report, HSE could consider the development of an assessment tool for dutyholders to enable them to monitor decrements in human function, capabilities and performance throughout the lifecycle of an employee. It is suggested that the following criteria should remain important in the development of a new tool:

- It identifies employees at high risk of injury;
- It is suitable for use across all sectors of industry;
- It should be ready for the duty holder to roll out and not require an occupational health professional or medical expert to administer;
- It is an easy to use web-based tool;
- It should link with information on workplace interventions;
- It should be framed as a tool to maintain ability and a safe working environment and not as a tool to monitor age-related changes.

The ethical issues involved in the development of a tool, namely, considerations relating to age discrimination, should be considered. It is suggested that such a tool should be used as a routine assessment throughout an employee's working life. As outlined in a guide by the Chartered Institute of Personnel and Development (CIPD), and the Trades Union Congress (CIPD *et al*., 2011), "*age-related criteria could be unlawful if older workers are more likely to be assessed than younger workers. Older employees could claim that they're being targeted for dismissal on health or disability grounds. Conversely, a younger person could argue that their health and safety needs are not being properly addressed*". The suggestion that a tool should be used throughout an employee's working life is also supported by findings relating to the large variations between the functional capacities of individuals with the same chronological age (Yeomans, 2010).

Development of such a tool could involve liaison with Loughborough University and/or work being carried out by Dr Judith Sluiter at Coronel Institute of Occupational Health (University of Amsterdam). It appears that the work underway at Loughborough University on the Organiser for Working Late (OWL) tool will consider workplace design interventions to improve worker safety and health and this could be a useful resource to take into account in the development of a new tool. Similarly, research on the development of health and performance tests for high demand jobs including firefighters, medical specialists and nurses (ongoing at the University of Amsterdam) could also inform any tool development. This may also help to address the question as to whether a number of tools should be developed that are occupation specific.

The development of a new tool may benefit from a consultation exercise with dutyholders and employees on the required content of the tool. This consultation could also seek to gain an understanding of the opinions of dutyholders and employees as to the extent of responsibility they think they should take in relation to the assessment of decrements in human function, capabilities and performance.

4.1.2.3 Research on intervention strategies for employers

There appears to be a need to develop intervention strategies for employers to enable them to provide sufficient support to older workers. According to recent research by McDermott *et al*. (2010), which reviewed current occupational health approaches, there were very few occupational interventions that have addressed the health and work ability of older workers. They concluded that there is considerable scope for developing occupational provision that accounts for the needs of the older workforce. Intervention strategies could involve the provision of guidance to employers on ergonomic design interventions that may support the older worker (e.g. improvement of workplace lighting) or exercise/stretch breaks.

5 KEY MESSAGES

Whilst there is evidence that cognitive and physical abilities decline with an increase in age, these do not necessarily have a negative impact on performance at work. Studies of age have found huge inter-individual variations in performance, and few studies have found any gender difference in performance.

The relationship between chronological age and performance is not a simple or straightforward one. A number of factors have been found to influence the association between age and performance. Broadly categorised into three levels, (individual, organisational and societal), they include factors such as functional capacity, work demands, work environment, stress, shift work, expertise, attitudes towards work and retirement etc.

It is the specific combination of demands (and complexity) required by a job that make it potentially high demand, as opposed to the job 'title' itself. Jobs that are high demand or high risk (with high physical, mental/cognitive or psychosocial job characteristics) are those which could potentially result in safety critical outcomes if workers' performance decreases. Individuals are able to use various strategies to compensate for age related declines in performance, such as their expertise, job knowledge, education and high motivation. However, when job demands exceed the overall capacity of a worker they may no longer be able to compensate for any decline.

There is evidence of 'healthy worker' effects, where individuals self-select to move into less demanding jobs, or retire as their ability to carry out a job decreases. There is also evidence of 'safe worker' effects where rigorous screening standards mean that workers lose their licence to work (e.g. pilots and offshore workers).

There is a scarcity of information about the performance of older workers in high demand jobs. For example the extent of 'healthy worker' effects or 'safe worker' effects within high demand jobs is unknown. The extent to which these effects act as a safegaurd against safety critical outcomes is also unknown. There is some evidence that older shift workers and construction workers are at greater risk of injury or accidents at work but further research is required on the performance of older workers (in high demand jobs) to ascertain the extent of this issue across industry.

More longitudinal research is required in order to investigate declines in performance over the lifespan. Such studies could establish what the expected physical and cognitive changes are across the lifespan and thereby help employers to plan intervention strategies to counteract any detrimental influence of age on an employee's health and safety. This work might include exploring how factors such as expertise, experience and working memory contribute towards performance.

A number of tools exist which could potentially be used by dutyholders to assess decrements in human function, capabilities and performance. The Work Ability Index, whilst a promising construct that has been used extensively across many occupational groups and in several countries, has its limitations. Based on the findings in this report, it is suggested that HSE could consider developing a tool to assist dutyholders. This would enable judgment to be made, both on the part of the employer and the employee, as to their functional capacity to work safely. In doing so, it is advised that HSE should take account of the ethical issues involved in the development of a tool, namely, considerations relating to age discrimination. HSE should frame the development of such a tool as one that is designed to maintain work ability and a safe working environment and not as a tool to monitor age-related changes.

It is recommended that any tool HSE advocate for dutyholders to enable them to judge the functional capacity of the workforce to work safely should be able to identify employees at high risk of injury. It should not require a health professional to administer, should be suitable for use across all sectors of industry and provide information on workplace interventions and strategies to support the worker throughout their working life.

It is recommended that HSE develop intervention strategies for employers of older workers to complement an assessment tool. Intervention strategies in the form of improvements in workplace design, training and other adaptations within the work environment could improve safety and performance and offset effects of physical and mental changes related to ageing.

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7 APPENDICES

7.1 APPENDIX 1. LITERATURE SEARCH RESULTS

The first search was undertaken using terms that incorporated combinations of words relating to age, performance and safety critical. A time limit of 3 years was applied and the search was limited to the English language only. No sectors were specified in the search. This was the initial strategy discussed and agreed with the HSE customer. The search included the following terms:

age or ageing or aging or elder or older
AND
perform* or able or abilit* or competenc* or capable or capabilit* or skill* or function* or capacit*
AND
hazard* or danger* or risk* or safe* or critical* or high (near3) reliability or (high near30 demand).

This initial search resulted in very few results that mainly related to studies of pilots and flying. The HSE search team recommended looking at age related performance more widely in an occupational setting in general (e.g. to look at specific types of work ability in connection with age, such as spatial or cognitive). They also suggested looking at specific hazardous industries. However, it was noted that when they had added the terms oil or gas or petroleum or chemical or offshore or nuclear or mining or explosives into this initial search, with no limitations placed on year or language, only 3 results were produced. When the search was run again in an industry specific database (Tulsa – petroleum abstracts) only one additional relevant result was produced.

A second search was then carried out with the addition of a number of specific hazardous industries (sectors). These were drivers (railways and road), defence, aviation, nuclear, construction, fire service and police service. Additional terms were also added to cover various aspects of work ability (human error, cognitive capacity, physical strength, endurance, sensory abilities (auditory and visual), mobility.

Identifying specific industries did not return huge numbers of results due to the time limitation of 3 years. Hence, a further search was undertaken applying the English language limit and removing the time limit. This included the following terms:

age or ageing or aging or elder or older
AND
perform* or capable or capabilit* or able or abilit* or function* or capacit* or competenc* or skill* or contingenc* or compliance or (human (w) factor*) or (human (w) error*)
AND
hazard* or danger* or risk* or critical or oil or gas or petroleum or chemical or nuclear or mining or quarry* or explosive* or diving or driver* or aviation* or construction or (air (3N) control*) or fire* or police* or pilot* or rail* or defence or defense or (high (3N) reliability) or (high (3N) demand*)
AND
industr* or occupation* or installation* or site* or employ* or job or jobs or staff* or work*

Results:

Oshrom - 49 results; Web of Knowledge - 9 results; OshUpdate - 15 results; Ergonomics Abstracts - 46 results; Medline, Embase, NTIS, Psycinfo and Wilson Social Sciences Abs (on the Dialog platform) - 15 results.

The research team asked Information Services whether any additional databases were available, beyond those listed above, that could potentially contribute to the Rapid Evidence Assessment. The research team was informed that all available and relevant databases have been searched and that no other databases would be likely to contribute significantly to the Rapid Evidence Assessment.

