Irish Ergonomics Society

Irish Ergonomics Review 2014

Proceedings of the Irish Ergonomics Society Annual Conference 2014

&

Symposium on Lean and Patient Safety in Healthcare: Lessons from the Medical Device Industry

Volume 1

Edited by:

Enda F. Fallon
Matjaž Galičič
Liam Chadwick
Wil van der Putten

ISSN 1649-2102

Irish Ergonomics Review 2014 Proceedings of the Irish Ergonomics Society Annual Conference 2014 & Symposium on Lean and Patient Safety in Healthcare: Lessons from the Medical Device Industry, Volume 1

Published by the Centre for Occupational Health and Safety Engineering and Ergonomics (COSHEE), Irish Centre for Patient Safety, NUI Galway, and The Irish Ergonomics Society

ISSN 1649-2102

Irish Ergonomics Society

NUI Galway
OÉ Gaillimh

I.C.P.S.
Irish Centre for Patient Safety
Ionad Éireannach um Shábháilteacht Othar

Sponsored by:

Boston Scientific
Advancing science for life™

ICBE
Irish Centre *for* Business Excellence Network

NUI Galway - University of Limerick
Strategic Alliance

Table of Contents

THE EFFECT OF AUTOMATED MANUFACTURING ENVIRONMENTS ON EMPLOYEE HEALTH

Fiona Wixted and Leonard O'Sullivan

Department of Design and Manufacturing Technology, University of Limerick, Ireland

AN ANALYSIS OF MUSCULOSKELETAL ACCIDENTS IN OPERATIONAL MILITARY TRAINING IN THE DEFENCE FORCES

Thomas O'Keeffe[1], Victor Hrymak[1], Leonard O'Sullivan[2]

[1]School of Food Science and Environmental Health, Dublin Institute of Technology, Ireland
[2] Human Factors & Product Design Research Group, Enterprise Research Centre, University of Limerick, Ireland

Abstract
This study analysed frequency of accidents suffered by members of the Defence Forces during operational military training in the period 2008-2013. Accident reports were examined and data gathered on a range of factors, including gender, age, weapon, load carried, environment, exercise type, training purpose, accident cause and injury site. Lost working time was used as a metric of injury extent. It was found that the majority of accidents occurred due to slips, trips and falls with a minority originating from manual handling events. The most common injury site was the lower leg with back and spine injuries also being significant. The activity engaged on when the injury occurred was found to be the most important factor determining the extent of injury, with most injuries occurring during tactical exercises and patrols.

Introduction

Military personnel are required to routinely carry out operational field training exercises on basic, career, and skills enhancement training courses and in preparation for overseas service. These exercises are designed to be more physically demanding than the normal scope of workplace activities. Indeed, the intention of the Defence Forces is for the exercises to be robust in order to prepare troops for the risks on operations (Defence Forces Training Instruction 05/2006). An analysis of Defence Forces accident data from 2004 to 2013 indicates that accidents in the training environment comprise 60% of all Defence Forces accidents and, of these, a significant number are related to tactical training exercises in the field. Such accidents on career enhancement courses can result in non-completion of training and limitation of career advancement.

Khanzode et al. (2012) described uncontrolled energy transfers leading to an accident and/or injury incident. Khanzode et al. (2012) also viewed occupational injuries as being caused by two types of energy exposures, acute and chronic. Injuries caused by sudden energy transfers to the body of the injured party are termed as traumatic injuries. Injuries caused by chronic exposure to repetitive motions or forceful exertions are termed as cumulative trauma disorders or repetitive strain injuries. The type of injuries noted in this study fall generally in the traumatic category, as very few chronic or overuse injuries were reported.

The exercises chosen for review in this study are characterised by the requirement to wear part or all of the Defence Forces Integrated Protection and Load Carrying System (IPLCS). This equipment consists of the following items of protective equipment: ballistic helmet, body armour, elbow pads and knee pads. Load carrying items consist of an assault vest or chest rig, 40 litre rucksack, 90 litre main rucksack and leg pouches. The equipment is modular and various combinations of equipment may be worn depending on the type of exercise envisaged. The weight carried can vary, but may reach in excess of 35kg when a 90 litre rucksack is worn. Helmets weighing 1.2 kg (on average) are worn on most exercises. Loads may consist mostly of ammunition, pyrotechnics (small military fireworks, designed to provide simulated noise or illumination), emergency rations and protective clothing. In addition, most exercises require the carriage of either a Steyr AUG Assault Rifle, (sometimes with an attached under-slung grenade launcher) or a General Purpose Machine Gun (GPMG). Protective equipment is worn in part to simulate live battle conditions as well as to provide protection against exercise hazards. The amount of weight borne in various exercises can depend on a number of factors such as exercise duration and anticipated resupply of ammunition, pyrotechnics food and water. However, based on guidelines, the following weights might be expected:

Figure 1. IPLCS Weights

Assault Vest	40 Litre Pack	90 Litre Main Pack	Total
10 kg	10 kg	15 kg	35kg

Carrying of heavy loads is common to most military forces. Treloar et al. (2011) reported Australian soldiers as carrying a minimum load of 21.6kg. The exceptional nature of this type of training is recognised to some extent in Section 6 (2) of the Safety Health and Welfare at Work Act 2005, which exempts training for active service and overseas operations from the statutory provisions. The position of Defence Forces training exercises in Irish case law was explained by Mr Justice Kinlen in the case of *Holohan v Minister for Defence*, (1998) when he stated that if there were strict Health and Safety Regulations applicable to military training it would impede training very considerably and would be counterproductive.

There is a significant body of research into various aspects of injuries occurring during military training. Jones and Knapick (1999) state that medical surveillance data from the US Army indicates that unintentional or accidental injuries cause about 50% of deaths, 50% of disabilities, 30% of hospitalisations and 40-60 % of outpatient visits. Jones and Knapick (1999) highlight the physical nature of military training comparing it to training conducted by athletes preparing for competition.

While there is literature on accidents which occur in military training, most studies focus on injuries suffered in basic training only. In the only similar Irish study, Kerr (2004) conducted a study into injuries suffered by 415 Irish recruits during basic training. It was found that lower limb injuries were the most frequently reported injury and that female recruits were more likely to suffer an injury than their male colleagues. Havenetidis and Paxinos (2011) also found a higher rate of injury among female Greek trainees than their male counterparts. What distinguishes recruit training is that there is a programme of fitness training to bring recruits up to the required fitness level prior to engaging in field training. However, preparatory training may not always be conducted prior to or during other forms of training which may leave personnel more susceptible to injury.

Types of Exercise

This study examines accidents which occurred during a range of training including basic, continuation and career training. The type of exercise which comes within the scope of this study all fall into the category of operational military training. The types of exercises considered are: navigational exercises by day and by night, patrolling (mostly by night), route marches on mixed terrain, and tactical exercises in both rural and urban settings. These exercises will be described briefly:

- Navigation exercise are essentially orienteering type exercises, mostly in forested or mountainous terrain and are conducted to practice and test navigational skills under time pressure. Full equipment is worn to maintain realism.
- Patrolling is an exclusively night time activity. The intention is to move stealthily through unknown terrain to gain information on a target, which could be either other troops on the exercise or a facility.
- Tactical exercises may be offensive, defensive or retrograde. Offensive tactical exercises typically involve short bursts of intensive activity involving a combination of sprinting, moving quickly into a lying or kneeling positions and crawling in order to take up a firing position, while at the same time concentrating on following orders and making decisions under time pressure. Defensive tactical exercises involve the digging and occupation of an entrenched position. Most of these exercises are conducted on Defence Forces training areas consisting of unimproved agricultural land but some were conducted on simulated urban environments.

Most exercises involve carrying a weapon, normally the standard Defence Forces weapon, the Steyr AUG rifle which weighs 3.6 kg when empty. When augmented with an M203 under-slung grenade launcher, weight is increased by an additional 2.15 kg. In each section of nine personnel, one soldier is equipped with a General Purpose Machine Gun (GPMG) which weighs 10.9 kg when empty. All weapons are supported by a sling worn around the neck. On some exercises when live ammunition is used, there is a requirement to wear body armour (7-8 kg) but this type of exercise did not appear frequently in accident reports.

Method

In order to examine the cause of accidents in operational training, the Defence Forces Accident Reporting System was analysed over a six year period from 2008 to 2013. While data were available from 2004, it was decided to examine data only from 2008 to coincide with the introduction of the Integrated Protective and Load Carrying System. The Defence Forces Accident Reporting System is an Oracle-based system on which digital records of details of all accidents, including minor accidents, which occur to Defence Forces personnel are inputted and maintained. On this system, accidents are categorised based on activity such as training, operational duty, etc., and circumstances, such as slip, trip, fall, manual handling, etc. For the purposes of this study, all accidents falling within the *operational military training* and *professional military training* categories of activity were analysed and details of accidents which resulted in musculoskeletal injuries, which occurred during tactical field training exercises were extracted and examined. Accidents which resulted in non-musculoskeletal injuries were not included. Accidents were examined from two Defence Forces formations, Defence Forces Training Centre based in the Curragh and 2nd Brigade, based in units in Dublin, Athlone and Finner Camp, Co. Donegal.

A brainstorming exercise was conducted with a small group consisting of a medical doctor, a military training instructor, a physical training instructor and a manual handling instructor to list potential causes of accidents. All the factors which could be related to the occurrence of accidents were then included in an Ishikawa (Fishbone) diagram. See Figure 1.

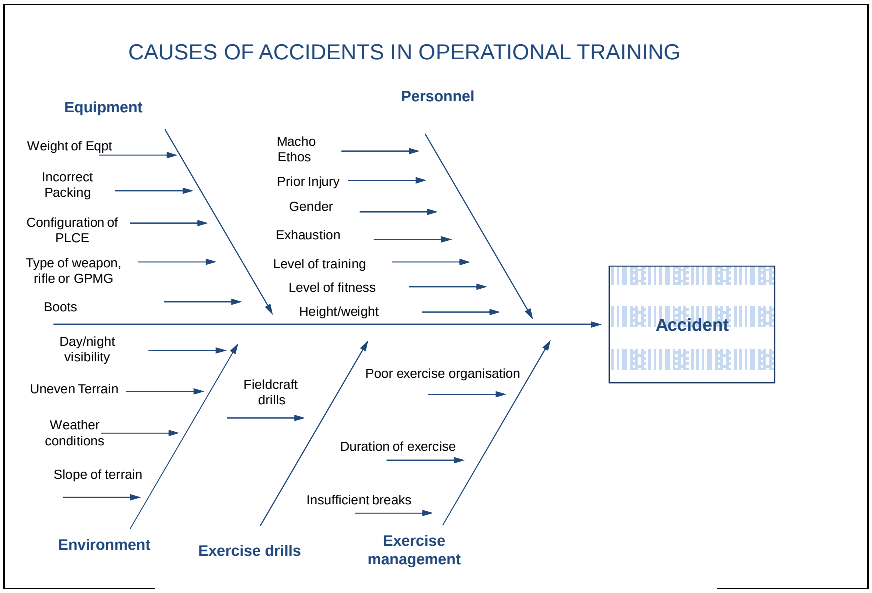


Figure 1. Ishikawa Diagram of Accident Causes

The diagram was analysed for factors which could be readily extracted from the Defence Forces Accident Reporting System and be subjected to statistical analysis. Following this process, it was decided to input data on the following variables: gender of the injured party, type of load being carried, type of location where the activity was taking place, type of activity, the weapon being carried at the time of the accident, the training purpose and injury type. Three further variables not directly related to injury cause were subsequently added: age of the injured party, site of the injury on the body and time lost due to the injury. A cross tabulation of the data using SPSS 21 was then conducted.

Results

The results of the cross tabulation of all variables versus extent of injury are detailed in Appendix 1. Lost working time was used as a metric of injury extent. Of all the independent variables, exercise type was the closest to significance (Table 7, p=0.055). An analysis of this variable indicates that most accidents were recorded from patrol and tactical exercise activity. While cross tabulation of extent of injury against other variables did not produce any result of statistical significance, nevertheless, some points of interest did emerge.

In the Gender and Extent of Injury Cross Tab (Table 2), injuries were recorded for 95 males and 15 females. The rate of accidents for females (13.5%) is approximately twice the percentage of females currently in service in the Defence Forces (6.2%), indicating a greater likelihood that females on the exercises will suffer an injury. However, the data indicates that gender has no effect on the severity of injury. Male personnel have an almost equal chance of suffering an injury resulting in light duty or an injury resulting in being excused duty or worse.

Table 7. Exercise Type and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Exercise type	Patrol	20	12	32
	Route March	11	9	20
	Day navigation	4	0	4
	Night navigation	2	8	10
	Tactical exercises	22	22	44
Total		59	51	110

Chi Square p = .055

In the Age and Extent of Injury Cross Tab, (Table 3), results reflect Defence Forces age structure with 88% of accidents occurring to those between the ages of 20 and 34, the age range when career level and skills courses are normally conducted by Defence Forces personnel. The data indicates that age does not have a significant effect on the extent of injury. The cross tabulation analysis for Weapon type by Extent of Injury is presented in Table 4. The data indicates that the weapon carried has no effect on the extent of injury.

It was expected that carrying the heavier 90 litre packs would result in a higher accident rate and greater extent of injury. The data for Backpack type (Table 5) indicates that this is not the case, with an almost equal chance of an accident with the three configurations of load carrying equipment, and no effect on the extent of injury.

Location and Extent of Injury Cross Tab (Table 6) indicates that the majority (55%) of accidents occurred in what is grouped in the data as 'fields', but no single environment affected the extent of injury to a significant level. While the Training Purpose and Extent of Injury Cross Tab(Table 8) indicates that more accidents (59%) occurred on career training courses, training purpose did not have a significant effect on extent of injury.