A further search was carried out to look at age related performance in an occupational setting in general. This was a broad search intended to give an idea of what is available in more general terms, but with results being specifically focused on an occupational/workplace setting. The search included terms such as cognitive and spatial, to see if this brought up anything with a more health focused aspect that may have been missed with the other set.

English language limit applied to all databases. Initially, when searching Oshrom and OshUpdate the search went back 20 years as these are very small databases, but when searching the larger databases the 3-year limitation was used. Terms included the following:

age or ageing or aging or elder or older
AND
perform* or capable or capabilit* or able or abilit* or function* or capacit* or competenc* or skill* or contingenc* or compliance or (human (w) factor*) or (human (w) error*)
AND
work* or job or jobs or employ* or occupation* or industr* or staff*
OR
age or ageing or aging or elder or older
AND
work* or job or jobs or employ* or occupation* or industr* or staff*
AND
spatial* or cognitive or cognition or physical or mental or ergonomic or visual or auditory or practical or hearing or health or stress or wellbeing or (well (w) being) or endurance or mobility or mobilities or sensory.

Results*:* Oshrom - 65 results, OshUpdate - 21 results; ASSIA, PAIS and Sociological Abstracts (on the CSA platform) - 23 results, Web of Knowledge - 21 results, Ergonomics Abstracts - 11 results, Healsafe (on the STN platform) - 6 results, Medline, Embase, NTIS, Psycinfo and Wilson Social Sciences Abs (on the Dialog platform) - 30 results.

7.2 APPENDIX 2. DATA EXTRACTION TOOL

Data was extracted from the selected papers under the following headings:

- Author;
- Title;
- Publication year;
- Journal;
- Fits selection criteria for safety critical sector;
- Fits selection criteria for decreases in performance;
- Fits selection criteria for the decrease in performance being safety critical;
- Job (participant details and sample);
- How were participants selected;
- Selection bias;
- Age factors covered in the study;
- Aim / objectives of the study and study design;
- Summary of data collection;
- How data was analysed;
- Summary of findings;
- What the paper suggests in terms of future work that is needed on age related decreases in performance and safety critical work;
- Authors' conclusions and study limitations.

7.3 APPENDIX 3. WHAT TOOLS ARE AVAILABLE FOR DUTYHOLDERS TO USE IN ORDER TO ASSESS DECREMENTS IN HUMAN FUNCTION, CAPABILITIES AND PERFORMANCE?

Table 1 Tools available for dutyholders to assess decrements in human function, capabilities and performance

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
1	**Work Ability Index (WAI)**	The questionnaire is adminstered by an occupational health professional.	The WAI was developed to promote and maintain the ability of older employees to work.	A a summary measure of seven items which are (i) Current work ability compared with lifetime best (ii) Work ability in relation to the demands of the job (iii) Number of current diseases diagnosed by a physician (iv) Estimated work impairment due to diseases (v) Sick leave during the past year (vi) An employee's own prognosis of work ability 2 years from now and (vii) Mental resources (TAEN, 2008)	Finnish Institute of Occupational Health (FIOH)	Tuomi (1998) or TAEN (2008 http://taen.org.uk/uploads/resources/Briefing_on_Work_Ability_web.pdf)	Requires administration by an occupational professional.
2	**Age Awareness Training for Miners**	Training modules which can be administered by the dutyholder at monthly or weekly safety talks. Could take between 2 and 9 months to administer.	Having recognised how changes in ability due to age could be accommodated for in the workplace to reduce the risk of injury to miners, NIOSH investigators designed an educational program for miners to help workers understand certain age-related risks, suggest ways to modify the workplace to accommodate older workers, and reduce the risk of injury among this working population.	A training package with the following nine modules: (i) Introduction to age awareness (ii) Vision (ii) Hearing (iii) Attention and Memory (iv) Musculoskeletal System (vi) Lower back (vii) Work Capacity and Endurance (viii) Slips, trips and falls (ix) Identifying high risk tasks. This training program involves a presentation for program leaders, modules for use with all employees including safety talk guides and activities which involve hearing self-assessments and working memory exercises, and evaluation/training record forms.	National Institute for Occupational Safety and Health (NIOSH)	http://www.cdc.gov/niosh/mining/pubs/pdfs/2008-133.pdf	Yes
3	**Eyes Right**	A screening programme	It was designed to enable the general public to	The tool checks for problems with near and far vision and contrast sensitivity (how well	Royal National Institute for the	http://www.rnib.org.uk/eyehealth/loo	No

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
		administered using a computer programme or using an A4 hand-held book. 'Participants receive a personalised vision report at the end.	screen older people (65+) for poor vision.	someone can see objects stand out from the background).	Blind (RNIB)	kingafteryoureyes/eyesright/Pages/eyesright.aspx	
4	**Driver Profiler 20:20**	Online risk assessment tool	The tool was developed to help companies risk assess fleet drivers and to help them prioritise high risk drivers for training. It was not developed because of any age related concerns.	A Driver Profiler 20:20 assessment consists of 45 questions, which take 10 minutes to complete. Questions are closely tailored to occupational driver risk factors, including fatigue, driving under pressure and work distractions. The tool measures psychometric, demographic and behavioural factors that influence driver safety. It then identifies measures to reduce the risk and helps employers prioritise action so they get the most benefit from their budgets.	Royal Society for the Prevention of Accidents (RoSPA)	http://www.rospa.com/drivertraining/morr/riskassessmentsolutions/driver-profiler.aspx	Yes
5	**Work Instability Scale for Rheumatoid Arthritis**	A yes/no questionnaire which allows clinicians and others to screen for, and monitor Work Instability related to Rheumatoid Arthritis.	To enable early intervention aimed at job retention and early aggresstive treatment of the cause of work instability. The first Work Instability Scale developed relates to the identification of Rheumatoid Arthritis.	Work instability is defined as "a state in which the consequences of a mis-match between an individual's functional (and cognitive) abilities and the demands of their job can threaten continuing employment if not resolved" (Chamberlain, 2010). A Work Instability measure has been developed which is specific to the measurement of Rheumatoid Arthritis. Work instability for other health conditions are planned.	University of Leeds	Carew (2010)	Yes but not currently available
6	**Office Work**	A 62-item	To give employers early	It is a short questionnaire incorporating both	The University of	See Gilworth *et al.*,	Yes

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
	Screen	screening questionnaire	insight into employees at risk of sickness absence (Gilworth *et al.*, 2008). According to the developers of the tool, Work Screens can help management improve work attendance by identifying how well people are coping at work, identifying individuals at risk of sickness-absence, targeting occupational health support and resources at the people who need them most and supporting and monitoring job retention and return to work programmes.	musculoskeletal symptoms and relevant psychosocial factors in one dimension.	Leeds, Work Fit Occupational Physiotherapy and Ergonomics Services Ltd and Work Screen Ltd, Leeds, UK.	2008) http://www.work-fit.co.uk/Library/Default/Documents/Office%20Work%20Screen.pdf	
7	**Nurse Work Instabililty Scale (Nurse WIS)**	A self-administered questionnaire consisting of 30 items	It is well documented that musculoskeletal pain and subsequent disability account for a high proportion of sickness absence and premature retirement in the nursing workforce. The challenge to clinicians is to identify such problems early so that appropriate interventions can be targeted to facilitate job retention.	Work Instability describes the extent of any mismatch among functional (in)capacity, work demands and its potential impact on efficiency/productivity at work. According to the authors of the questionnaire, it measures the risk of job loss relating to musculoskeletal symptoms, but also captures relevant psychosocial issues (Gilworth *et al.*, 2007)	The University of Leeds, Work Fit Occupational Physiotherapy and Ergonomics Services Ltd and Work Screen Ltd, Leeds, UK.	Gilworth *et al.* (2007)	Yes
8	**Health**	Administered	Safety critical workers are	This includes (i) The Cardiac Risk Score is	Unknown??	http://www.ntc.gov	No. Requires a