The Injury Cause and Extent of Injury Cross Tab (Table 9) indicates that the number of accidents caused by slip trip and fall events (82%) was far greater than those caused by manual handling causes. There was no significant relationship between the cause and resulting extent of injury

Body Part and Extent of Injury Cross Tab (Table 10) demonstrates that the most common site of injury was the lower leg (45%), with the next most common site being back or spine. There is no relationship between the body part injured and the extent of the injury.

Discussion

Overall, the majority of accidents, 82% were noted as resulting from a slip, trip, fall event, with the remainder, 18% being reported as resulting from manual handling type events. The accident rate of males to females at 85.7% to 14.3% by comparison with the ratio of those currently in service of 6.2% (Defence Forces Annual Report, 2012) indicates that females are more likely to have an accident in this type of training. This trend was also noted by Kerr (2004) but only in relation to recruit training.

When the activities which resulted in the accidents were analysed, the largest number occurred during tactical training exercises, which involve short bursts of intense activity. The next highest proportion of accidents occurred on patrols, which by contrast are conducted over longer duration and distances but with an emphasis on stealth. Evidence from the narrative reports indicate that a large number of the accidents during patrols were related to trip events during periods of limited visibility in forested or heavily vegetated areas. Day and night navigation exercises and route marches resulted in the lowest rate of accident, although these are mainly conducted in forest and mountain environments and required the carriage of the heavier 90 litre packs. Narrative accounts in the accident reports also frequently cite terrain as a factor in the accident event. Yet, over half of all accidents are reported as having occurred in a field type environment. By comparison with a forest or mountain environment, this type of terrain might be seen as presenting fewer trip hazards. The normal distribution of GPMG to Steyr is one GPMG for a 9 person section. The data indicates a lower accident rate for those equipped with GPMG than might have been expected. This may be related to the use of the GPMG on tactical exercises which generally involves less movement. The type of load carrying equipment worn was not found to be significant. This study did not take account of the frequency of use of each particular configuration of IPLCS and it could be the case that the larger capacity load carrying equipment is worn less frequently.

On examination of where the injury occurred on the body almost half of the injuries were lower leg injuries, while almost a third were back and spine injuries. Kerr in his 2004 study and Sell et al. (2013) found that the lower leg was the most common injury site for accidents occurring in operational training.

Although resulting in a greater extent of injury, manual handling related accidents occur far less frequently than slip, trip and fall type accidents. Narrative accounts in accident reports indicate that many slip, trip and fall events occurred on small scale offensive exercises when the subject was running or taking cover. Trelaor et al. (2011) identified this type of activity as an explosive and anaerobic military task and identified 30 metre sprints as a typical type of activity which could be expected during tactical training. Studies conducted by May et al. (2009) suggested that balance control became more difficult as sensory demands were increased. They found that the requirement of wearing a backpack load resulted in significantly less postural control than when a backpack load was not worn.

There are some limitations with this study. It was decided not to include some factors which may have contributed to accidents, such as weather conditions at the time of the accident, levels of fitness, precise nature of terrain, etc., as measurable data on these factors could not be extracted from the accident reporting system. Information on the weapon being carried at the time of the accident was dependent on information provided in accident report narratives and if not specified, an assumption was made that the Steyr rifle was being carried. An issue which emerged from the brainstorming session was the potential for non-reporting of an injury, particularly a chronic injury due to career limiting implications of not completing a particular exercise. This may explain the low number of reported chronic or overuse injuries. The small size of the dataset is acknowledged. The purpose of the paper is a preliminary study of the issue in preparation for a MSc dissertation.

Conclusion

None of the variables cross tabulated against extent of injury were found to be statistically significant with exercise type coming closest to statistical significance. Nevertheless a number of trends emerged, including the high number of slip, trip, fall events and lower leg injuries. This study will be continued using a larger dataset to confirm the trends noted. Possible interventions aimed at reducing the frequency of slip, trip and fall accidents will be explored as part of this wider study.

Acknowledgements

The authors wish to thank the Defence Forces for the kind provision of accident data.

References

Defence Forces, 2012, Annual *Report 2012*

Defence Forces, 2006, *Training Instruction, 05/2006, Training Risk Management*

Government Publications, 2005, No 10 of 2005*, Safety Health and Welfare at Work Act 2005*

Havenetidis, K and Paxinos K, 2011, Risk Factors for Musculoskeletal Injuries among Greek Army Officer Cadets Undergoing Basic Combat Training*, Military Medicine*, 176, 10:1111, 2011

Holohan v Minister for Defence (1998), IEHC 126, Available from, http://bailii.org/ireland/cases.html, Accessed 20 Mar 2014

Jones, B. H. and Knapick, J.J, 1999, Physical Training and Exercise Related Injuries, Surveillance, Research and Injury Prevention in Military Populations, *Sports Medicine*, 2, 111-125

Kerr, Dr. G, 2004, Injuries Sustained by Recruits during Basic Military Training in the Irish Army*, Irish Medical Journal*, Vol 97, No 3.

Khanzode VV, Maiti J, Ray PK, 2012, Occupational injury and accident research: a comprehensive review, *Safety Science*, 50 1355-1367.

May B, Tomporowski P D, Ferrara M, 2009, Effects of Backpack Load on Balance and Decisional Processes*, Military Medicine*, 174. 12:1308.

Sell CT, Pederson JJ, Abt, JP, Nagai,T, Deluzio J, Wirt M, McCord, LJ, Lephart, SM, 2013, The Addition of body Armor Diminishes Postural Stability in Military Soldiers*, Military Medicine*, 178, 1:76.

Treloar, Alison K. Laing and Billing, Daniel C, 2011, Effect of Load Carriage on Performance of an Explosive Military task*, Military Medicine*, 176, 9:1027.

Appendix 1

Cross Tabulation of all variables versus extent of injury

Table 2. Gender and Extent of Injury

		Extent of injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Gender	Male	50	45	95
	Female	9	6	15
Total		59	51	110

Chi Square p = .595

Table 3. Age and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Age	U-19	4	2	6
	20-24	18	21	39
	24-29	23	13	36
	30-34	12	10	22
	34-39	2	3	5
	40+	0	2	2
Total		59	51	110

Chi Square p = .357

Table 4. Weapon and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hospital, sick leave	
Weapon	Steyr 1	57	51	108
	GPMG	2	0	2
Total		59	51	110

Chi Square p = .185

Table 5. Load carried and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Backpack	Assault Vest	19	11	30
	40lt Pack	23	21	44
	90lt Pack	17	19	36
Total		59	51	110

Chi Square p = .414

Table 6. Location and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Location	Fields	35	26	61
	Forests	8	12	20
	Mountains	13	12	25
	Buildings	3	1	4
Total		59	51	110

Chi Square p = .458

Table 7. Exercise Type and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Exercise type	Patrol	20	12	32
	Route March	11	9	20
	Day navigation	4	0	4
	Night navigation	2	8	10
	Tactical exercises	22	22	44
Total		59	51	110

Chi Square p = .055

Table 8. Training Purpose and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Training purpose	Career	37	28	65
	Skills	22	23	45
Total		59	51	110

Chi Square p = .406

Table 9. Injury Cause and Extent of Injury.

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Injury cause	Manual Handling	8	12	20
	Slip/Trip	51	39	90
Total		59	51	110

Chi Square p = .176

Table 10. Body Part and Extent of Injury

		Extent of Injury		Total
		Light Duty or Medicine	Excused duty, hosp, sick leave	
Body Part	Lower Leg	28	22	50
	Upper Leg & Hip	5	1	6
	Back Spine	16	19	35
	Head & Neck	4	5	9
	Wrist arm elbow	4	1	5
	Shoulder	2	3	5
Total		59	51	110

Chi Square p = .392

BIOMECHANICAL AND PHYSIOLOGICAL ANALYSIS OF AN EXOSKELETON FOR MANUAL HANDLING

Kirsten Huysamen, Rachel Nugent and Leonard O'Sullivan

Department of Design and Manufacturing Technology, University of Limerick, Ireland

Abstract

Work-related musculoskeletal disorders (WRMSDs) are highly prevalent in industry, where back disorders are the most commonly reported disorder. These disorders highly correlate with manual tasks that involve handling of heavy loads and frequent lifting and lowering. Research is now focusing on the use of exoskeletons to reduce the external load placed on the human body in order to reduce the risk of developing WRMSDs. However, the research is in its infancy and detailed investigation is needed. The aim of this study was to evaluate the effect of reducing external load with respect to biomechanical and physiological responses. Compression force in L5/S1, energy expenditure data and risk of developing back disorders was determined during a lifting task which started at knee height and ended at shoulder height. This data was captured using 3D Static Strength Prediction Program, Energy Expenditure Prediction Program and the NIOSH lifting equation respectively. The task involved lifting three different loads, 5kg, 10kg, 15kg, at three different lifting frequencies (1 lift/min, 5 lifts/min, 9 lifts/min). The results indicate that compression force of L5/S1, energy expenditure and the risk of developing back disorders decreased with reduction in the external load for all test cases examined. It is concluded that an exoskeleton which augments the musculoskeletal system may reduce physical stresses to the human body and will subsequently reduce the risk of developing WRMSDs.

Introduction

Despite the development of modern technology, extensive automation, mechanisation and work-related interventions, many occupations still require manual material handling (MMH) activities such as pushing, pulling, lifting and carrying (Zurada, 2012; Bos et al., 2014). These activities place physical demands on the individual. If physical overload occurs in the workplace, it may result in the development of work-related musculoskeletal disorders (WRMSDs) (Zurada, 2012; Bos et al., 2014). In the USA, more than 600 000 workers have WRMSDs resulting in lost work time each year (da Costa and Vieira, 2010). Additionally, WRMSDs are the most expensive form of work disability, costing the USA approximately $215 billion in 1995 and Germany €38 billion in 2002 (da Costa and Vieira, 2010). According to Luttman et al. (2003), one-third of all health-related absences from work were due to WRMSDs, where back disorders having the highest prevalence (60%), followed by disorders of the neck and upper extremities.

The most commonly reported back disorder is lower back pain (LBP) (Hillman et al., 1996). This disorder is occupationally associated with prolonged or repeated exertion, such as heavy lifting, frequent bending and twisting of the spinal column, maintaining awkward postures and/or physical workload for long durations, and whole body vibrations (Bernard, 1997; da Costa and Vieira, 2010). Ergonomic aids have been used in industry in order to reduce these risk factors and the associated risk of developing back disorders (McGill, 2007). These aids help workers by minimising the physical stresses applied to the body (Marras and Karwowski, 2006; McGill, 2007). Some of these aids exist in the form of hand tools such as ergonomically designed screwdrivers or of supporting devices, such as back supports (McGill, 2007; Bhattacharya and McGlothlin, 2012). In spite of these aids, excessive spinal loading may still be present during MMH tasks such as lifting and lowering of loads.

There has been research in the use of exoskeletons as an ergonomic aid in the workplace (Lee and Sankai, 2002; Boff, 2006). An exoskeleton is a wearable robot attached to the human body to influence or assist human motion (Boff, 2006; Yang et al., 2008). Some exoskeletons are used for rehabilitation to assist human movement (Boff, 2006; Yang et al., 2008). Other exoskeletons, such as HAL 5: CYBERDYNE (Lee and Sankai, 2002), have been developed to enhance muscular strength in industrial workers or soldiers. The aim of these latter exoskeletons is to assist with MMH tasks such as lifting and lowering activities in order to reduce the external load applied to the body (Siciliano and Khatib, 2008). Conversely, this may result in reduced muscle strength due to the overload principal (Raven et al., 2012). As such applications are fairly recent; there is little research on biomechanical and physiological risks and responses to reduced external load.

There is strong evidence that frequent lifting and lowering activity increases risk for back disorders (Bernard et al., 1997; da Costa and Vliera, 2010). Commonly used assessment tools to assess the risk of developing back disorders during MMH include the Revised NIOSH Lifting Equation and 3D Static Strength Prediction Program (3D SSPP) (Waters et al., 1994; Guild et al., 2010). Both assessment tools are limited to the assessment of static handling tasks and employ questionable spinal load limits (Marras and Karwowski, 2006). It has been suggested that 3D SSPP is a better assessment tool than the Revised NIOSH Lifting Equation because it estimates compression forces, particularly at L5/S1, the region of the spine most prone to low back injuries (Marras and Karwowski, 2006). However, unlike the Revised NIOSH Lifting Equation, 3D SSPP does not consider task duration or lifting frequency. In order to assess physiological responses during MMH tasks, energy expenditure needs to be evaluated. This is obtainable using an ergospirometer, but this is impractical in industry, as it interferes with the working tasks. A program was developed to estimate energy expenditure during MMH tasks: Energy Expenditure Prediction Program (EEPP) (Martin et al., 2013). While this is not entirely accurate and is limited to static MMH tasks, it is the most practical assessment tool available (Martin et al., 2013).

The aim of this study was to note the effects of reduced external load on the risk of developing back disorders, compression forces at L5/S1 and energy expenditure, using the Revised NIOSH Lifting Equation, 3D SSPP and EEPP, respectively.

Methodology

Experimental Design

The literature stated that an exoskeleton reduces the external load applied to the user, however there is little research on biomechanical and physiological responses. This study aimed to analyse these effects whilst performing an eight-hour lifting task. It is important to note that the exoskeleton has not yet been developed as the benefits first need to be assessed, thus this study assumes that the external load applied to the human whilst using an exoskeleton will be reduced.

The magnitude of the reduction is unknown, thus two reductions will be assessed: 25% and 50%. From this, biomechanical and physiological responses will be determined and benefits examined for various external loads and lifting frequencies. This allows the results to be representative for numerous lifting tasks performed in industry. Additionally, the lifting task analyzed was graphically simulated, where working heights and body dimensions were based on the anthropometry of a specified population (See below).