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
	Assessment for Safety Critical workers in the rail industry, Australia	by a Health Professional to 'high level safety critical workers' when they commence work, then 5 yearly up to the age of 50, 2 yearly up to the age of 60 and yearly thereafter (National Transport Commission, 2011).	defined as 'those whose action or inaction due to ill-health, may lead directly to a serious incident affecting the public or the rail network'. Safety Critical Workers in the rail industry are required to have a comprehensive physical and psychological assessment to detect conditions that may affect safe working ability, for example heart disease, diabetes, epilepsy, sleep disorders, alcohol and drug dependence, psychiatric disorders and eye and ear problems.	a "predictive" tool which helps identify those at risk of having a cardiovascular event (heart attack, stroke etc) over the next 5 years. It combines information about age, sex and cigarette smoking, with results for blood glucose and cholesterol, blood pressure and an ECG, to calculate a risk score which is then interpreted by the examining health professional. Depending on the score you may be required to have further tests and/or more frequent health assessments (ii) The Epworth Sleepiness Scale (described as tool no.2 in Table 2 above) (iii) Screening Tool for alcohol dependence and (iv) a screening tool for anxiety and depression (v) Safety Critical Worker Health Questionnaire - asks about medical history and includes a number of health screening questions		.au/viewpage.aspx?documentid=997 An example of this can be found at: http://www.transportsafety.vic.gov.au/__data/assets/pdf_file/0010/38548/040716-Forms-Vic.pdf	health professional to administer.
9	**2cRisk**	A web based application	To enable businesses to assess the risk around people with a view to avoiding injury and keeping workers healthy and productive.	This web-based application manages employee risk through the full employment cycle - from pre-employment through to them leaving your organisation. The software analyses demographic, environmental and medical information to assess risk. This product has been commercially available only in the last 12 months but was 4-5 years in development. Interest in the tool has come from mining, mining services, construction, health services. According to the developers, there is a range of drivers for take-up including Return on Investment, a growing business interest in health and wellness, wanting to be a good corporate citizen, awareness of an	A new Australian company called 2CRisk	http://www.2crisk.com.au/solutionoverview.php	Yes

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
				ageing workforce and upcoming skills shortages and thus the need to keep people in the workplace (2cRisk, 2011)			
10	**Workplace Well-being tool**	Online Tool	A review of the health of Britain's working age population identified significant opportunities for improving the well-being of our workforce, but simple commonsense advice about effective interventions is hard to come by. It is often hard to build an informed, sound business case for investing in the health and well-being of the workforce. The Workplace Well-being Tool is designed to fill these gaps by providing easy access to relevant information and practical support for change.		Department of Work and Pensions	http://www.dwp.gov.uk/health-work-and-well-being/	Yes
11	**Ability Match**	Computer based online tool	A tool called the Activity Matching Ability System (AMAS) was the forerunner of what is now known as Ability Match. AMAS (Activity Matching Ability System) was was designed to help young disabled / disadvantaged people to enter the labour market Birkin *et al.*,	It is a tool that assesses the ergonomics aspects of jobs (the activities) and the abilities of an individual. The two sets of information are then matched and the results talked through with the individual to see if a good match has been obtained. This includes questions on hearing communication, vision and perception, posture and movement, movement around the work area, the physical environment, cognition, controls and displays and a	Department of Work and Pensions, UK.	See Appendix B in Haines et al., 2003 https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/2169/1/AMAS.pdf	Yes but not yet available.

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
			(2004). In 2006 DWP commissioned an update of AbilityMatch which would be tailored for use by Jobcentre Plus Work Psychologists.	section on matching abilities with jobs.			
12	**Automated Psychophysical Test (APT)**	A computer-based psychophysical test.	A screening tool to screen for diminished capabilities in elderly drivers (McKnight and McKnight, 1994).	The authors stipulate that all of the measures included in the test are those required to drive a car. The program is designed to measure sensory (including static and dynamic visual acuity), attentional, perceptual, cognitive and motor abilities). The 1994 article highlights that no large scale validation of the measure has been carried out.	National Public Services Research Institute, Maryland, USA.	McKnight and McKnight (1994)	No
13	**Fatigue and Risk Index**		This tool is a further development from the HSE Fatigue Index (FI) which arose from the requirement to assess the risks from fatigue associated with rotating shift patterns and, in particular, the requirement to provide guidance in support of the Railway (Safety Critical Work) Regulations.	The derivation of the component associated with cumulative fatigue is related to the amount of sleep loss that is likely to be associated with the pattern of work and rest. The estimation of the increase in risk on consecutive shifts has been based on the relative risk data over four successive night and day shifts. The tool generates two separates indices for fatigue and risk.	QinetiQ in collaboration with SFA (Simon Folkard Associates).	http://www.hse.gov.uk/research/rrpdf/rr446.pdf	Yes
14	**HSE Management Standards for Work-Related Stress**	Online or paper and pencil test	In the 1990's there was a significant increase in reports of work-related stress which prompted the UK authorities to tackling stress and develop explicit guidance on stress risk assessment known as the	The Management Standards is a framework for managing stress and the associated risk assessment.	HSE	Mellor *et. al* (2011)	Yes

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
			Management Standards approach (Mellor *et al.*, 2007)				
15	**Nurses Work Functioning Questionnaire**	A 50-item self-report questionnaire	The NWFQ aims to measure impaired work functioning due to CMDs in nurses and allied health professionals (Gartner *et al.*, 2011)	It consists of seven subscales: 1) *cognitive aspects of task execution and general incidents*; 2) *impaired decision making*; 3) *causing incidents at work* (not applicable for allied health professionals); 4) *avoidance behavior*; 5) *conflicts and annoyances with colleagues*; 6) *impaired contact with patients and their family*; and 7) *lack of energy and motivation* (Gartner *et al.*, 2011)	Gartner *et al.* Unpublished.	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3112124/	Unknown
16	**Workers' Health Surveillance mental module**	Comprises of two modules and requires the intervention of an occupational health professional.	A preventive strategy for Common Mental Disorders and impairments in work functioning in the health care sector.	The first WHS mental module strategy encompasses an online screening for mental health complaints and work functioning problems plus an optional consultation with an Occupational Health Professional for employees with mental health problems and/or work functioning problems. Directly after filling out the screening questionnaire, participants will automatically receive digital feedback on the screening results. The second WHS mental module strategy encompasses an online screening for mental health complaints and work functioning problems plus tailored advice on self-help e-mental health interventions (Gartner *et al.*, 2011)	Gartner *et al.*, 2011)	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3112124/	Unknown
17	**National Health Services' Screening and Testing Timeline**	Interactive online resource for public use	Unknown	A guide to screening and tests recommended during various life stages, classified under '0-16 years', '17-29 years, '30-64 years' and '65+ years'. Information in the '65 years +' category includes guidance and support regarding diabetic retinopathy, blood pressure, height and	National Health Service, UK	http://www.nhs.uk/Tools/Pages/Screening.aspx?Tag=Screening+and+tests	No

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
				weight, lungs and airways, cholestorol, heart disease, osteoporosis and glaucoma) (National Health Service, 2011).			
18	**The Work Capability Assessment**	A medical assessment by an approved healthcare professional to determine benefit entitlement	To determine entitlement to Employment and Support Allowance.	The assessment of a claimant's capability for work involves a physical and cognitive assessment e.g. assesssment of manual dexterity, navigation and maintaining safety, learning tasks, awareness of everyday hazards, reaching, understanding communication (DWP, 2011b).	Department of Work and Pensions	http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/@disabled/documents/digitalasset/dg_177366.pdf	No
19	**A set of tools to assess Mental workload assessment for train drivers**	Rating scales and Questionnaires	To assess the cognitive demand on train drivers	These include (i) a Train Driver Integrated Workload Scale which drivers can use to report their perceived workload (ii) Train Driver DRAWS (DRA (Defence Research Agency) Workload Scales which can be used to probe driver perceived workload (iii) Acceptable Workload Evaluation (AWE) which is a set of questions which can be used to identify unacceptable conditions (iv) Train Driver Workload Probe, a series of prompts to explore workload in depth (v) Time Line Analysis, to demonstate the relationship between workload and task activity (RSSB, 2004)	Rail Safety and Standards Board	http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/Research/T147_rpt1_final.pdf	Users of the tools require training.

Table 2: A sample of 'standard' scales/tests available for dutyholders to assess decrements in human function and performance

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
1	**Impact of Event Scale- (IES)**	A self-report questionnaire which measures stress reactions after traumatic events	According to Christianson and Marren (2008), the impact of a traumatic event on the elderly can be magnified by illness and medication, sensory limitations, mobility impairment, and literacy. that place the older adult in the special needs population after such an event. Thus the developers considered it important to evaluate an older adult's response to a traumatic event.	Sluiter and Frings-Dresen (2007) suggest that the IES could prove useful to screen out firefighters whose present health prevents them from performing their jobs safely. The IES-Revised has 15 questions some of which relate to measures of intrusion (intrusive feelings and imagery) and avoidance (avoidance of feelings, situations and ideas).	Horowitz *et al.* (1979)	http://consultgerirn.org/uploads/File/trythis/try_this_19.pdf	No
2	**The Epworth Sleepiness Scale (ESS)**	A short self-administered questionnaire.	To provide a measurement of an individual's general level of daytime sleepiness. It helps to diagnose those with excessive daytime sleepiness.	The questionnaire asks the subject to rate his or her probability of falling asleep on a scale of increasing probability from 0 to 3 for eight different situations. Sluiter and Frings-Dresen (2007) suggest that the ESS could be used to assess firefighters because of research which suggested that older firefighters tend to have greater difficulty with active duties during night hours and with the quality of sleep after these activities. This tool is also administered to safety critical rail workers in Australia as outlined by the National Transport	Johns (1991)	Johns (1991)	No

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
				Commission (NTC, 2011).			
3	**European Fitness to Dive Standards (EFDT)**	A series of medical and physical tests professionally administered and assessed.	To test the physical fitness of fire fighters who perform diving activities.	Consists of cardiovascular, ear, nose and throat, neurological, musculo-skeletal and vision tests. Exercise stress testing through the cycle ergometer test is also conducted.	European Diving Technology Committee (2003)	EDTC (2003) http://www.edtc.org/EDTC-Fitnesstodivestandard-2003.pdf	
4	**Multi-Attribute Task Battery (MAT)**	Computerised aircraft simulation tasks.	Developed for human operator workload and strategic behaviour research.	Consists of (i) a compensatory tracking simulating an aircraft fluctuating from its course (ii) a system monitoring task which simulated' system malfunctions' and required the subject to use temperature and pressure gauges and (iii) a fuel management task which simulated the actions required to manage an aircraft's fuel system (Vincenzi and Mouloua, 2001).	Comstock and Arnegard (1992)	http://www.faa.gov/library/online_libraries/aerospace_medicine/sd/media/Vincenzi.pdf	No
5	**Digit Symbol Subsitution Test (DSST)**	This can be administed electronically or as paper and pencil tests.	Designed to objectively evaluate cognitive function.	The DSST consists of (e.g. nine) digit-symbol pairs followed by a list of digits. Under each digit the participant is required to write down the corresponding symbol as fast as possible. The number of correct symbols within the allowed time (e.g. 90 or 120 sec) is measured.	Wechsler (1981)	Vincenzi and Mouloua (2001)	No. It has been used to test the cognitive competency of pilots.
6	**Sentence span test**	This can be administed electronically or as paper and pencil tests.	Designed to test working memory	The test contains a listening and reading component and measures the ability to simultaneously store and manipulate information in working memory (Morrow *et al*., 2003)	Original form of the test developed by Daneman and Carpenter (1980)	Morrow *et al.*, (2003)	No. It has been used to test working memory in pilots
7	**Letter comparison and pattern comparison tasks**	This can be administed electronically or as paper and pencil tests.	To measure processing speed	Participants are required to decide as quickly as possible whether pairs of letters or line patterns are the same or different	Used by Salthouse and Babcock (1991) to determine age-related declines in working memory	Morrow *et al.*, (2003)	No. It has been used to test speed of processing in pilots

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
					function.		
8	**Weschsler Adult Intelligence Scale –Revised (WAIS-R) Block Design test**	This can be administed electronically or as paper and pencil tests.	The WAIS-R Block Design Test is one of the tests within the Weschsler Adult Intelligence Scale (WAIS). The WAIS is a clinical instrument used to measure adult intelligence. The WAIS-R Block Test acts as one of the measures of perceptual organisation.	The participant is required to arrange a set of blocks to reproduce a displayed pattern (Salthouse, 1987).	Wechsler (1981)	(Salthouse, 1987).	No. It has been used to test perceptual organisation in pilots.
9	**Sternberg memory search task**	Presented aurally or visually electronically or as a paper and pencil test.	To test working memory	In the Sternberg Memory Search task the participant is required to memorise a series of stimuli known as the memory set. In aviation, these are typically letters or numbers. After hearing or seeing the list and holding it in working memory, the participant then receives probe stimuli and has to determine whether each probe stimulus presented was in the memory set.	Sternberg (1975)	Tsang and Voss (1996)	No. It has been used to test working memory in pilots and as an index of pilot workload (Wickens *et al*., 1986)
10	**Planikin mental rotation task**	This can be administed electronically or as a paper and pencil test.	Used to test processing required for mental rotation.	The Planikin task tests the ability to rotate mental representations of two-dimensional and three-dimensional objects and represents a test of the processing required in pilots for spatial orientation (Tsang and Voss, 1996).	Originally discovered by Shepard and Metzler (1971)	Tsang and Voss (1996)	No. It has been used to test the processing required for spatial orientation in pilots.
11	**The National Aeronautics and Space Administratio n Task Load Index (NASA**	A subjective workload questionnaire. This tool can be administered	To examine user workload for a specific task when working with human-machine systems such as aircraft cockpits, command, control, and	This requires participants to rate their feelings of task demand on six component scales regarding their working day, with each scale having a range of 0-20. The 6 subscales are: mental demand, physical demand, temporal demand, performance,	Human Performance Group at NASA's Ames Research Center over a three year development	Hart and Stavenland (1988)	Yes. It has been used in research by the Institute of Naval Medicine

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
	TLX)	as a paper and pen questionnaire or as an automated tool.	communication (C3) workstations; supervisory and process control environments; simulations and laboratory tests.	effort, and frustration level. An overall workload score is derived based on a weighted average of ratings on six subscales.	cycle that included more than 40 laboratory simulations. See Hart and Stavenland (1988)		(INM) to assess average daily work demands on personnel aboard Royal Fleet Auxillary vessels (INM, 2011)
12	**The Nordic Musculoskeletal questionnaire (NMQ)**	The NMQ can be used as a questionnaire or as a structured interview (Crawford, 2007).	To develop and test a standardized questionnaire methodology allowing comparison of low back, neck, shoulder and general complaints for use in epidemiological studies. The tool was not developed for clinical diagnosis (Crawford, 2007)	Section 1 is a general questionnaire of 40 forced-choice items identifying areas of the body causing musculoskeletal problems. Completion is aided by a body map to indicate nine symptom sites being neck, shoulders, upper back, elbows, low back, wrist/hands, hips/thighs, knees and ankles/feet. Respondents are asked if they have had any musculoskeletal trouble in the last 12 months and last 7 days which has prevented normal activity. Section 2 has additional questions relating to the neck, the shoulders and the lower back further detail relevant issues. Twenty-five forced-choice questions elicit any accidents affecting each area, functional impact at home and work (change of job or duties), duration of the problem, assessment by a health professional and musculoskeletal problems in the last 7 days (Crawford, 2007).	Kuorinka *et al.* (1987)	Kuorinka *et al.* (1987)	No. The NMQ has been used a numerous studies of occupational groups to evaluate prevalence of musculo-skeletal problems.
13	**Finger Tapping Test**	Computerised motor skills test	To measure fine motor speed	The participant is required to tap a key with their index finger as rapidly as possible during 10 second trials (Nygard *et al.*, 1991).	Unknown		No

No	Name of Tool	Type of Tool/Test	Reason for development	Tool/Test Description	Developed by	Further information	Designed for Dutyholders to use
14	**Bourdon-type letter cancellation test**	This can be administed electronically or as a paper and pencil test.	A visual search test	The task was to search and cancel, in 5 min, the given five letters in the rows of letters on a standard sized (A-4) sheet of paper. The result was the number of letters read in 5 min.	Unknown	(Lezak, 1983 as cited in Nygard *et al.*, 1991).	No
15	**Useful Field of View (UFOV) assessment**	Computer administered teast	This is a standard field of view test. The authors, based on their meta-analysis, suggest that this instrument could be used as a screening test for at risk older drivers.	The UFOV test is performed binocularly and measures the ability to process rapidly presented complex information and incorporates tests of stimulus identification, divided attention and selective attention. Studies have confirmed a relationship between UFOV test performance and future crashes, supporting the use of this instrument as a potential screening measure for at-risk older drivers.	Ball and Owsley (1993) http://138.26.36.150/VAI/PDF%20Pubs/The%20UFOV%20-%20A%20new%20technique%20for%20evaluating%20age-related%20declines%20in%20visual%20function.pdf	http://138.26.36.150/VAI/PDF%20Pubs/Clay_UFOV_Meta-analysis.pdf	No
16	**Operational Fitness Test (OFT)**	Role related physical tests	To determine the ability of the Royal Air Force (RAF) to fulfil their generic operational role, assist in preparing individuals for the physical demands of operations and to mitigate the risk of injury in the operational environment (Richmond *et al.*, 2008)	The OFT involves 4 representative service tasks (RSTs). These are (i) a single lift which represents the physical demands of loading/unloading a truck (ii) a repetitive lift and carry to encompass demands of loading a truck and carrying sandbags, (iii) a fire and maneouvre to test ground defence on foot against an enemy attack and (iv) a dig to test physical demands of sandbagging. Each of these RSTs represent the physical elements of generic core operational tasks likely to be performed by RAF personnel on deployment in an austere environment (Richmond *et al.*, 2008)	Optimal Performance Ltd., UK	http://www.tandfonline.com/doi/pdf/10.1080/00140130801939725	Designed for the Royal Air Force