This study examined three external loads (5kg, 10kg and 15kg), and 25% and 50% reductions in these loads were also assessed. Additionally, these loads were examined at three different lifting frequencies: 1 lift/min, 5lifts/min and 9 lifts/min. The type, dimensions and shape of the external load was not necessary as the assessment tools used does not require this information (See below).

Lifting Task Heights and Anthropometric Parameters

The lifting task comprised a standard stooped lift originating from knee height (origin) and ending at shoulder height (destination). Anthropometric data required for assessment was based on the 50^{th} percentile British male adults aged between 19-65 years (Pheasant and Haslegrave, 2006). These measurements acquired from Pheasant and Haslegrave (2006) were inserted into the various assessment tools resulting in the data representing the average British male population (See below).

Assessment

Back disorder risk, compression forces at L5/S1 and energy expenditure were examined for each load and reduction in load lifted at each lifting frequency being investigated. All three factors were examined using static risk assessment tools commonly used in industrial evaluations. Back disorder risk was examined using the Revised NIOSH Lifting Equation, where a lifting index greater than 1 indicates an increased risk of developing a back disorder. Anthropometric measurements required for this assessment tool included: knee height (54cm), shoulder height (142cm), upper limb length (78cm), stature (174cm) and mass (75kg) (Pheasant and Haslegrave, 2006). 3D SSPP was used to estimate compression force at L5/S1, where an increase in compression force indicates increased risk of developing lower back pain. It must be noted that 3D SSPP does not consider lifting frequency or task duration. Anthropometric measurements required for this assessment tool was stature (174cm) and mass (75kg) (Pheasant and Haslegrave, 2006). Finally energy expenditure was accessed using the EEPP, where an increase in energy expenditure increases the likelihood of physical fatigue. Anthropometric measurements required for this assessment tool was mass (75kg) (Pheasant and Haslegrave, 2006). Figure 1 displays the graphical simulation of the lifting task which was designed in 3D SSPP.

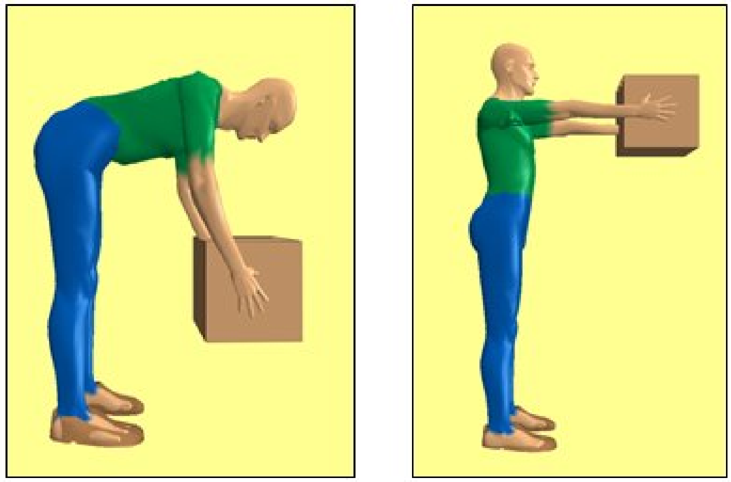


Figure 1. Graphical simulation of the lifting task designed in 3D SSPP. Model on right represents the origin of the lift (knee height) and model on left represents the destination of the lift (shoulder height).

Results

Both lifting index and energy expenditure increased with an increase in the external load and lifting frequency (Figure 2, Figure 3 and Figure 6). Compression force in L5/S1 increased with an increase in the external load (Figure 4 and Figure 5). All three parameters decreased linearly with a 25% and 50% reduction in weight for each external load assessed (Figures 2 to 6). This decline in risk was also noted for each frequency analysed, both for the lifting index and energy expenditure (Figure 2, Figure 3 and Figure 6). Additionally, this linear decline was noted for both origin and destination positions for the lifting index and compression force in L5/S1 (Figure 2 to Figure 5).

The greatest linear decline occurred for the lifting index (between 25% to 50% reduction), which was followed by compression force in L5/S1 (between 10% to 30% reduction) and the smallest decline was noted for energy expenditure (between 1% and 23% reduction). Furthermore, when comparing the external loads by lifting index and energy expenditure, the greatest decline in risk occurred for the highest load (15kg) at the fastest frequency (9 lift/min) . In contrast, the smallest decline occurred for the lowest load (5kg) at the slowest frequency (1lift/min) (Figure 2, Figure 3 and Figure 6). With regards to compression force in L5/S1, the greatest decline due to reduced external load occurred for 15kg and the smallest decline for 5kg (Figure 4 and Figure 5).

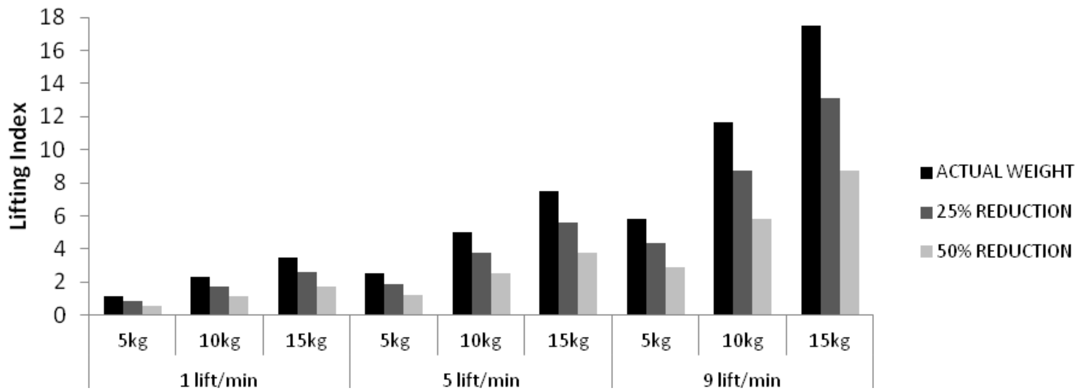


Figure 2. Lifting index calculated from the Revised NIOSH Lifting Equation for three loads (5kg, 10kg, 15kg – actual weight) lifted at three frequencies (1 lift/min, 5 lift/min, 9 lift/min) from knee height to shoulder height, where 25% and 50% reduction in these loads were also analysed: Data represents the origin of the lift.

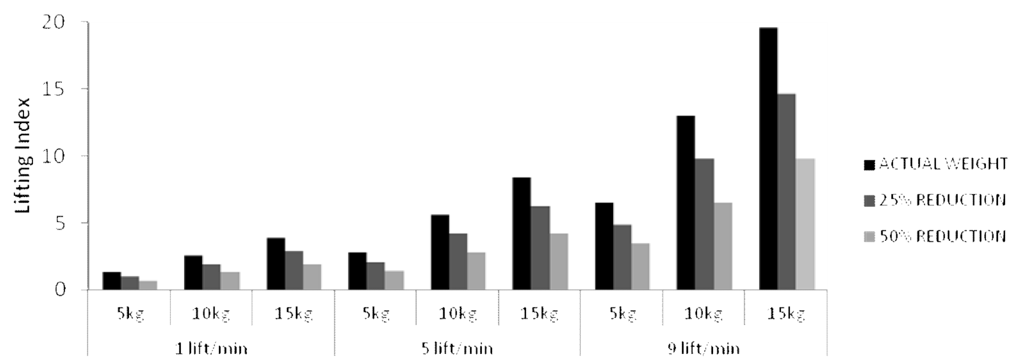


Figure 3. Lifting index calculated from the Revised NIOSH Lifting Equation for three loads (5kg, 10kg, 15kg) lifted at three frequencies (1 lift/min, 5 lift/min, 9 lift/min – actual weight) from knee height to shoulder height, where 25% and 50% reduction in these loads were also analysed: Data represents the destination of the lift.

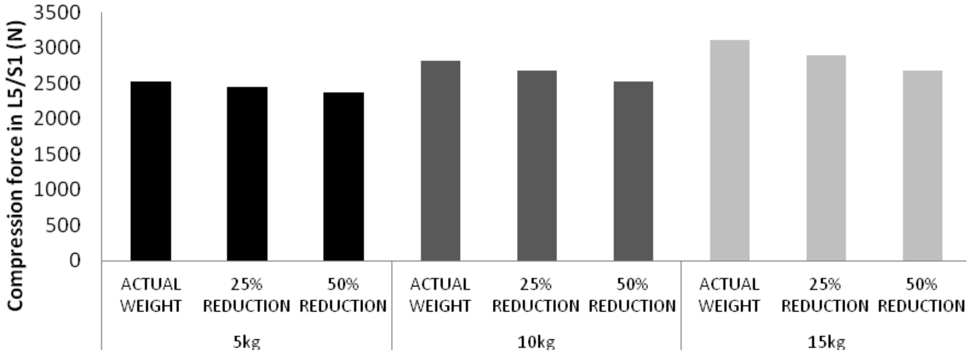


Figure 4. Compression force in L5/S1 calculated by 3D SSPP for three loads (5kg, 10kg, 15kg – actual weight) from knee height to shoulder height, where 25% and 50% reduction in these loads were also analysed: Data represents the origin of the lift.

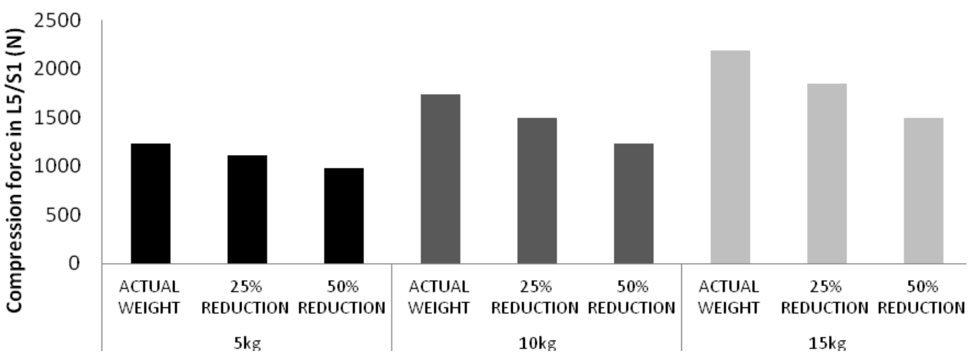


Figure 5. Compression force in L5/S1 calculated by 3D SSPP for three loads (5kg, 10kg, 15kg – actual weight) from knee height to shoulder height, where 25% and 50% reduction in these loads were also analysed: Data represents the destination of the lift.

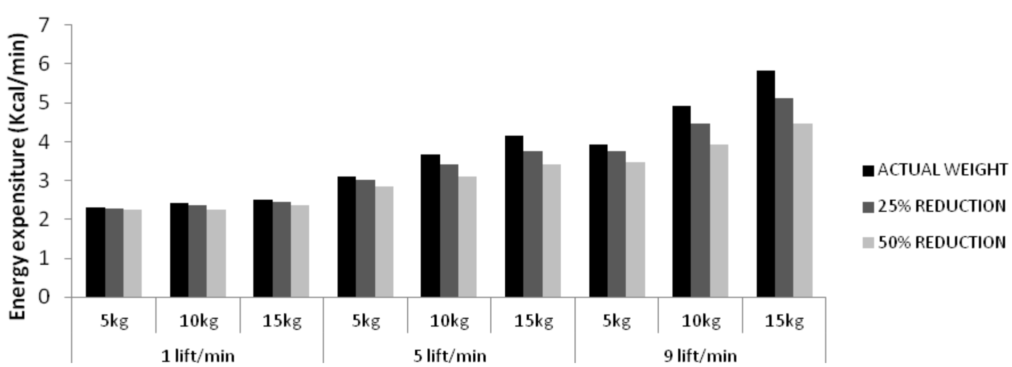


Figure 6. Energy expenditure calculated by the EEPP for three loads (5kg, 10kg, 15kg actual weight) lifted at three frequencies (1 lift/min, 5 lift/min, 9 lift/min) from knee height to shoulder height, where 25% and 50% reduction in these loads were also analysed.

Discussion

As expected, biomechanical and physiological risks and responses were positively correlated with external load and lifting frequency. With a 25% and 50% reduction in the three external loads assessed, a linear decrease was observed for back disorder risk, compression force in L5/S1 and energy expenditure. Therefore the risk of developing back disorders and the risk of physical fatigue was reduced. Moreover, the decline in risk was greater for heavier loads and faster lifting frequencies. Thus the reduction in the load is more beneficial for heavier loads lifted at high frequencies which are commonly involved in MMH tasks (Karwowski, 2010). The reduction in the external load revealed a greater decline for biomechanical responses compared to physiological responses. Thus, reduction in external load has a greater effect on decreasing the risk of developing back disorders than on decreasing the onset of physical fatigue.

Both biomechanical and physiological risks and responses will decrease with a reduction in external load. Therefore an exoskeleton may reduce the physical stresses applied to the human body during MMH and hence the risk of developing WRMSDs and physical fatigue. This will benefit both user and industry as worker well-being will be improved which translates into increased efficiency and productivity at work. However, it should be noted that the assessment tools used in this study are simplistic in nature and more research is suggested to examine the exact biomechanical and physiological responses to reduced external load. None of the selected assessment tools consider dynamic parameters which occur during MMH such as acceleration, velocity and torque (Duffy, 2008). These parameters are important when assessing a MMH task, as they affect biomechanical forces and tissue stresses (Wagner et al., 2007). Additionally, the tools do not provide information regarding muscle activation and muscle strength, so physiological fatigue and effort is not being fully examined or assessed (Salvendy, 2001; Karwowski, 2006).

With regard to the exoskeleton, the static assessment tools neglect to provide information on human-machine interaction. For instance, there may be a delay between exoskeleton movement and operator limb movement. Movement of a limb is necessary to activate movement of the exoskeleton, which results in the limb applying torque to overcome resistance of the exoskeleton. The static assessment tools are unable to provide information of the effect of this torque resistance on the operator. Moreover, these models do not consider balance. The use of an exoskeleton results in extra weight being placed to the posterior aspect of the human body thus altering the centre of mass. This may result in a change in muscle activation or muscle recruitment in order to maintain balance. However, the static models do not consider muscle activation, muscle recruitment or centre of mass, thus these effects are not considered.

The static models used for this study revealed an improvement in biomechanical and physiological risk whilst using an exoskeleton. However, these models failed to consider dynamic parameters, muscle responses/capabilities and human-machine interaction. It is clear that a more detailed dynamic assessment tool is required to assess the value of an exoskeleton as an ergonomic aid for industrial work. Therefore, further research will be conducted using AnyBody Technology software. AnyBody Technology Modelling System is a software solution designed for simulating the mechanics of human body during activities of daily living (Wagner et al. 2007). The software enables accurate musculoskeletal simulation via inverse dynamics (Wagner et al. 2007). Thus motion capture data, working activity or tasks, anthropometrics and working environment (i.e. external loads and exoskeleton) are imported into the software, which models the functions and parameters of bones, muscles, ligaments and joints. The output data from this analysis includes, but is not limited to: muscle forces, muscle power, muscle activity, joint reaction forces and joint moments. From this analysis a greater understanding of the effects of an exoskeleton in reducing biomechanical risk and physiological strain might be obtained.

Acknowledgements

This research was co funded under the European Commission supported FP7 project Robomate, Grant number 608979.

References

Bernard, B.P. 1997. *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of he neck, upper extremity ad low back*. Department of Health and Human Services, Centre for Disease Control and National Institute for Occupational Safety and Health, Cincinnati.

Bhattacharya, A. and McGlothlin, J.D. 2012. *Occupational Ergonomics: Theory and Applications*, Second Editon, CRC Press,

Boff, K.R. 2006. Revolutions and shifting paradigms in human factors and ergonomics, *Applied Ergonomics*, **37**, 391-399.

Bos, J., Kuijer, P.P.M. and Frings-Dresen, M.H.W. 2014. Definition and assessment of specific occupational demands concerning lifting, pushing and pulling based on a systemaic literature search, *Occupational and Environmental Medicine*, **59**, 800-806.

da Costa, B.R. and Vieira, E.R. 2010. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies, *American Journal of Industrial Medicine*, **53**, 285-323.

Duffy, V.G. 2008. *Handbook of Digital Human Modelling: Research for applied Ergonomics and Human Factors Engineering*, CRC Press, Florida.

Guild, E., Harralson, M., Meekins, D., Petry, W., Schwab, P. and Werner, S. 2010. *Application Guide for Maunal Matrials Handling Requirements in SEMI S8*, International SEMATECH Manufacturing Initiative, NY.

Hillman, M., Wright, A., Rajaratnam, G., Tennant, A. and Chamberlain, M.A. 1996. Prevelance of low back pain in the community: implications for service provision in Bradford, UK, *Journal of Epidemiology Community Health*, **50**, 347-352.

Karwowski, W. 2006. *International Encyclopaedia of Ergonomics and Human Factors*, Second Edition, Volume 3, CRC Press, Florida.

Karwowski, W. 2010. *International Encyclopaedia of Ergonomics and Human Factors*, Second Edition, Taylor and Francis, Florida.

Lee, S. and Sankai, Y. 2002. *Power assist control for walking aid with HAL-3 based on EMG and impedance adjustment around knee joint*. International Conference on Intelligent Robot and Systems, 0-7803-7398-7, Lausanne, Switzerland.

Luttman, A., Jager, M., Griefahn, B., Caffier, G., Liebers, F. and Steinberg, U. 2003. *Preventing Musculoskeletal Disorders in the Workplace*. World Health Organisation, Switzerland.

Marras, W.S. and Karwowski, W. 2006. *Interventions, controls and applications in occupational ergonomics*, CRC Press, Florida.

Martin, J., Lockett, J., Allender, L. and Savage-Knepshield, P. 2013. *Designing soldier systems: Current issues in human factors*, Ashgate publishing, England.

McGill, S. 2007. *Low Back Disorders: Evidence-based Prevention and Rehabilitation*, Human Kinetics, United States of America.

Pheasant, S. and Haslegrave, C.M. 2006. *Bodyspace: Anthropometry, Ergonomics and the Design of Work*, Taylor and Francis, Florida.

Raven, P., Wasserman, D., Squires, W. and Murray, T. 2012. *Exercise Physiology*. Cengage Learning, California.

Salvendy, G. 2001. *Handbook of Industrial Engineering: Technology and Operations Management*, John Wiley and Sons, Canada.

Siciliano, B. and Khatib, O. 2008. *Springer Handbook of Robotics*, Springer, Berlin.

Wagner, D.W., Reed, M.P. and Rasmussen, J. 2007. *Assessing the importance of motion dynamics for ergonomic analysis of manual materials handling tasks using the AnyBody Modelling System*, SAE Digital Human Modelling for Design and Engineering Symposium, 2007-01-2504, Seattle, WA.

Waters, T., Putz-Anderson, V. and Garg, A. 1994. Applications Manual for the Revised NIOSH Lifting Equation. DHHS (NIOSH) Publication No. 94-110, Virginia.

Yang, C., Zhang, J., Chen, Y., Dong, Y. And Zhang, Y. 2008. A review of exoskeleton-type systems and their key technologies, *Journal of Mechanical Engineering Science*, **222**, 1509-1612.

Zurada, J. 2012. Classifying the risk of work related low back disorders due to manual materials handling tasks, *Journal of Expert Systems with Applications*, **39**, 11125-11134.

PROCESS ERRORS RESULTING FROM AN ERGONOMICS-FOR-ONE APPROACH TO THE DESIGN OF ASSISTIVE TECHNOLOGY FOR AGRICULTURAL WORKERS WITH DISABILITIES: CONSEQUENCES AND REMEDIES.

Robert W. Stuthridge[1] and W. E. Field[2]

[1]AgrAbility Project, Drimoleague, Ireland
[2]Purdue University, West Lafayette, IN, USA

Abstract

Disabled agricultural workers may increase the accessibility of tasks using assistive technology (AT), the selection or design of which is undertaken either by the disabled worker or by professional AT designers, such as occupational therapists. Typically, the AT selection and design process reflects an ergonomics-for-one approach that exclusively focuses on meeting the functional needs of the disabled worker (primary user), rarely considering the effect the modifications might have on other (secondary) users who share the task or work environment with the primary user. This ergonomics-for-one approach can increase injury risk to secondary users due to an unintended reduction in person-task fit. A checklist was therefore developed to help AT designers consider potential risks to all workers.

Disability and the use of Assistive Technology in Agriculture

Farming and ranching are hazardous occupations, with agricultural workers suffering above average prevalence rates of permanent disability (Deboy, 2008; NIOSH, 2009). In the United States, more than 70% of disabled agricultural workers choose to modify their tasks, equipment, or environment, so that they can continue working (Gruver *et al.*, 1997). These modifications are known collectively as assistive technology (AT), and Figures 1 and 2 show examples of agricultural AT. Agricultural AT may be designed and fabricated or purchased directly by the intended user, or designed, fabricated or selected by others—such as AT professionals, occupational therapists, carpenters, engineers, or metal workers.

Slips, falls and incidental contact with sub-optimally designed AT are known to increase risk of "secondary injuries" for intended disabled users (Allen *et al.*, 1995; Willkomm, 1997; Yoder, 2001; Yoder, 2002; Willkomm, 2004; Mathew, 2009). Organisations such as AgrAbility (www.AgrAbility.org, www.AgrAbility.org.uk) and the Rehabilitation Engineering and Assistive Technology Society of North America (www.RESNA.org) are actively engaged in the promotion of best practice in the design, fabrication and selection of AT.

Figure 1. Agricultural AT: A powered man-lift allows cab access for a farmer with paraplegia.

Figure 2. Agricultural AT: Hand lever extensions enable an operator with lower-limb impairments to actuate foot pedal controls.

Until the present study however, it was not known if due consideration is given by AT designers to the safety and health of *co-workers* whose tasks might be affected by the provision of AT—even if the modifications are optimally designed for the intended user.

Given the high prevalence of disability in agriculture, the hazardous nature of farmwork, its diverse workforce (for example, young and old workers, family members, seasonal labour), and multi-user operation of high capital cost equipment, it was postulated that modified tasks might be performed not only by the disabled "primary" user, but also by "secondary" users, for whom the design modifications might not be optimal or safe.

Ergonomists minimise injury risk by ensuring that tasks are optimally designed for all probable incumbents (Pheasant, 1986). This differs from optimising a task to suit one particular person—a design approach known as "ergonomics-for-one" (McQuistion, 1993). Ergonomics-for-one is commonly adopted by people fabricating or designing AT either for their own use, or for use by another individual, in order to make up the shortfall between work demands and reduced work capacity resulting from an injury or disability (Rice, 1998). However, AT that is optimally designed for one user might be suboptimal for another user.

In occupational settings where only the primary user makes use of AT, this approach is not problematic. The same may not hold true for farming, where AT—particularly if it involves the modification of high cost, essential equipment such as a tractor, truck or combine harvester, for example—may be shared between several people for extended periods or on a regular basis. If modified tasks are performed by several people in agricultural settings, AT designers would need to reject the ergonomics-for-one design paradigm in favour of an inclusive approach.

The present research therefore considered:

1. Whether tasks modified for a disabled primary user are also performed by secondary users
2. If they are, is there evidence that secondary users are at increased risk of injury as a consequence of these modifications?
3. What factors influence the likelihood that the AT design process will erroneously fail to take account of usability of shared AT for all users?
4. How might risk be reduced for this design process failure?

Method

The researcher sought to describe the agricultural AT design process *as it is*, not to advance a course of inquiry based on an hypothesis of *how it might be*. A grounded theory methodology (Glaser and Strauss, 1967) was therefore used to describe the agricultural AT design process, process errors and their causes.

The researcher passively observed and recorded eight meetings between AT designers and their agricultural clients. During the meetings, the researcher took notes and made audio recordings. These data were transcribed to NVivo 8.0 (QSR International, 2009), which facilitated the identification of conceptual categories and the highlighting of aspects of the AT design process that might have a bearing on shared usability risks and merit further investigation.

These aspects were operationalised as prompts during telephone discussions between the researcher and twenty-three agricultural AT designers (fifteen professional designers and eight farmers who had designed their own AT). Participants were encouraged to describe factors which influence their approaches to the design of AT that is shared. During the conversations, which typically lasted about an hour, the researcher took notes and made audio recordings. These data were also analysed using NVivo 8.0, together with any AT design resources cited by participants.

Through repeated analysis of concepts and categories contained within the data, a grounded theory emerged which describes and explains the level of consideration given to usability during the agricultural AT design process. This theory was then verified against the primary data and by study participants.

Results

Eight categories of factors were identified which, to varying degrees, influenced the consideration of users and usability during the process of designing agricultural AT. Salient features of these categories are described below.

1: Characteristics of AT Designers

AT designers exhibited a desire to show empathy for the primary client, aiming to appear professional but not "coldly logical." They tended increasingly to rely on their own experience and case knowledge in solving AT design problems, even when they had access to wider networks of professionals. One outcome of this independence was that AT designers and primary users might not subject design decisions to any external evaluation process.

2: Consequences of AT Design

AT designers anticipated AT having beneficial consequences for primary users, maintaining or increasing their productivity, enhancing their independence, and reducing their disablement and risk of personal injury. Rarely did designers consider the consequences of task modification for other users, but when prompted to consider such consequences, were able to provide examples of adverse outcomes—including injuries and near misses—affecting secondary users of AT they had designed.

3: Design Paradigms

The most common approach to agricultural AT design was based on an exclusive, ergonomics-for-one paradigm in which rarely were the needs and capacities of secondary users formally considered. AT designers accepted upon reflection that an inclusive design approach would have been more appropriate. Designers had a tendency to stereotype occupational or disability situations, resulting in solutions that being applied on the basis that they had worked in similar circumstances. This might result in a failure to critically evaluate each solution on a case-by-case basis. Like their primary clients, AT designers tended to be task-oriented, attending more to utility than to usability.

4: Design Resources

AT fabricators were sometimes used as sources of design advice. They might have little awareness of wider usability issues, and worked to specifications provided by the end user. Many professional AT designers and some end users sought solutions in "The Toolbox" (a CD ROM and online resource of examples of agricultural AT (Breaking New Ground, 2009)). Internet searches were often used when looking for potential AT solutions, but the internet was considered by some to be too time-consuming because it produced results irrelevant to agriculture and disability. To a lesser extent AT designers referred to libraries of printed materials gathered from trade shows and conferences.

Equipment suppliers and AT designers' family members were also used to elicit design suggestions. When AT designers solicited help from engineers or occupational therapists, the focus was exclusively on meeting the needs of the primary user. None of the aforementioned resources encouraged designers to address AT usability issues for secondary users.

5: Economic influences on Design

Economics was a significant design factor both for client and designer. Economic factors could shape the design process, affecting the goals of the workplace modification, the attention given to the suitability of the AT for multiple users, and the extent of "design freedom" available to an AT designer. Some clients wanted AT to enable them to contribute more of their labour to the farm as a business, and designers encountered situations in which this motivation to contribute was a factor in the design process, creating an incentive to modify tasks in order to improve their client's psychological wellbeing by increasing their economic productivity.