7.4 APPENDIX 4. OVERVIEW OF AVIATION STUDIES OF PILOTS

Authors	Year	Age factors covered	Study aims	Research design	Sample	Key Findings / Conclusions
J. L. Taylor; R. O'Hara; M. S. Mumenthaler; A. C. Rosen; J. A. Yesavage	2005	Decrease in working memory and communication task accuracy.	To examine difference in aviation performance related to age and expertise. Examined communication performance, working memory, speed and interference.	Longitudinal. Quantitative study. Collected data on 3 cognitive constructs – working memory, speed of processing and attentional control in the face of interference or distraction	97 pilots aged between 45 & 69. Excluded major air carrier pilots, as they retire at 60.	Expertise (developed via experience and training) can increase performance on domain-relevant tasks for all ages. Age related differences in working memory (WM) span could account for age differences in communication performance. Age differences in WM could be explained by age-related difference in processing speed and interference control.
Li G ; Baker SP ; Grabowski JG	2003	Vision. Compares age and crash risk.	To examine the relationship between pilot age and risk of involvement in general aviation crashes	Empirical study analysing prospectively collected exposure and safety data	3306 commuter air carrier and air taxi pilots	Age did not have a significant effect on crash risk. The lack of association between pilot age and crash risk may reflect a 'healthy worker' effect, stemming from rigorous medical standards for pilots. Flight experience showed a significant protective effect against risk of crash involvement.
J. L. Taylor; M. S. Mumenthaler; H. C. Kraemer; A. Noda; R. O'Hara; J. A. Yesavage	2001	Cognitive performance – general speed / working memory; visual associative memory; tracking; motor-coordination.	To identify if there is one age at which critical declines appear in aviator performance.	Longitudinal study. Quantitative. Measures at 3 time points	87 pilots aged between 49 & 69.	Each age group increased its performance on the computer administered cognitive test battery. The test scores showed significant practice effects, with the exception of visual associative memory, which stopped increasing after the second test.
Li G ; Grabowski JG ; Baker SP ; Rebok GW	2006	Errors	To understand the effects of ageing on safety performance among commercial aviation pilots	Quantitative study. Analysis of past aviation investigation reports	Studied 558 air carrier accidents	Prevalence and patterns of pilot error in air carrier accidents are not significantly associated with pilot age. This lack of association between pilot age and error may be due to the 'safe worker effect' resulting from rigorous selection process and

						certification standards for professional pilots.
D. G. Morrow; W. E. Menard; H. E. Ridolfo; E. A. L. Stine-Morrow; T. Teller; D. Bryant	2003.	Verbal and spatial ability (communication and navigation). Vocabulary and verbal working memory capacity, processing speed.	To investigate expertise, cognitive ability and age related declines in pilot communication.	Comparative design – comparing pilots and non-pilots based on the outcome of 3 aviation tasks.	91 pilots & 96 non-pilots 3 age groups 22-40 50-59 60-76	Age related declines in cognitive ability were found in pilots and non-pilots. Measures of working memory capacity and spatial ability predicted communication performance. Pilots excelled (more than non-pilots) on the aviation tasks because of their domain specific knowledge. Older pilots may not have been able to compensate for cognitive decline, via using their domain relevant expertise, due to being tested in a simulated as opposed to 'real live' flight environment.
P. S. Tsang; D. T. Voss	1996.	Cognitive skill – time sharing	To investigate what effect age and expertise have on time-sharing performance.	Comparative study of pilots and non-pilots across 3 age groups. Non-pilots used as a control group (as believed to have no time sharing skills).	45 pilots and 45 non-pilots aged between 20 and 79. Three age groups (20-39; 40-59; 60-79).	The influence of age on time-sharing seemed to be moderated by expertise. Age alone is not a definitive discriminator of an individual's time-sharing skill. Experience and expertise play a role in level of performance. NB covered in review paper by Hardy and Parasuraman (1997) in detail
D. A. Vincenzi; M. Mouloua	2001.	Cognitive competency (fluid intelligence)	To identify significant differences in performance between age groups, and investigate the influence of experience.	Comparative study of 2 age groups (young and old) and 2 types of experience (pilots / non-pilots). Quantitative – used a multi attribute task battery.	120 participants, 60 pilots, 60 non-pilots. Two age groups (18-30 and 60-75) with 30 pilots and 30 non-pilots in each group.	Cognitive speed and ability reduce as age increases. Cognitive competency was highest in the younger groups. Correct detection of automation failures is affected by both age and experience, pilots performed better than non-pilots, and younger groups better than the older ones. Performance appears to be a function of time-sharing ability, and experience may enhance this ability as well as determining how available resources are distributed to deal with multiple tasks.
D. J. Hardy; R. Parasuraman	1997	Covers theories of cognitive ageing; studies of older pilot cognition and the role of expertise.	To review studies of cognitive proficiency and flight performance of older pilots	Literature review	Review paper	There may be important age-related differences in pilot performance that are not picked up in laboratory measures of cognitive proficiency.

Li-G; Baker-SP; Grabowski-JG; Willoughby-S; Rebok-GW	2002.	Cognitive abilities:- memory; concentration; mental acuity and reaction speed. Piloting skills. Health.	To investigate the relationship between age and self-reported changes in cognitive function and piloting skills.	Survey. Self-report - for pilots to rate changes over a ten year period.	1310 commercial airline pilots aged between 28 and 59, divided into 3 age groups (under 39; 40-40 and 50-59)	Self-rated changes in health and cognitive abilities (particularly concentration and mental acuity) were significantly related to self-rated changes in piloting skills. Higher age was associated with less positive self-ratings on the tests, perhaps due to greater optimism at younger ages. Memory and reaction speed were the abilities that the highest percentage of pilots across the age groups rated as having declined. Pilots reporting negative changes in anxiety reported more negative changes in cognitive abilities, piloting skills and health status, regardless of age.
P. S. Tsang	1997.	Short term memory Perceptual motor speed; tracking; mental rotation; memory	To examine the relative contribution of age to performance, against demographic and flight experience variables	Comparative design – comparing pilots and non-pilots	Not specified but appears to use sample as in 1996 study 45 pilots and 45 non-pilots aged between 20 and 79	Age is not a good predictor of an individual's performance. Other variables, such as intelligence and perceptual motor speed, are more predictive of both single and time-sharing performance. Pilot expertise contributed only modestly to the single task and time-shared tracking performance.
C. Pelegrin; V. Maho; R. Amalberti	1995.	Exam performance, Learning (to fly different / unfamiliar aircraft).	To draw a typology of the difficulties met during training, according to pilot age		Pilots transitioning to Airbus A320. Aged between 20 and 62	Age was found to be a handicap to making the transition to a new system and older pilots needed longer to adapt. However, some older pilots performed very well which demonstrates variability between individuals. If experience on the system and task management can be transferred, age does not affect performance. Pilots compensate for slow learning with better consciousness of their own possibilities