If the cost of the AT was beyond the means of the primary user and their business, this could influence the design process. If an external funding agency was engaged to meet the cost of the AT, they tended to apply criteria for evaluating whether the proposed AT solution was something they were prepared to fund. Although they aimed to cause no harm to any user, some professional AT designers felt obliged to be seen to focus only on the employment needs of the primary client if this was the stance adopted by the funding agency. Although increased productivity was not usually described as influencing the AT design process, it might be an additional incentive for funders of agricultural AT.

6: Influence of users on Design:

The primary user was an active participant in the agricultural AT design process. Primary users typically exhibited a strong desire to participate fully in tasks necessary to running the agricultural operation. Some were prepared to compromise their personal safety in order to contribute their labour to the business. While AT designers may have felt the need to balance this task-orientedness with a need to ensure the safety of the primary user, they sometimes found themselves reliant on the primary client to explain what they needed to overcome their disability within the context of their particular occupational setting.

AT might be intended for use in an area of agriculture with which the professional AT designer was unfamiliar, and in such situations, the client could exert even greater influence over the design process. The task-orientedness of primary clients increased the risk that the AT might enable the primary client to complete a task, but at increased risk of injury to both primary and secondary users. Little consideration was given to the potential effect of modified equipment on secondary users. Exceptions to this occurred if the equipment to be modified was the property of the secondary user, who wished to share the equipment with the primary user following its modification.

7: Social Influences on Design:

Several social factors influenced the agricultural AT design process, the most significant of which were family relationships and the social culture of agriculture. Within the family of the primary client, the design process might be affected by the relationships between family members. Family members who were secondary users of AT generally tolerated sub-optimal task modifications because of their motivation to see the primary user enabled and more fully engaged in the activities of the farm and family. This could lead to secondary users being unwilling to bring sub-optimality of solutions to the attention of the AT designer, compromising their own health and safety in the interest of enabling their family member.

Non-family co-workers who were secondary users were also likely to tolerate sub-optimal AT, perhaps because of employment status and equipment ownership, but were more likely than family members to express discontent. The culture of farming might be resistant to modifying the way workers have traditionally performed tasks. This was not merely aversion to technology, which agriculture has generally embraced for productivity and efficiency; rather, it was resistance to AT that might significantly change the traditional format of a task.

Professional AT designers and their clients perceived farmers as unique. This uniqueness had both constructive and destructive features. On the one hand farmers were seen as creative and natural problem-solvers, and on the other they prioritised task completion above safety.

8: Usability

In agricultural settings there was a tendency to define AT usability in terms of its utility—its capacity to accomplish the task (Table 1).

Rank	Attribute	Number Mentioning
1	Accomplishes the task	11
2	Easy to use	5
2	Inclusive	5
4	Easy to learn	3
5	Compatible with users' needs	2
6	Operable	1
7	Safe	1

Table 1: "Usability" definitions by 23 AT designers

Often, AT designers assumed that AT would make work easier for secondary users, if it was thought to affect them at all. Rarely was there a rationale for such assumptions. The design process primarily focused on meeting the needs of highly task-oriented primary users who were motivated to subordinate usability to utility. This might explain primary users adopting unsafe behaviors in order to accomplish a task. AT was considered successful if it increased the primary user's independence enough to complete the task. Users were prepared to accept AT that fulfilled the task effectively even if it was not optimally usable, the evidence for which was that primary users continued to perform unsafely modified tasks, and secondary users were prepared to subordinate their safety to the primary client's need to perform a task.

Grounded Theory of Agricultural AT Design: Utility over Usability

A grounded theory emerged from the data analysis: “The task-orientedness of both primary and secondary users’ results in an agricultural AT design process that is predominantly utility-driven. This results in the subordination of usability to utility” (Stuthridge, 2012).

This grounded theory provided the conceptual framework for an “Agricultural AT Design Process (Usability) Checklist” designed to alert its user to process errors that might compromise the usability and safety of the AT.

The checklist was heuristically evaluated by seven usability and ergonomics professionals, redesigned to incorporate improvements to its organisation, terminology, and content, field tested by ten agricultural AT designers, further improved, then presented to, discussed with and evaluated by, fourteen specialists in agricultural AT design during a special session of the US National AgrAbility Project's National Training Workshop in 2011. The final version is shown in Appendix A. A design process usability decision tree was also developed that complemented the checklist and aided designers in identifying users who might at risk of injury from use of the proposed task modification. This decision tree is shown in Appendix B. The checklist prompts a consideration of usability error during the design process for agricultural AT. The attention to hazards/risks directs the AT designer to focus on areas of potential failure, rather than success. Discovering design flaws is crucial to system safety (Petroski, 1994), and the checklist can help balance the desire for utility with an awareness of injury risk.

Conclusion

The present research investigated the agricultural AT design process at a level of detail not previously attempted, through the words, actions, and resources used by participants in the process. It revealed several factors that influenced to varying degrees the agricultural AT design process. The research resulted in a checklist capable of revealing potentially important design process errors. Factors that influence the design process may point to more effective ways of preventing injuries on the farm. The grounded theory might be improved and refined by comparing it with new data.

References

Allen, P.B., Field, W.E., Frick, M.J., 1995. Assessment of work-related injury risk for farmers and ranchers with physical disabilities. *Journal of Agricultural Safety and Health* **1**, 71-81.

Breaking New Ground, 2009. *The Toolbox.* Breaking New Ground Resource Center, West Lafayette, IN.

Deboy, G.R., Jones, P.J., Field, W.E., Metcalf, J.M. and Tormoehlen, R.L., 2008. Estimating the Prevalence of Disability within the U.S. Farm and Ranch Population. *Journal of Agromedicine* **13**, 175-189.

Glaser, B., Strauss, A., 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Aldine de Gruyter, New York.

Gruver, M.L., Allen, P.B., Field, W.E., Schweitzer, J., 1997. Potential health and safety risks of farming/ranching with a disability. *Plowshares* **27**. Breaking New Ground Resource Center, Purdue University, West Lafayette, IN.

Mathew, S.N., 2009. *An assessment process to estimate the secondary injury potential of assistive technology adopted by farmers with disabilities.* PhD Thesis. Purdue University, West Lafayette, IN.

McQuistion, L., 1993. Rehabilitation Engineering: Ergonomics for One. *Ergonomics in Design*, 9-10, 1993:**9**.

NIOSH, 2009. *Agricultural Safety*. NIOSH Safety and Health Topic. Centers for Disease Control, National Institute for Occupational Health and Safety, Cincinnati, OH.

Petroski, H., 1994. *Design Paradigms: Case Histories of Error and Judgment in Engineering*. Cambridge University Press, Cambridge, UK.

Pheasant, S., 1986. *Bodyspace : anthropometry, ergonomics, and design*. Taylor & Francis, London ; Philadelphia.

QSR International, 2009. *QSR NVivo*.

Rice, V.J.B., 1998. Defining the Terms. In: Rice, V.J.B. (Ed.), *Ergonomics in Health Care and Rehabilitation*. Butterworth-Heinemann, Woburn, MA.

Stuthridge, R.W., 2012. *The consideration of usability in the process of designing and selecting assistive technology for use in agricultural settings.* Ph.D. Thesis. Purdue University, West Lafayette, IN.

Willkomm, T., 1997. *Risks in using modified tractors by operators with spinal cord injuries and their co-workers*. Ph.D. Thesis. University of Pittsburgh, Pittsburgh, PA.

Willkomm, T., 2004. *Farming and Ranching with a Disability*. National Ag Safety Database, Gainesville, FL.

Yoder, A., Kingman, D.M., Field, W.E., 2001. *Influences of disabling conditions on the nature and frequency of farm/ranch-related injuries*. National Ag Safety Database.

Yoder, A.M., 2002. *Ergonomic evaluation of commercially available operator lifts for farmers with disabilities*. Ph.D. Thesis. Purdue University, West Lafayette, IN.

Appendix A: Agricultural AT design process (usability) checklist.

Section C: Injury Hazards for Users of the Proposed AT

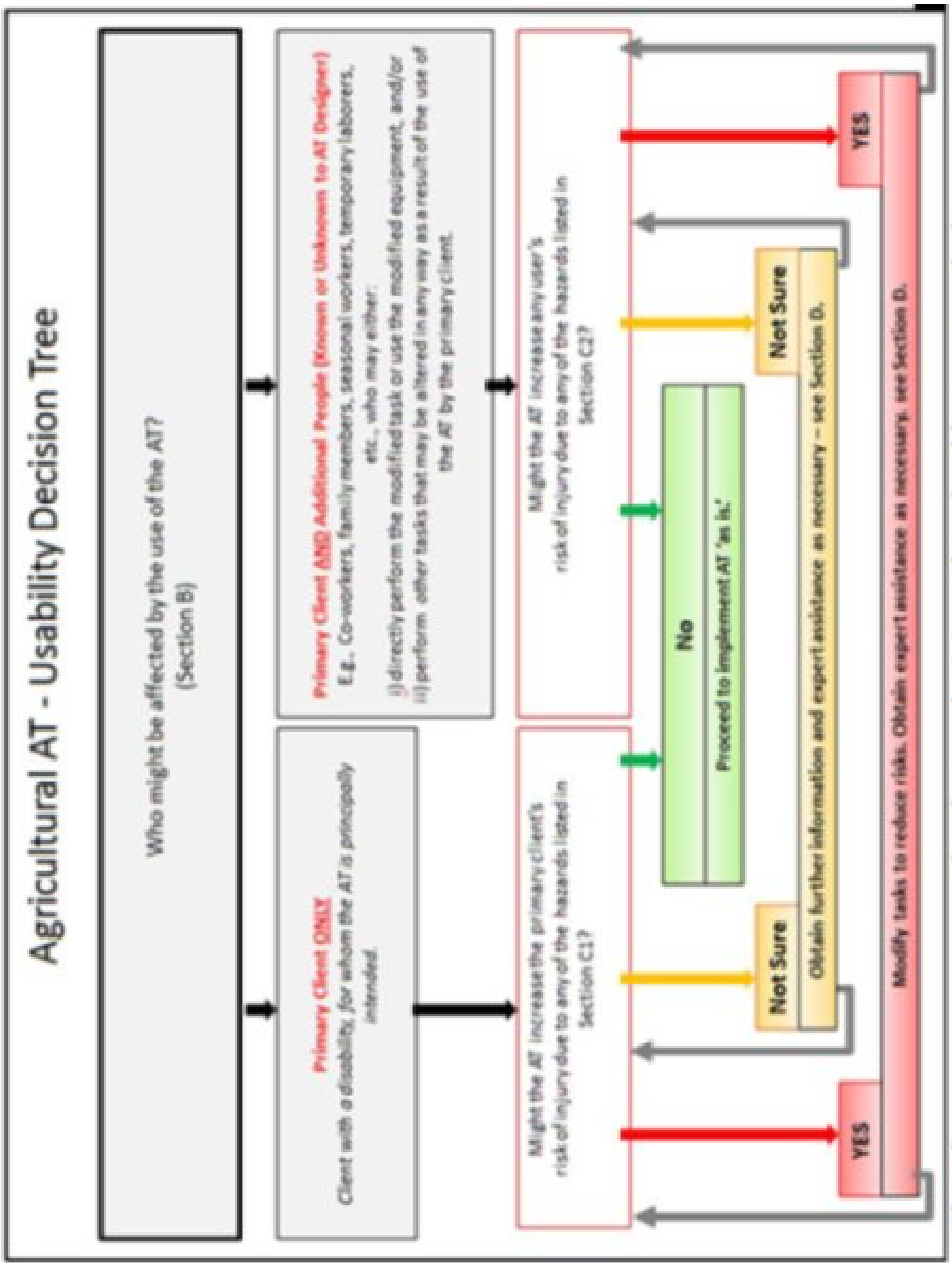
C(1): Could use of the AT increase a user's exposure to the injury hazards listed?

Instructions: Check the most appropriate response (Yes/No/Not Sure). If you need more information on a hazard to make a decision, choose "Not Sure."

Item	Hazard	C1 Primary User			C2 Secondary User			Notes
Musculoskeletal Hazards (MSH)		Yes	No	Not Sure	Yes	No	Not Sure	
a	Awkward trunk, neck, hand/arm, foot/leg postures							
b	Repetitive motions of the upper-limbs or lower-limbs							
c	Vibration: whole body							
d	Vibration: segmental - e.g., hand-arm							
e	Excessive force: e.g. pushing, pulling, gripping, twisting, lifting.							
f	Other MSH (describe)							
Environmental Hazards (EH)		Yes	No	Not Sure	Yes	No	Not Sure	
g	Excessive noise							
h	Excessive heat							
i	Excessive cold							
j	Airborne or contact allergens or irritants							
k	Working in confined spaces							
l	Other EH (describe)							
Safety Hazards (SH)		Yes	No	Not Sure	Yes	No	Not Sure	
m	Slipping, tripping or falling							
n	Handling of Animals							
o	Contact with hazardous fumes, chemicals, or biological agents							
p	Laceration, abrasion, pinching, crushing, or bruising hazards							
q	Electrical shock - contact with energized electrical components							
r	Trauma - contact with operating machine parts (e.g., shafts, gears, pulleys)							
s	Vehicular incident (e.g. rollover)							
t	Fire/explosion hazard							
u	Other SH (describe)							

- If you chose **"Yes"** for any of the above hazards, complete Section D of this checklist.
- If you chose **"No"** to all of the above hazards for all users, proceed with your usual process for AT design or selection.
- If you chose **"Not Sure"** for any of the above hazards, seek professional advice on risk assessment (use approach D4) in Section D).

Appendix B: Agricultural AT usability decision tree.