7.5 APPENDIX 5. OVERVIEW OF STUDIES FITTING THE SEARCH CRITERIA (EXCLUDING PILOTS)

Author	Year	Sector	Study aims	Research design	Sample / jobs	Key findings / Conclusions
Sluiter J.K.	2006	Fire; Ambulance; Police; Medical Aviation; Space; Submarine.	To identify if the age of the worker is an important factor in explaining diversity in work ability in high demand jobs. To present an overview of what is known about work ability and age in high demand jobs.	Literature review on relationship between work ability and age in the context of high demand jobs.	Sample N/A Fire fighters; Ambulance workers; Police officers; medical specialists; pilots / astronauts; submarine officers	Currently there is no information about the performance of older workers in high demand jobs. Assessment of single demands will probably not reveal enough relevant information about work ability (WA) in high demand jobs and there will be a call for more integrated measures. Specific details about WA of ageing workers in high demand jobs are scarce. Existing studies have used various methods to address the issue such as task analysis for quantifying physical work demands, observations of psychological and physiological parameters, measures of psychosocial work demands and health complaints. Functional performance is the most critical predictor of future job performance, but it has not been applied extensively in job surveillance. Criteria should be established for 'successful' and 'unsuccessful' performance. Time on task could be a valid criterion. Work situations with higher risk of health issues could also be valid criteria. Criteria could be used for decisions involving interventions or permission to continue working.
Tobia	2005	Chemical, Energetic, Sanitary and public fields	To examine the differences in work ability scores in four different fields and in age groups.	Participants completed the work ability index. (no details on how sample was selected or further information on design).	416, 45-64 year olds. Chemical industry (workers, area managers, maintenance agent); Energetic field (workers, powerplant managers); Nurses; public bodies (functionaries, managers)	Average work ability scores were lowest in the chemical field, although there was no substantial change in this score between age groups in this field. Average work ability scores in the public and sanitary field were the highest and showed a decrease as age increased. **WAI scores were lower in those fields where more psycho-physical effort is required.** When all fields were taken together, work ability decreased as age increased. Work ability will be a dynamic process, as it is the result of an interaction of individual resources, work conditions and society. Ageing has a negative influence on perceptions of work

						ability. Good self-esteem and psychosocial wellbeing can positively influence the development of work ability
Costa G.; Sartori S.	2007	Construction, Chemical plant, Health care.	To report main results from several studies of Italian workers, using the work ability index	Quantitative study – measuring scores on the work ability index according to age, gender, work activity and working hours.	1449 workers divided into 5 groups. Health care - Nurses, Physicians, lab technicians, biologists, clerks. Chemical: blue collar workers, foremen, clerks. Construction: miners, carpenters, maintenance workers, dumper drivers, storekeepers, clerks	WA remains quite constant and high over the years in jobs with higher mental involvement and autonomy. It significantly decreases with a steeper trend the higher the physical workload and the lower the job control (e.g. in nurses and manual workers). Women showed a higher percentage of poor / moderate WA than men at all age groups except the youngest (both for shift an non-shift workers). Shift workers in general showed a higher percentage of poor / moderate WA than day workers. Shift workers suffer more illness at all ages Female shift workers show a much earlier decreasing of work ability than men, as compared to their day working colleagues. In male shift workers, the effect of work on WA appears to be relevant only in the oldest decade. WA progressively decreases as long as the number of illnesses increases. This has a higher influence than age – although there is a significant increase in the number of illnesses with increasing age.
Becker-JT; Milke-RM	1998	Air control	To discuss the effects of ageing on the performance of air traffic control (ATC) specialists. Discusses data from a number of studies and literature on aviation (including studies of pilots i.e. wider than ATC).	Discussion paper based on previous studies and literature. Does not include detail on how data was collected or selected for inclusion. Does include some studies of pilots.	Air traffic controllers	Multitasking is perceived to be an integral and important component of the ATC specialist job. The two most important forms of multitasking, according to controllers, involve the use of auditory and visual modalities to gather information simultaneously or near simultaneously and the continuation of job activities despite having to handle frequent interruptions". There have been no clear demonstrations that older age necessarily leads to poorer job performance. Blanket statements regarding age and performance are probably unwarranted, and it would be a mistake to assume that the age / performance correlation is simple and straightforward. It is factors other than age (but those that may be correlated with age) that are suggested to affect performance. Amongst air traffic control specialists, it is cautiously

						predicted that, domain relevant processes and processing are less affected by age, than less relevant processes. It is not clear whether competence is moderated by experience, or whether only expertise affects performance. Whilst having on the job experience in the ATC environment appears to moderate the effects of advancing age, this benefit cannot be maintained over the life span of a controller. As age and experience are highly correlated, it is difficult to disentangle the separate effects of these two factors on performance ratings. Chronological age and factors highly correlated with age affect the performance of demanding cognitive tasks with the aviation environment. There is a relationship between age and job performance among ATC specialists. Whilst a variety of factors can negatively affect job performance (e.g. motivation) the data reviewed here implies that the age-related changes in cognitive abilities also may contribute to changes in performance.
J. T. Becker; D. Broach	2003	Air control	To compare the interaction between chronological age and on the job experience. To test the prediction that performance on time-based measures of the air-traffic scenario test would decline with advancing age.	Comparative study of experienced and new air traffic controllers	Air traffic controllers – maximum age of 40.	Experienced controllers showed a small decrease in efficiency over the age range, whilst trainees had significant declines in performance. On the safety variable (index of procedural errors) there was a small but significant effect of age i.e. older controllers made more errors than younger ones In 20 to 40 year old air traffic controllers, job experience can moderate measures of job or task efficiency i.e. experience can moderate the effects of age on the performance of a job-relevant task by affecting the efficiency with which certain operations are performed. Domain specific expertise such as ability to predict future events can be seen as critical for the efficient transit of an airplane through simulated airspace.
Janke, M.K.	2001	Driving	To evaluate non-driving tests (such as tests of visual acuity, recognition speed and reaction time) and choose those that	2 studies. Study one was 135 subjects, two groups of experienced	Driving	Overall, referrals showed a significantly worse performance than volunteers in most driving tasks and all driving measures. Almost all non-driving measures were significantly related to both age and group, only the Doran reaction distance and knowledge test errors were not

			could be used to identify and assess drivers whose ability to drive safely is in question. To select tests that could be used by the licensing agencies. To develop a model testing system for evaluating drivers with ageing-related disabilities.	older drivers. 102 referrals for re-examination because of a medical condition, licensing test failure, flagrant driving error or other serious problem likely to affect driving. Group 2 were 33 paid volunteers. (The age range changed during the study from max of 55 to max of 65). Study 2 was 101 highly educated older drivers aged from 72-90.		significantly related to either. No non-driving measure was related to gender. The Snellen test is now used to screen applicants, along with the standard knowledge test. This appears to constitute the first tier batter that could be administered, regardless of age. The Pelli-Robson contrast sensitivity was the most significant first tier measure in distinguishing referrals from volunteers. Previous studies have found this test to be related to prior crash experience for drivers aged 70+ and young drivers wearing contact lenses. So it is a test that could be used for all ages.
Llaneras-RE; Swezey-RW; Brock-JF; Rogers-WC; Van-Cott-HP	1998	Driving	To investigate 15 human abilities, the changes in these that occur with ageing and the effect on truck driving performance. To identify and reduce risks associated with older commercial drivers. To map key functional abilities to driving performance in order to aid development of screening tools to identify unsafe drivers and	Sample was divided into 5 age cohort groups (under 30 to greater or equal to 50) Ages ranged from 31 to 76. Data collected in 3 geographical areas on drivers from 12 organisations.	107 commercially licensed truck Drivers.	Age in itself was not predictive of driving performance. There is a significant relationship between the 15 abilities and driving performance. All 4 interventions led to enhanced performance. All 6 perceptual abilities showed a negative correlation with age. Significant differences were found between the under 50 group and the 65 and over in static visual acuity, dynamic acuity, contrast sensitivity UFOV (Useful Field of View) field dependence and depth perception (the over 65s were significantly poorer). Whilst all 6 perceptual measures were found to significantly degrade by age 65, dynamic acuity and field dependence both degraded at age 55. 3 cognitive abilities decreased with age. The exception was

			ergonomic interventions to help drivers continue working safely.			decision-making accuracy. However, decision making speed was negatively correlated with age.
National Institute for Occupational Safety and Health (NIOSH).	2005	Driving	Fact sheet to help prevent crashes – for use by employers and workers. To present a commentary and list of tips for employers and workers.	Statistical data is from NIOSH analysis of the census of fatal occupational injuries and national transportation safety board highway accident report.	Drivers	The National Institute for Occupational Safety and Health (NIOSH) analysis of fatal occupational injuries found that roadway crashes are the leading cause of occupational fatalities for older workers in the US. In the general population, fatal crash involvement rates decrease with age. However deaths for work-related roadway crashes increase steadily beginning around the age of 55. Older drivers are more likely to have a crash at an intersection, particularly when turning across the line of traffic, and when merging or changing lanes on a freeway. The effect of many conditions on driving can be reduced or resolved with treatment for illness or other health problems. Forward thinking safety programmes, reasonable accommodations and open lines of communication between employers and workers can help protect older employees from death or disability due to roadway crashes.
Cloutier E; Champoux D	2000	Fire	To examine the effect of ageing on the frequency, severity and nature of accidents. To analyse the relationship between 2 risk factors – frequency rate and median duration of absence, and between age and the characteristics of accidents involving fire fighters	Quantitative analysis of accident data. Interviews with fire fighters and observations of actual fire fighting operations.	1041 fire fighter accidents 7 age groups. Max age group was 50+ Sample was from 2 municipalities	Accident frequency rate significantly decreased with age (consistent with the findings from other studies). Data from the field interviews suggested that the informal distribution of work that takes place at fire sites takes fire fighters age into account and the older fire fighters request transfers to districts with lower fire fighting workloads. Fire fighters exposure to particularly demanding tasks decreases with age. It is primarily young fire fighters who are exposed to exploration and ventilation hazards. An age related increase in falls is reported in virtually all studies that have examined the variation of the type of accident with age. The relationship between age and the incidence of accidents may reflect the exclusion of older workers not longer able to