INCLUSIVE TASK ANALYSIS AND RISK ASSESSMENT IN HIGH-RISK INDUSTRIAL CLEANING: A CASE STUDY USING SCOPE SOFTWARE

Yilmar Builes, Nora Balfe, Chiara Leva, and Ewan Douglas

Centre for Innovative Human Systems, Trinity College Dublin, Ireland

Abstract
This paper describes the method and results of a practical exercise engaging workers in the risk assessment of their task using specialist software called SCOPE. The task chosen was the cleaning of large grain storage bins in a malting company. This task entails abseiling from the top of the bin while cleaning the sides; additional hazards include the possible presence of carbon dioxide and other gases at potentially fatal levels. Data on the task was collected through site visits, interviews with workers and the safety manager at the plant, and observations of the task in practice. This data was used to construct a task model and conduct a local hazard analysis, using SCOPE. The analysis identified three new recommendations to improve safety on the task and was positively received by the workers and managers involved.

Introduction

Risk assessment involves careful examination of each of the activities implemented in a workplace that could cause harm to workers (HSA, 2005). This facilitates the analysis of whether sufficient precautions are in place or whether more should be done to prevent damage. The goal of the risk assessment is to minimise the risk of injury or fatality in the operation of equipment or processes. To achieve this, the hazards should consider not just technical equipment within the design but also possible hazards generated from work activities, particularly safety critical activities (Wells, 1996). Risk assessments are often conducted by safety specialists, and in the case of new designs, in consultation with engineers. However, the inclusion of the workers involved in the operation allows their experiences and knowledge to be captured in the risk assessment process and facilitates the identification of risks regarding the operation that may not be apparent to specialists more removed from the actual task. The workers themselves may also have ideas for possible improvements that can be incorporated in to the design or operational process.

Risk assessment is important because it helps to create awareness of hazards and risks related to specific work activities. It aims to reduce the probability or severity of the consequences of hazards by adding necessary control measures and precautions. Risk assessment also prioritizes hazards and helps determine if the existing control measures are adequate. Another major reason to conduct risk assessments is because they reduce the risk that businesses may be facing by improving their preparedness and in most instances they are a legal requirement, becoming a fundamental requirement for businesses.

Large scale risk assessments allow management to identify the hazards in each area of their business and the results can be used to justify investment decisions to improve safety (HSA, 2005). In this way, it is possible to create a safety project to address the risks identified, with planned investment oriented to achieve a tolerable level of safety, ensuring loss prevention and business continuity. Risk assessments can be considered the best way to identify the risks and the possible mitigations at an organisational level. At a lower level within an organisation, risk assessment can be considered important because it helps to create an awareness of the hazards and risks related to specific work activities. The risk assessments identify necessary control measures which allow the probability or severity of hazards to be reduced, but the communication of the risk assessment is necessary in order for workers to take responsibility for consistent implementation of control measures.

The case study reported here involved cleaning operations in a confined space in the malting industry. There are many risks that can occur in confined spaces; in most cases these are assigned exclusively to risks originating from atmospheric conditions of the inside or to an improper installation of the abseiling system. However, these tasks involve the convergence of several other hazards related to the task. For this reason, the realization of a workshop is important, as during the process it is possible to identify different factors that threaten the health and safety of workers. After running an analysis of human functions and a subsequent study of the human factors during the tasks included in the cleaning process, the next step would be to identify the main hazards. In order to develop this new phase of the work it is necessary to gather the personnel responsible to run each of these cleaning tasks, as they are the people with the expertise necessary to solve and at the same time give their opinions on each of the tasks performed.

Having a task analysis to be shared with the workers during a workshop can facilitate the identification of those activities that create a higher risk for the workers and in this way develop a more comprehensive risk assessment. Gathering together the responsible staff makes it possible to achieve a more thorough risk assessment, as they have the necessary expertise to solve, and at the same time, give their opinions on each of the tasks performed.

Method

The following method of evaluation was implemented to integrate the human factors in the risk assessment during the cleaning process in grain storage bins. The first phase involved the collection and analysis of all the relevant information for the process in order to enable the development of a thorough understanding of the factors presents in the cleaning process of the bin. This was achieved through site visits, observation of the task, interviews with the workers, and analysis of the relevant procedural and process information. This provided the necessary information for the functional analysis which was visualised as a process map within the SCOPE software. This task analysis described in an effective way the cleaning operations in the order undertaken and included all tasks from the arrival on site of specialist staff to their departure. Data was collected regarding the hazards that can be generated in confined spaces and this was used to inform a risk assessment workshop with the workers.

This workshop was performed in order to obtain a more complete risk assessment and full awareness of hazards and dangers. Printed copies of the process model were used to structure the workshop. The workshop began with the presentation of the process map developed by the researchers describing the various tasks that need to be executed during cleaning operations in the bin. The workers had a chance to analyze each of the functions described in the map, and where necessary provided a better description of the map itself. Simultaneously an acknowledgment of the greatest hazard activities was performed – each task was examined with the workers; they studied, discussed and identified the activities that needed further attention. Once the identification stage was accomplished, the workshop proceeded with a much deeper study and understanding of each of tasks listed; workers described any possible deviations that may arise during the execution of each of these activities. The whole group discussed and reached a conclusion about the possible deviations. After learning about the deviations in the tasks, the workers defined the antecedent events that could cause deviations. This antecedent helps to reveal the actors or actions that could lead to a deviation. The workers reported then the consequences that can be generated because of these deviations. The results were captured in the hazard analysis section of the SCOPE software and recommendations were made on the basis of the results where required.

Results and Discussion

For the mapping process a flow chart was drawn using the software SCOPE. This tool helps the user to undertake an analysis of the processes involved and describe the tasks achieved in operations at the level of detail required for the analysis. Thus, a mapping process can be performed with the help of SCOPE, which describes the different activities to be executed during the cleaning process.

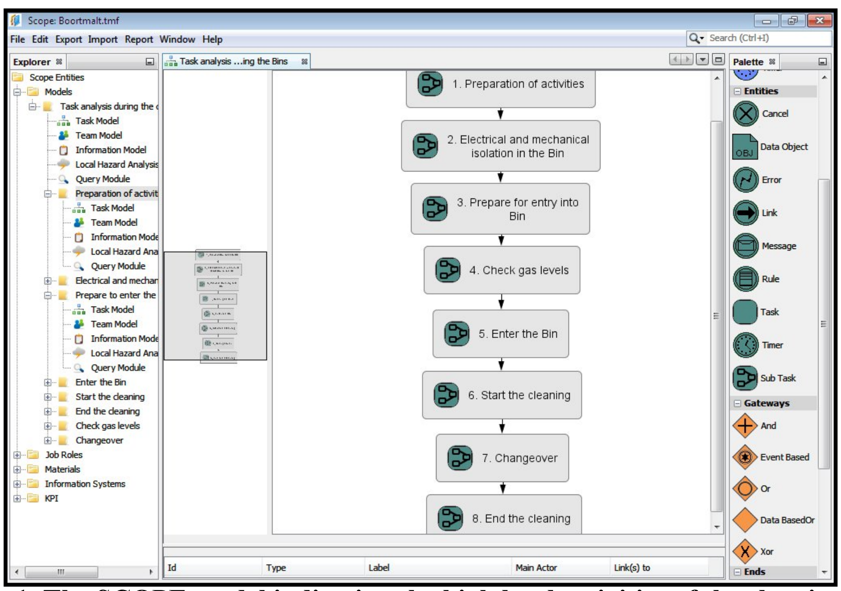


Figure 1. The SCOPE model indicating the high level activities of the cleaning process

To increase clarity about the functions that must be performed during the internal cleaning of the bin, this SCOPE model has been developed in a synthetic approach, where the main functions are divided into eight groups, which are defined as key tasks. After arranging these main functions, it continues with the development of the tasks that are contained within each of the eight main groups. Each of these tasks is connected in a coherent order; the display of main tasks shown in Figure 1.

The cleaning process can be summarized in the following steps:

1. The development of some preliminary tasks. The cleaning activity starts with the performance of some preparation activities. During this stage, the weather conditions need to be assessed to ensure the abseiling operation can be undertaken safely, and also gathering the working group together to perform a briefing on operational issues, and to talk about the precautions they should take.
2. Electrical and mechanical isolation of the bin. Before performing any maintenance work, it is important to perform an isolation of each of the devices that connect to the bin. The procedure in place in this case was dual redundant, with the bins isolated at the control room, and mechanically isolated at the bin itself. The SCOPE model captures this, and the distribution of these tasks across different workers.
3. Preparation for entry in to the bin. This group of tasks involves the installation of the abseiling equipment and personal protective equipment. SCOPE uses business process modeling notation, allowing checkpoints to be inserted in to the model. The sequence of activities for this group of tasks in SCOPE is presented in Figure 2. This step involves the critical tasks of setting up the abseiling equipment and ensuring that the equipment is in good condition.

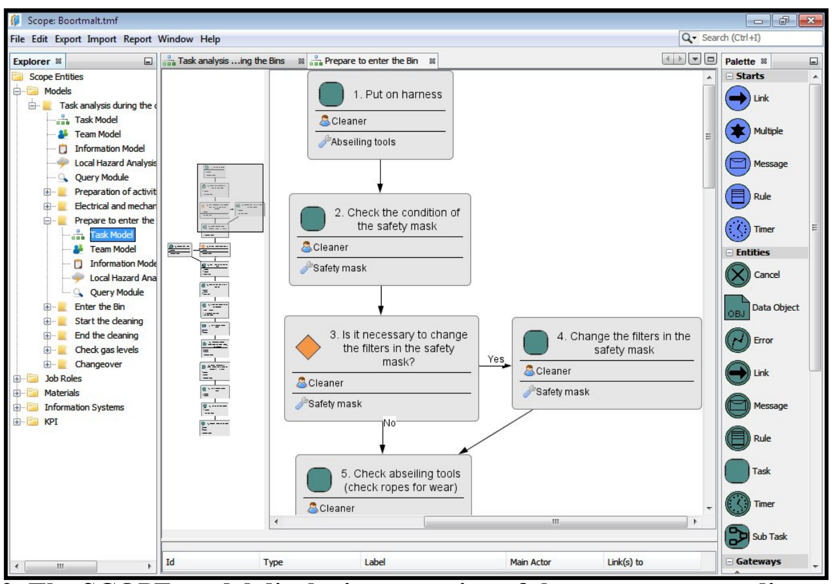


Figure 2. The SCOPE model displaying a portion of the map corresponding to the process of checking and installation of equipment

4. Check gas levels. Once the relevant installations are completed, it is necessary to check the gas levels inside the bin. A specific instrument must be used for this purpose and it must be handled with professionalism. The SCOPE model captures these responsibilities (delegation of work) in the process diagram.
5. Enter the bin. After the gas check, the workers can proceed and enter the bin, start the descent, and begin the cleaning. One worker will remain at the top of the bin controlling the ropes and the other is suspended inside the bin operating the

cleaning equipment. The procedures in place require that visual contact is maintained at all times to ensure the safety of the worker in the bin.

6. Start the cleaning. During the cleaning operation, the worker cannot exceed a certain time suspended because of the upright posture, with the legs relaxed straight beneath the body. This problem can trigger a series of events that threaten the health of the workers. The procedures for the work dictate that the workers change position at regular intervals.
7. Changeover. The changeover task involves the worker suspended in the bin ascending to the top (or dropping to the bottom, if easier) and changing position with the worker on the top.
8. End the cleaning. The final group of tasks involves removing and re-checking all the equipment used and closing up the bin after the cleaning process is completed.

The local hazard analysis conducted on each of the steps within these tasks identified the potential deviations, antecedents and consequences. Figure 3 shows one excerpt of the risk analysis of the cleaning process and what are the factors involved in the evaluation of the functions. The first column are the functions that we call nodes that correspond to each task, then the deviations related to each activity that could be the potential dangers, a third column with the antecedents, then the causes of the deviation and finally the consequences.

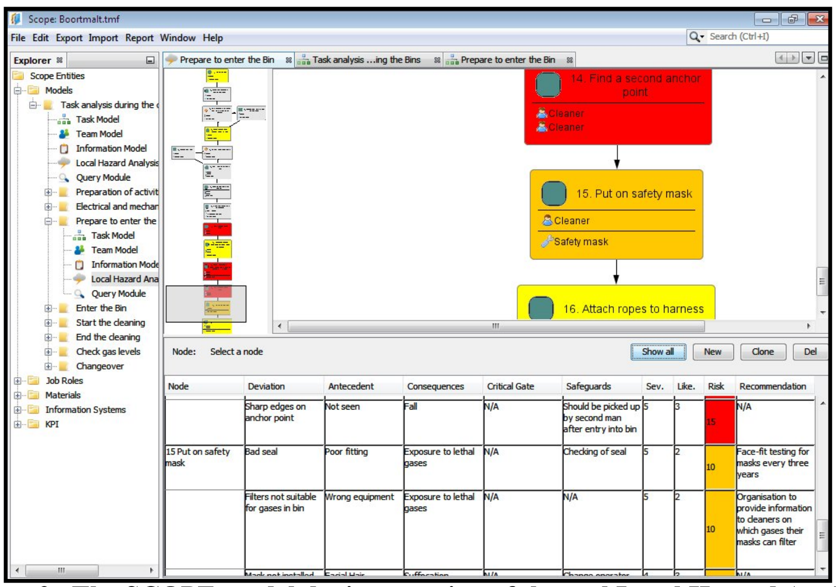


Figure 3. The SCOPE model during running of the tool Local Hazard Analysis

A qualitative risk matrix was used to define the level of risk. A numerical value is assigned for the frequency and severity of each risk identified in the process – the likelihood ranges from 1 to 5, 5 being very frequent and 1 sporadic and the severity also goes from 5 to 1, 5 indicates that the risk has lethal effects and 1 only can cause stress. The multiplication of the values of likelihood and severity gives a result of the overall level of risk shown in Figure 3. The assignment of a level of risk as high, medium or low allowed the identification of areas of risk. The high-level risks require immediate attention, while those with a low level are examined when all the others have been adequately resolved.