						cope with certain work stressors. The authors suggest that the decreased incidence observed amongst older fire fighters may reflect their lower exposure to certain critical tasks (e.g. those associated with extinction operations). Older fire fighters probably exploit their experience and know-how to develop protective individual and collective work strategies. The age-related increase in accident severity may reflect an age-dependent increase in recovery time.
Sluiter, JK & Frings-Dresen, MHW	2007	Fire	To study the relationship between the age of fire fighters and their work ability. to answer following questions: Are specific tasks demands known? Are there any indications that older workers lose their ability to meet the work demands (safely)? Is there any evidence that (WR) ill health is worse in older workers?	Systematic literature review Quantitative analysis of secondary data. Qualitative interviews.	Secondary analysis of 1100 questionnaires from one previous study, data from 273 subjects in a second task analysis field study, and data from a third study involving functional physical capacity assessments of 25 fire fighters.	The oldest fire fighters had fewer accidents compared to their younger colleagues. Most indicators of work ability in fire fighters are related to age, but huge inter-individual variation between and within age groups has been found in task performance and task-related percentage of heart rate reserve. Although fire-fighters may be a healthy group of people, compared to the general population, with increasing age work-related ill health is worse and is up to six times higher in older fire-fighters than it is in their youngest colleagues. The international literature proved to be lacking in age-relevant evidence about the work-related emotional or psychological effects of fire fighting.
Kowalski-Trakofler K.M.; Steiner L.J.; Schwerha D.J.	2005	Mining	To discuss psychological and physical issues specific to the ageing workforce and relate this to the mining industry.	Literature review / commentry	Sample N/A Miners	With reference to the literature this paper provides a list of age related cognitive and physical declines (see Appendix 3). The biggest issue in mining is the low light environment A socio-ecological approach (to training) is suggested to support the older worker. This approach focuses on 1. the individual employee; 2. the physical workplace; 3. organisational dynamics and 4. the community / culture. It focuses on the interactions between humans and their environments, including the institutional and cultural context. Recommends a template for maintaining older workers in mining.

L. Laflamme; E. Menckel; L. Lundholm	1996	Mining	To examine age and accident rates in Swedish iron-ore miners	A retrospective longitudinal analysis of accidents over a 10 year period from 1980-1990	5 age groups of miners	Aggregated age related accident rates were generally lower in older age categories. This may be due to inequalities in risk exposure e.g. better employment conditions for older workers mean they are exposed to less risk, or because they use compensatory skills. Injuries tended to be more severe in older age groups.
Bresic	2007	Oil Industry	To see if different working conditions and occupational exposure to different hazards in an oil refining company would be associated with different perceptions of work stressors and work ability.	Cross sectional design. Convenience sample. Quantitative questionnaire. Comparative study looking at the difference in work ability in 3 jobs in an oil company	Oil company office workers, lab workers and oil field workers.	Stress at work can reduce safety and increase chances of occupational injury of workers working on oil platforms. Most workers in the study believed they were exposed to stress but the perception of specific stressors depended on the workplace environment (between offices, labs and platform). Fear from chemical hazards was greatest in the lab and field workers. Work overload and overtime & shift work, night shifts and 24 hour time on duty were more often perceived as stressful by the oil field workers than the other 2 groups. Stressors perceived by oil field workers indicate more difficult work conditions and stressful working schedules. Poor communication with colleagues and conflicts were not perceived to be a stressor in field workers but was a stressor for lab workers. The perception of 23 potential stressors did not differ between the groups of workers The average WAI score for all workers showed satisfying work ability. The lowest WA was found in the oil field workers (39.7) then the lab workers (43.2) and then the office workers were highest (44.9). ANCOVA showed that after adjusting for age, there was a significant difference in WAI scores between the workplace groups (which could be due to different conditions at work).
Shahani-C	1987	Petroleum	To examine the relationship between risk of accident involvement and the ageing process. To examine the extent to which progressive selection was a factor (i.e. that the proportion of employees in different age groups will differ	5 age groups were constructed 21-30; 31-40; 41-50; 51-60; 61+ Secondary accident data from existing databases was analysed. Accidents were	5 ‘job families’ were created: Operations personnel; Electrical craft; Process craft; Maintenance craft; Miscellaneous Data from 1839	The relationship between accidents and age was negative. It does not appear as though increased age is associated with an increase in the rate and severity of industrial accidents, at least for the current occupational sample. It did not appear that the proportion of employees in different age groups differed across the job families. Therefore, this study provides little evidence of progressive selection. The proportion of major accidents did not differ considerably between age groups. However, the 5 job families had markedly different accident frequency rates. In terms of

			across job categories).	classified into 3 levels of severity – no injury, minor injury and major injury.	different Shell Oil company employees.	accident severity, there was little difference in the proportion of major accidents across different job groups. High and low risk jobs did not greatly differ in proportion of severe accidents. Past research has generally ignored the situation or job context when examining the relationship between industrial accidents and age. Regardless of the risk of occupational groups, the youngest age group had the highest frequency of accidents. The accidents for all age groups increased for high risk jobs. In general, there were few differences in the relationship between accident frequency and age across job families except in the oldest age group. However, since there were few people in this oldest group, it is difficult to make conclusive statements about these differences. There were few differences in the relationship between accident frequency and severity with age across the different job families. The relationship of age and accidents did not differ for high and low risk occupational groups
Attwood-DA	2005	Petroleum	To describe the physical, physiological and psychological changes that take place with age, using examples from the petroleum workplace. To look at how performance might be affected by age and how equipment, facilities and work processes can be improved to account for the limitations of the ageing worker. To look at three categories of performance, physical, sensory and mental capabilities	Is a commentary based on 5 research papers.	Covers tasks not jobs: Operating valves, manual material handling, processing visual information, hearing alarms.	Many jobs in the process industry require the operation of valves, which if not optimally located and oriented, require force to operate them. This may cause issues for older individuals who have reduced force capability. Manual material handling tasks require strength and high energy levels expended over long periods of time, which is an ability that reduces with age. Older workers may experience difficulties hearing high frequencies and have reduced ability to resolve visual information. If displays are confusing, it will take longer for older process workers to decode / process them, which could cause problems in ‘upset conditions’ due to slower decision-making responses.

Bjerkebaek, E.	2002	Petroleum	To present and discuss ageing and health risk in the Norwegian offshore petroleum industry. To present how authorities, employer organisations and labour unions are working together to develop strategies to manage problems of age and health. Presents results in changes in demographic and health variables, specific offshore-related health risks for older workers associated with long-term exposure effects.	Comparative design looking at changes between 1992 survey data and 1998 survey data. Five age groups	Sample is from operating companies, rig-owners and entrepreneur companies with activity on the Norwegian continental shelf. The 1998 data represented approximately two thirds of the total offshore population. No breakdown by job.	Mandatory health licensing and special working conditions offshore probably result in a marked 'healthy worker' selection effect. Employees aged 60 or over showed a 50% rise in loss of license than younger age groups. Mandatory licensing is required to work offshore due to 'emergency preparedness' reasons, yet physicians claim that licenses are mainly revoked based on reduced work ability in the offshore environment. Age related health problems are a major contributor to loss of license and early exit from offshore employment. Prolonged exposure to shifts is believed to increase the risk of gradual reduction in physical performance capacity. Although loss of license represents one of the major career end points for offshore workers, there is no systematic knowledge or statistical information as to which health problems are the most important in reducing work ability for the ageing offshore worker.