The results from this exercise identified 32 possible deviations during the cleaning process. These included possible deviations such as not isolating the correct bin, not checking equipment prior to use, mis-reading the gas detector, and dropping equipment during the cleaning process. Of these, 29 were assessed to have sufficient mitigations in place to accept the risk as tolerable. Three deviations were highlighted for further mitigation; these related to the anchor points for the abseiling equipment, the fit of gas masks used during the cleaning, and the filters used in the gas masks. Currently the workers identify a suitable anchor point for the abseiling equipment. The risk assessment highlighted this as a potential weakness and a recommendation was made for the organization to identify and label suitable anchor points for each bin. A possible issue was highlighted regarding poor fitting gas masks, and a recommendation was made to have face-fitting every three years. Finally, the workers involved in the workshop were not aware for which gases the filters in their masks were suitable and a recommendation was made to supply this information to the cleaners to facilitate better decision making and risk control on a daily basis.

Conclusion

In this study it was possible to identify the main risks during the cleaning process and relate them with the human functions, to integrate them in the design of process control increasing the effectiveness, efficiency, reliability and safety. The SCOPE tool allows the integration of human functions within the maintenance function and the evaluation of possible sources of deviations and forecasting of accident scenarios.

The involvement of the workers in the validation of the task model and the analysis of the risks was very successful and feedback from the workshop highlighted how useful each participant had found it. The identification of new risks and required mitigations proves the valve of this approach, and the new ideas generated offer increased learning for the entire workgroup, causing an increase in understanding the perspectives of others, while leading to better ideas and decisions. Involving everyone in the risk assessment process may also provide a sense of security and develop interpersonal relationships. This method could be particularly useful for SMEs who have been shown to have a limited ability to conduct traditional risk assessments requiring an investment in resources and staff competence (Miceli and Cagno, 2009). The structured approach provided by SCOPE allows SMEs to use their existing staff to generate the data for the risk assessment and identify possible improvements to their work processes.

The next steps for the research will be further workshops with additional staff operating across different sites. These workshops will aim to communicate the risks and to compare the results from different work groups to establish the reliability of the method and the required number of participants.

References

Health & Safety Authority, 2005, Safety, Health and Welfare at Work Act, Section 19

Micheli, G. and Cagno, E. 2009, Perception of safety issues and investments in safety management in small and medium-sized enterprises: a survey in the Lecco area. Prevention Today, 4(10), 7-18.

Wells, G. 1996, Hazard Identification and Risk Assessment, Institution Chemical Engineers, UK

ASSESSING THE REPORTING SYSTEM WITHIN A SAFETY MANAGEMENT SYSTEM – AN ACTION RESEARCH APPROACH

Ewan Douglas, Sam Cromie and Chiara Leva

Centre for Innovative Human Systems, Trinity College Dublin, Ireland

Abstract

Safety Management Systems are now a requirement within the EASA Part 145 regulation for Aviation Maintenance Organisations. For a SMS to collect usable data it has to allow for reports to be collected from staff in a way that is unobtrusive and impartial. This paper will outline a planned Action Research intervention plan for an Irish Aviation Maintenance Organisation, and the methods that will be implemented during the intervention.

Introduction

Within the aerospace maintenance industry there is now a regulatory requirement from the regulatory bodies to implement a Safety Management System (SMS) within aircraft maintenance organisations (Stolzer, Halford, & Goglia, 2010). A Safety Management System is a broad and systematic approach to managing safety taking into account the necessary organisational structures, accountabilities, policies and procedures that can influence safety within an organisation (SKYbrary, 2014; ICAO, 2006). For a Safety Management System to provide a net benefit to safety within an organisation requires good quality data entering the system; one common source for this data is through reports submitted by staff within an aerospace maintenance organisation.

CAP716 is a publication by the UK aviation regulator Civil Aviation Authority (UK) (2013) which lays out a Human Factors programme the Air Maintenance Organisations should implement. This is the standard that UK Aviation Maintenance Organisations should manage their Human Factors programmes to. Error Reporting and the data from the investigation from this will feed into the continuous monitoring process, which can be seen as a form of constant risk assessment. There is scope for reporting to also to be used to report inaccuracies and ambiguities within procedures.

Aerospace is a heavily regulation driven and there is a requirement for Maintenance Organisations to actual and potential safety risks including problems with procedures and documentation, this is known as Mandatory Occurrence Reporting (Civil Aviation Authority (UK), 2013).

The CAP716 specification for a Safety Management System makes a specific requirement for a maintenance organisation to report and investigate any maintenance errors that occur within an aerospace maintenance organisation. While investigating reports is frequently seen as a crucial step improving safety within an organisation; (Leva, Cahill, Kay, Losa, & McDonald, 2010; Tsukada & Kotani, 2001) investigating reports after an error has occurred and potential damage has occurred is a reactive approach. As discussed earlier there is a potential benefit in collecting information proactively that can help identify the precursors to a damage event occurring. Approaches such as the (Leva et al., 2012) methods of integrating reporting into their day-to-day operations, these approaches will be discussed later on in this chapter.

The CAP713 standard also requires that inaccuracies and ambiguities within work and procedures are reported back to the aircraft or part manufacture, this means that there is considerable interest in collecting reports from the mechanics who will complete the procedure. The Just-In-Time approach could allow this to happen as the procedure is carried out, collecting the most useful data for the organisation.

Why Reporting?

A risk assessment is a requirement for most industries. For an accurate quantification for the level of risk encountered within an industry the assessment must identify as many hazards as possible. The importance of identifying hazards can be found within the Carter & Smith, (2006) statistical model for accident causation, that is shown in the figure below :

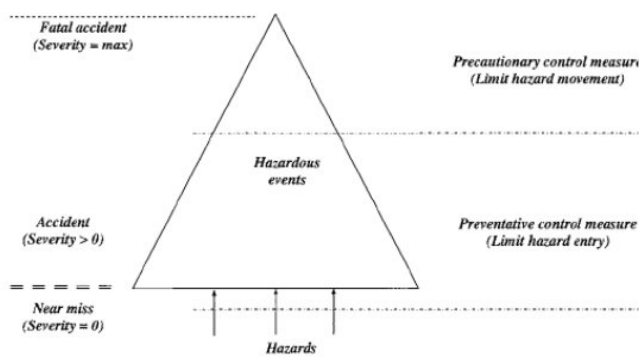


Figure 3 Carter & Smith (2007) Statistical Model for accident causation

If a hazard is not identified, it can enter the triangle and can have an unknown severity and an unknown likelihood of occurrence. For example a hazard is unidentified, it has an equal probability of causing a near miss to causing a fatality, so therefore the potential severity of the hazard is unknown. It can be said to have complete freedom of movement within the triangle shown in figure 1 (Carter & Smith, 2006). Therefore each unidentified hazard can introduce a potentially catastrophic level of risk within an organisation so therefore the only way to ensure that such a scenario can be mitigated would be to develop methods that will ensure that each hazard is identified.

Existing risk assessment methodologies such as THERP, HEART, HAZOP etc. are all intended to be used to determine a priori value for the risk involved within the a process from both a mechanical and ergonomic viewpoint (Kirwan, 1996). However risks will almost certainty appear during the implementation phase of a project during day-to-day operations that were not anticipated during the risk assessment at the initial risk assessment. Reporting would enable data from near misses, incidents, suggestions for improvements and anomalies to be catalogued and integrated into the risk assessment process improving the accuracy of the assessment (Reason, 1997; Williamsen, 2013). Tsukada & Kotani (2001) suggests that at an organisational level; the prevention of hazards and incidents can be furthered by eliminating potential risks through analysing reported near incidents and developing mitigation strategies in response, however this is referring to a system that has yet to be implemented by the authors and is therefore based on assumptions which may be incorrect within a real world implementation. Data gathered from reports can also be used in similar systems that may be susceptible to the same hazards as part of a risk assessment process (Tsukada & Kotani, 2001). Reporting systems involved within a safety management system are described within ICAO (2006) as a crucial element within the Safety Management system. Within the aerospace maintenance industry a reporting system is seen as an important element within the safety management process within a maintenance organisation (CAA(UK), 2013). Reporting could be seen as fundamental to the broad goal of reducing errors within an organisation (Cohen, 2000).

There are two primary approaches to reporting, these are leading and lagging approaches (sometimes referred to as proactive and reactive approaches). Leading approaches are intended to catch potential near misses before they have an opportunity to trigger an accident scenario. One such approach to this is the "day to day" approach put forward in (Kontogiannis & Malakis, 2009; Leva, Cahill, Kay, Losa, & McDonald, 2010).

Reason (1991) states that lagging methodologies are intended to be implemented after a near miss or incident and are only useful to prevent the same incident reoccurring, however there is scope of even limited reactive reports to be used proactively a source for historical data that can be used in future risk assessment processes. For example: A problem with a control interface that lead to a near miss could be mitigated in future implementations of a system.

As shown in Figure 1, SMS requires a method wherein anomalies with procedures to be relayed back to the aircraft or part manufacturer for potential mitigation to the procedure. Therefore the SMS should allow the reporters to share the specific information relating to the part and/or aircraft involved, in fact a reporting system that fails to allow the reporters to share the information that they want will negatively affect the level of reporting (Leveson, 2011).

Assessing an Aerospace Maintenance SMS

The action research methodology that is adopted is aimed at identifying an intervention that would actually be of use for the industrial partner. In order to achieve this there is a need for a relationship based on trust between the organisation and the researchers. By adopting a practice of trust, areas that would otherwise be neglected may be exposed. The basic plan for the overall PhD research is shown in the figure below the areas that will be focused on by this case study are highlighted:

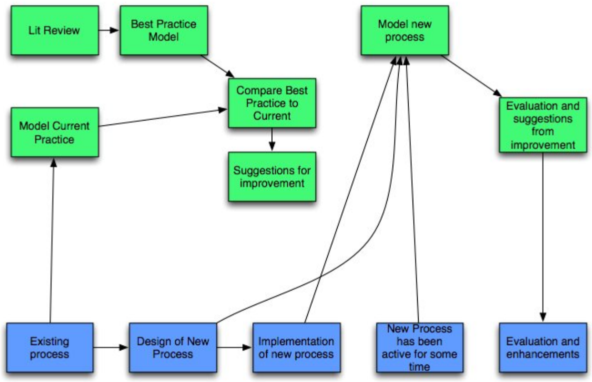


Figure 4 Planned intervention strategy

An in-depth review of the literature around the topics of safety culture and reporting systems has been completed. The literature review has been used to develop a best theoretical practice model, which suggests a way of integrating reporting into the risk assessment process within an organisation.

The literature review will be used to develop a best practice model using the SCOPE methodology. The "SCOPE" methodology a software tool developed within the CIHS at TCD. SCOPE is designed to assist in understanding the systematic factors that can influence how projects function.

SCOPE utilises a variant of the Business Process Modelling symbology and can allow the reporting process to be modelled, an example of a SCOPE process model is included in the figure below:

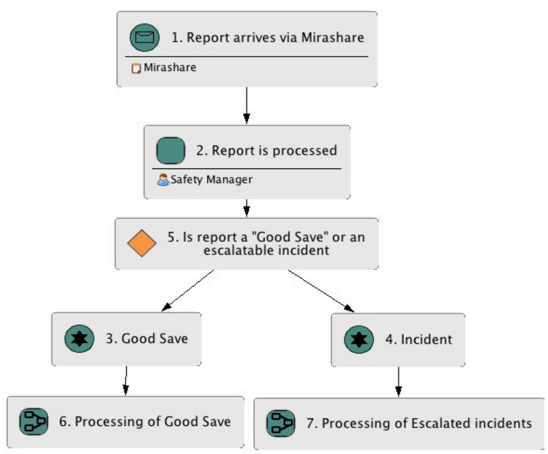
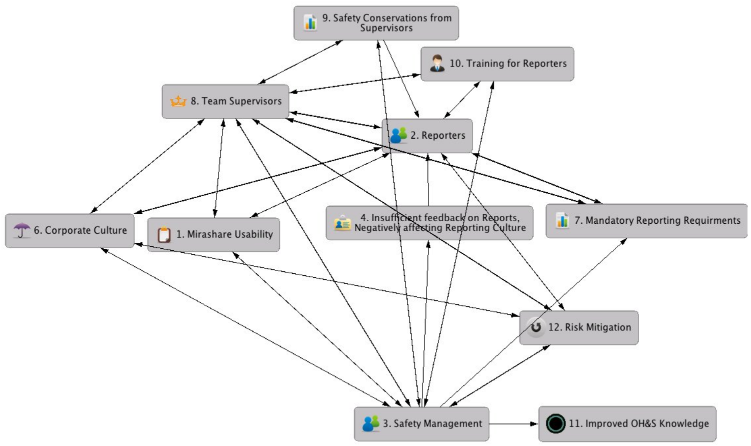


Figure 5 SCOPE task model

Figure 5 shows a decision that will be taken by a Safety Manger, regarding the classification of an incident where a Good Save (near miss) would be treated differently by management, which is indicated by the deviation flow, each deviation flow will then lead to two different sub graphs which indicate the processes for dealing with good saves and incidents. The SCOPE model allows the relationships between actors, information flows, etc. to be studied, and areas of vulnerability (tasks which can affect the whole process) can be explored using the SCOPE models.

Using the existing literature, SCOPE can be used to visualize a theoretical best practice, which can be compared to a SCOPE model of a current practice to determine areas of improvement. SCOPE allows for a visual description of the information map showing information and means of communication shared among users so as to help highlight areas of a system where vulnerabilities in the information flow can be found, and identify ways of mitigating them. An example of an information map is shown in the following figure:



Using the literature to develop a best practice model which can then be compared to the models developed using the current practice
This approach will allow the feasibility of the theoretical best practice to be compared to the industrial practice and would set the foundations for a best practice model to be developed.