7.6 APPENDIX 6. OVERVIEW OF ADDITIONAL STUDIES

Author	Year	Sector	Subject Covered	Research design
Bohle, Pitts and Quinlain	2010	N/a	Risks. Work ability and working hours	Review
Charness	2008	N/a	Types of human factors topics published in a journal	Review of journal content
Choi	2009	Construction	Injuries, illness and fatalities in the United States	Narrative study / Literature search
Duffy	2003	N/a	Shift work	Review
Findley and Bennett	2002	Nuclear	Injuries	Quantitative data analysis
Folkard	2008	N/a	Injury rates in night shifts	Review
Kloimuller, Karazman and Geissler	2000	Driving	Work ability and stress	Quantitative study
Leaviss, Gibb and Bust	2008	Construction	Analysis of construction accident statistics	Quantitative secondary data analysis
Ng and Feldman	2008	N/a	Job performance	Meta-analysis
Popkin et al.,	2008	Transportation	Impact of older workers on the transportation workforce. Skills and abilities required by transport jobs.	Review
Ringenbach & Jacobs	1995	Nuclear	Injury and safety behaviour	Quantitative and qualitative study
Mahta and Agnew	2008	Construction	Effects of muscle fatigue on performance	Quantitative study
Muller	2011	Aviation	Job of Apron control. Attention performance and subjective workload	Quantitative study
Silverstein	2008	N/a		Review
Williams, Bell & Daniels	2007	N/a	Human reliability assessment	Review
Yeomans	2010	N/a	Age-related effects on employment	Review

7.7 APPENDIX 7. PHYSICAL AND COGNITIVE FUNCTIONS THAT MAY DECLINE WITH INCREASING AGE (ADAPTED FROM KOWALSKI-TRAKOFLER ET AL., 2005).

Areas of cognitive decline	**Sub-categories of decline**
Decreases in working memory	Difficulty learning new concepts (see learning sub categories)
	Difficulty recalling complex or uncommon operational procedures
	Difficulty solving novel problems
Decreases in attentional capacity	Difficulty performing concurrent activities
	Difficulty switching attention between competing displays of information (divided attention problems)
	Reduction in accuracy and need for more processing time for indirect / not logical tasks
	Problems attending to / selecting information on complex displays
Intelligence	
Language	
Decision making	
Learning	Comprehension difficulties
	Lower capacity or greater vulnerability of short term memory storage
	Consolidation problems
	Changes in long term memory storage
	Search and retrieval problems
Decrease in speed of info processing	
Decreases in perceptual abilities	
Areas of Physical decline	**Sub-categories of decline**
Vision	Loss of contrast sensitivity
	Decreases in dark adaptation
	Declines in colour sensitivity
	Heightened susceptibility problems with glare
	Decline in visual search skills
	Ability to detect targets against a background
Hearing / auditory function	Loss of sensitivity for pure tones, especially high frequency
	Difficulty in understanding speech, especially if speech is distorted.
	Problems localizing sounds
	Problems in binaural listening
	Increased sensitivity to loudness
Balance	
Muscular Strength	
Aerobic capacity	Reduction in ability to regulate temperature of the body
	Increase in difficulty in carrying out demanding tasks
Joint mobility	Decline in small motor movements (grasping, gripping, twisting, turning)
	Decline in large motor movements (walking, bending, sitting, climbing, stooping, reaching).

	Impairment in ability to locate and identify textures and surfaces leads to increased difficulty grasping, holding or manipulating small, smooth objects.
	Increase in the incidence of arthritis and shoulder muscle fatigue
	Decline in pressure receptors in the body - may inhibit ability to detect pressure cues (e.g. pressing a switch or button)
Sensitivity	Decreases in sensitivity to pain caused by thermal stimuli (heat / cold)
Manual dexterity	
Reaction and movement times	Decreases due to decline in sensory organs and musculoskeletal system
Endurance	
Osteoporosis	
Cardiovascular disease	
Metabolic disorders	

7.8 APPENDIX 8. DRIVING RELATED ABILITIES (ADAPTED FROM LLANERAS ET AL, 1998)

Perceptual abilities	Definition	Relationship to age	How this was measured
Static visual acuity	The ability to resolve details of a stationary object	Acuity changes as a function of increasing age; changes become recognisable in the mid forties. Static visual acuity has been found to have a weak, but consistent relationships to traffic accidents.	Titmus vision tester
Dynamic visual acuity	The ability to resolve details of a moving object	Decreases with advancing age, accelerating rapidly after age 50. Believed to be important for many driving activities including reading street signs and locating road boundaries.	Dynaviz
Contrast sensitivity	The ability to detect targets of varying contrast	Older drivers have a significant decrement in discriminating detail under low levels of illumination, and therefore may have difficulty in reading road signs and detecting objects in the presence of glare or under poor viewing conditions.	Functional acuity contrast test chart
Useful field of view (UFOV)	The area of the visual field that is useful for acquiring information during a brief glance	Older drivers are less able to detect or process information in the periphery due to a shrinking attentional window. Restrictions in the UFOV may increase the probability of vehicle crashes due to perceptual slowing, increased sensitivity to distraction, and inability to divide attention between central and peripheral tasks	Visual attention analyser
Field dependence	The ability to perceive relevant targets embedded within a complex scene	Age related degradations in this ability cause drivers to require longer eye functions to gather relevant information.	Part of an automated psychophysical test battery designed by the National Public Service Institute
Depth perception	The ability to judge distance and changes in distance	The ability to make accurate depth judgements and detect changes in depth decreases with age; age related changes have been shown to occur before the age of 40. Inability to judge distances through angular movement may be a critical contributor to accidents, such as following too closely which comprises a majority of vehicle crashes	Titmus vision tester

Cognitive abilities	Definition	Relationship to age	How this was measured
Decision making	The ability to determine when a situation requires action, select among alternative courses of action, and to execute the appropriate response	Older adults show slower performances when faced with reaction time tasks involving multiple response alternatives. As a result older drivers have difficulty making quick and accurate decisions under demanding situations. Executing left turns (across the line of traffic in America) through intersections, parking and backing, merging into traffic and right angle turns – all situations requiring decision making have been shown to be problematic for older drivers	Automated psychophysical test battery (icon choice reaction time test)
Selective attention	The ability to select one stimulus source from among others, and to filter out potential distractors	Attentional capacity generally becomes more limited with increasing age. Older drivers have been shown to make mistakes of omission, characteristic of attentional deficits, such as failing to yield and running red lights.	Automated psychophysical test battery (selective attention test)
Attention sharing	The ability to shift attention between multiple sources of information	Deficits in the ability to divide attention have been associated with advancing age and increase accident rates. Older drivers have difficulty in sharing attention between two tasks, especially when at least one task is complex or greatly emphasised.	Automated psychophysical test battery (dual task measure of attention sharing)
Information Processing	The ability to search for and extract information and perform mental operations	The speed at which information processing operations are performed decrease with age . Problems are pronounced when attention sharing between two or more tasks is required.	Trail marking test

Psychomotor abilities	Definition	Relationship to age	
Reaction time	The ability to respond quickly to a signal	Reaction times remain constant until about age 26, then gradually decline. Although equivocal, studies tend to indicate that reaction times are slower for older drivers under conditions of	Automated psychophysical test battery (icon simple reaction time test)

		unexpected roadway hazards	
Multi-limb coordination	The ability to coordinate multiple limb movements	Few studies have examined this ability as defined here. Studies investigating related aspects, such as muscle strength, grip strength, and proprioception, have indicated higher incidences of vehicles collisions with decrease in these measures	Gear shifting performance on the TT150 simulator
Control precision	The ability to accurately position controls quickly and repeatedly	Age related differences in the ability to control lever movements similar to those associated with operating a manual transmission, have been reported in the literature	Visuo-spatial I package, maze 2 program
Tracking	The ability to follow a path or pursue a moving target	This ability progressively deteriorates, in a near linear fashion with age. Significant decrease in this ability is evident by age 55.	
Range of motion	Limb/joint movement and flexibility as measured by degrees of angles of movements	Trunk and neck flexibility have been shown to decline with age. This may influence older drivers ability to perform various driving tasks such as checking the mirrors during turns and backing.	Goniometer (to record flexibility)

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Age related changes and safety critical work

Identification of tools and a review of the literature

The removal of a compulsory retirement age may have implications for health and safety at work, and as such is a cross-cutting issue for HSE. HSE is concerned that some workers may continue to perform tasks with deteriorating performance. This may be a particular issue in safety critical and major hazard industries, and could potentially lead to an increase in the risk of major incidents or injury. More generally, dutyholders may also be finding it difficult to judge whether workers have the functional capacity to work to the required level of safe performance.

This piece of work has aimed to assess existing evidence on age related changes in performance and safety critical work, identify tools that assist dutyholders to assess human function and performance and to critically consider what the findings mean in terms of the need for future work.

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