Current Practice

Analysing current practice – using the existing paper-based reporting system - will allow the areas that can influence the reporting culture to be studied. This will suggest methods that could easily be established within the organisation's management to encourage good reports from staff and to maximise the application of the Safety Management System within the organisation. The approach that will be implemented to determine the current practice will be as follows:

- Interviews/ Meetings/Workshops with the QA team within Dublin Aerospace to determine the current practice within Dublin Aerospace and how management deal with the reporters.
- Interviews, Surveys and Observations with the staff who make the reports and who will be inputting into the new SMS system, and to see what they would expect from a proactive reporting system.
- Analysis of historical data – content of reports, nature of events reported, level of detail, who reports, etc.
- Modelling the current process and allowing for a representation of a system to be developed and used to analyse ways of improvement.

This will be a primarily qualitative approach to this collection method, however quantative data will also be collected from the interviews and surveys with the reporting staff in Dublin Aerospace to assist in the process of determining the quality of the cultural change.

Comparing Current Practice to Best Practice
Determining the best practice within the organisation will also allow the mostly theoretical literature on this area to be assessed.

This will use the information collected from the onsite data collection, it will be used to find ways of maximising the effectiveness of the SMS system by ensuring that high quality information flowing into the SMS system, this will be compared to the best practice model that will be developed from the literature, and can then be used to suggest ways of effecting the cultural change that will ensure a good reporting culture. This can input into the refinement of the new reporting system.

The data that has been collected with be processed and used to develop a model of the current practice, and will then be compared to the best practice model developed earlier in the process. The model will allow for suggestions that could be implemented to refine the new reporting system to be rolled out

Afterwards

After the initial intervention, the organisation will be revisited after some time to estimate the effectiveness (if any) of the reporting strategy; this will allow the literature to be validated. The experiences of this will allow for a new framework for integrating reporting into the safety management process to be developed and contributed as part of the InnHF programme.

Acknowledgements

This work forms part of the EU FP7 funded Marie Curie Actions Initial Training Networks project titled Innovation through Human Factors in Risk Analysis and Management (InnHF; see www.innhf.eu)

References

(UK), C. A. A. (2013). CAP 716 Aviation Maintenance Human Factors (EASA / JAR145 Approved Organisations).

Carter, G., & Smith, S. D. (2006). Safety Hazard Identification on Construction Projects. *Journal of Construction Engineering and Management*, *132*(2), 197–205. doi:10.1061/(ASCE)0733-9364(2006)132:2(197)

Civil Aviation Authority (UK). (2013). CAP 716 Aviation Maintenance Human Factors (EASA / JAR145 Approved Organisations).

Cohen, M. R. (2000). Why error reporting systems should be voluntary. *BMJ*, *320*(7237), 728–729. doi:10.1136/bmj.320.7237.728

ICAO. (2006). *Safety Management Manual (SMM)*. montreal.

Kirwan, B. (1996). The validation of three human reliability quantification techniques - THERP, HEART and JHEDI: part 1 - technique descriptions and validation issues. *Applied Ergonomics*, *27*(6), 359–373.

Kontogiannis, T., & Malakis, S. (2009). A proactive approach to human error detection and identification in aviation and air traffic control. *Safety Science*, *47*(5), 693–706. doi:10.1016/j.ssci.2008.09.007

Leva, M. C., Cahill, J., Kay, a M., Losa, G., & McDonald, N. (2010). The advancement of a new human factors report--'The Unique Report'--facilitating flight crew auditing of performance/operations as part of an airline's safety management system. *Ergonomics*, *53*(2), 164–83. doi:10.1080/00140130903437131

Leva, M. C., Mattei, F., Mcdonald, N., Montanari, F., Corrigan, S., Cacciabue, C., & C, D. (2012). Information support tools for MASCA (first release). Dublin: Trinity College.

Leva, M. C., Mcdonald, N., Del Sordo, D., Righi, P., & Mattei, F. (2010). Performance Management in a Small Regional Airport , from Day to Day Data Collection to Resilience. In *EUROPEAN SAFETY AND RELIABILITY CONFERENCE*. Helsinki.

Leveson, N. G. (2011). *Engineering a Safer World*. Cambridge ,MA: Massachusetts Institute of Technology.

Reason, J. (1991). Too Little Too Late□: A Commentry on Accident and Incident Reporting System. In T. Van Der Schaff, L. DA, & A. . Hale (Eds.), *Near Miss Reporting as a Safety Tool* (1st ed., pp. 9–27). Ocford: Butterworth Heinemann.

Reason, J. (1997). *Managing the Risks of Oragnizational Accidents* (1st ed.). Aldershot: Ashgate.

SKYbrary. (2014). Safety Management System. Retrieved March 21, 2014, from http://www.skybrary.aero/index.php/Safety_Management_System

Stolzer, A. J., Halford, C. D., & Goglia, J. J. (2010). *Safety Management Systems in Aviation* (1st ed.). Farnham, England: Ashgate Pub Ltd.

Tsukada, T., & Kotani, F. (2001). Sharing Knowledge on Human Error Prevention. In *Safety Culture in Nuclear Power Operations* (pp. 301–316).

Williamsen, M. (2013). Near-Miss Reporting - A Missing Link in Safety Culture. *Professional Safety*, (May).

ERGONOMICS ASPECTS OF DIVERSE WORK ENVIRONMENTS – AIRCRAFT MAINTENANCE & MANAGEMENT OPERATIONS

Seamus Clare and Thomas Waldmann

Department of Design and Manufacturing, University of Limerick, Ireland

Abstract

According to the 2013 'State of Global Aviation Safety Document'[1], "The safety of global air transport is the International Civil Aviation Organisation's (ICAO) most fundamental safety objective". The never ending efforts of ICAO, the National Regulatory Authorities and industry stake-holders continue to yield improvements in the safety of air transport. However variables associated with the 'human factor' often prevent proponents from claiming the elusive prize of a zero accident rate. Unfortunately aircraft accidents often involve human factor deficiencies at some point in the causal chain. Therefore exercising a strong degree of awareness by all involved should assist in recognising and managing these factors so that an acceptable level of safe operation can be continuously achieved.
For many years human factors and ergonomics may have only been considered in the context of pilots and air traffic controllers and the impact of degraded performance in these areas. The main objective of this paper is to give an appreciation of human factors as they present in the aircraft maintenance & management environments and how related occurrences are harvested to support an effective safety management system.

Introduction

During the 1940's it was recognized that aviation had developed far beyond expectations at that time. This was largely due to technical advancements that came about in this period and it was considered that such a new paradigm could support the noted potential for mobility of persons and much needed fiscal development internationally.

In 1944 the US government after consultation with other interested parties extended an invitation to 55 states and authorities to attend an international civil aviation conference in Chicago. Of the 54 states that attended this landmark gathering, 32 states signed up to the establishment of an International Civil Aviation Organization (ICAO).

ICAO's main remit was and still is to "secure international co-operation and the highest possible degree of uniformity in regulations and standards, procedures and organization regarding civil aviation matters". The work initiated by the Chicago Convention and its signatories was monumental in terms of the foundations it laid for the establishment of rules and regulations that supported the emergence of a common global air navigation system. This in

[1] Further information can be accessed at;
http://www.icao.int/safety/State%20of%20Global%20Aviation%20Safety/ICAO_SGAS_book_EN_SEPT2013_final_web.pdf

turn contributed to aviation continuously pursuing levels of safety that make it one of the safest forms of transport today.

From its Montreal headquarters ICAO continues to promote and steward the safe and orderly development of international civil aviation, security and related environmental standards. It also provides the conduit for communication and co-operation between the 192 member states that subscribe to its vision.

The Air Navigation and Transport Act 1946 transposed the necessary elements of the Chicago Convention into Irish Law. The regularizing of a standard approach to aviation regulation in Ireland which the Act enabled was an antecedent to the current body, (the Irish Aviation Authority) that today discharges the State's aviation oversight and development in Ireland.

As Ireland is a member state of the European Union it is also obliged to comply with regulatory outputs from the European Aviation Safety Agency (EASA). In Europe EASA support the EU in the technical development and compliance oversight of aviation regulations; monitors and approves organizations involved in the design, manufacture and maintenance of aviation products; it promotes the Single European Sky II[2] initiative; with the desired outcome of supporting safe and efficient use of air traffic control and airspace. In addition to these mandates, a major aspect of the Agency's work is the analysis of safety data and safety research.

Since the first recorded manned flight in 1903 by the Wright brothers, it could be said that the aviation domain has transferred many technological developments to support and augment safer levels of operation. Of course in addition to the efforts to continue improving the reliability of the "machine", it is important to note that the "man-machine" interface must also be continuously developed, maintained and monitored. There is no doubt that aviation's many operational strands are affected by activities of varying degrees, each with a latent potential to do harm if and when things go wrong.

Ergonomics and Human Factors

During the 1940's Ergonomics could be said to refer to the "study of man-machine design" (Rouse, W.B. and Cody, W.J. 1998). Ergonomics has been applied throughout civilization for many years in one form or another. The world of aviation initially benefitted from this 'philosophy' through addressing pressing issues for pilots such as open cock-pits and basic aircraft design (Brookhuis K.A. et al. 2008) to today implementing equipment designs making operating and controlling an aircraft more user friendly and error tolerant. (Demagalski, J et al. 2002). According to the ICAO Human Factors Training Manual (ICAO Doc 9683), ergonomics is considered to be the "study of the principles of interaction between human and equipment, for the purpose of applying them in design and operation". Although ergonomics is somewhat specific in terms of man-machine design/interface, the term is often expanded to include "human factors" in some jurisdictions.

It is noted that the term human factor's encapsulates many aspects of human performance & limitations and the interfaces with the systems they interact with. The ever present compromise in aircraft maintenance and management between production and safety remains complex and what Perrow terms 'tightly coupled' (Perrow. C. 1999).

[2] Single European Sky II - Its ultimate objective is to increase the economic, financial and environmental performance of the provisions of the Air Navigation Services in Europe.
http://ec.europa.eu/transport/modes/air/single_european_sky/ses_2_en.htm

In the United States of America in the mid 1980's it was recognised by policy makers[3] and practitioners at that point aircraft design had matured and was reasonably reliable. So, as far back as almost thirty years ago, there was a realisation dawning that the licenced engineer/certifying staff/technician could also be affected by the limitations of a human being. Unfortunately some fatal accidents were the result of the less that satisfactory performance of the companies oversight and management systems that were ultimately exposed by the human factor.

Fatal Accident Rates – A Global View

In Europe air transport is considered to be one of the safest forms of transport. The following table illustrates an overview of the global fatal accident rates by region of the world for scheduled commercial air transport per million flights.

Table 1. Scheduled Commercial Air Transport Fatal Accident Rate per million flights by World Region 2004 – 2013.

Region	Accident rate for scheduled commercial air transport per million flights
EASA Member States	1.8
North America	1.9
Oceania	5.8
Asia	6.3
Central America	11.1
Middle East	15.5
South America	16.9
Europe Non-EASA Member State	28.8
Africa	38.3

* Source - Adapted from EASA Annual Safety Review 2013

This table gives an overview of Commercial Air Transport (CAT) accidents on a global scale. Accident involving European Member State aircraft over the period 2004 to 2013 show that there were 1.8 accidents per million flights. This is compared to 38.8 accidents per million flights in the lowest performing ICAO region. The data refers to the period 2004 to 2013 with no fatal accidents occurring in the CAT sector in 2013. Over the last ten years the accident rate in civil aviation has remained fairly constant. However as forecasted, when increases in air traffic begin to occur, this may lead to an increase in the number of accidents in the near future. To further enhance State's civil aviation safety system capabilities, better information relating to occurrences is required in order to facilitate analysis of underlying issues and further reduce aviation related accidents.

In order to generate data to support representations such as those in table 1 above, information is derived from safety occurrences reported by the various disciplines within the aviation domain. Within Europe mandatory occurrence reporting has been actively promoted since the effective date of EC Directive 2003/42/EC. This Directive requires occurrence reports to be collected, evaluated and processed. The responsibility for this task in Europe is managed

[3] United States Congressman James Oberstar (ICAO Doc 9824)

by a competent Authority such as a national civil aviation authority and /or an investigating body established under Directive 94/56/EC or any other independent body or entity tasked with this function. In 2014 the importance of reporting in Europe has further been fortified with the imminent adoption of Regulation (EU) 376/2014 which has been developed in response to some of the deficiencies and constraints that affect mandatory occurrence reporting

Mandatory Occurrence Reporting

It is a fundamental International Civil Aviation Organisation (ICAO) requirement for all (aviation) design, production, operational and maintenance organisations to subscribe to an occurrence reporting system. For example, in Europe EU Regulation 2042/2003 that relates to the aircraft maintenance code Part 145 (refers to AMC 20-8) requires entities and individuals involved in maintenance to consider and report defined occurrences to a number of parties. In parallel, flight crew and other professionals are also obliged under similar operational requirements to submit mandatory reports. The Part 145 concept is predominantly intended to highlight technical and design issues that affect or could affect aircraft safety. However any issue that could result or has resulted in an unsafe condition that seriously hazards the flight safety is also intended to be captured by this important provision.

Following a comprehensive review of the EU legislation that supports accident and incident investigation, (performed on behalf of the European Commission) EU Regulation 376/2014 was developed. One of the main impetuses of this legislation was the recognition that expertise and regulatory framework requirements have had to evolve considerably over recent years. The directive also sets out to put greater emphasis on accident prevention by facilitating the holding of efficient and high quality safety investigations. Some of the tasks and responsibilities associated with EU Regulation 376/2014 are the brief of dedicated air accident investigation entities that were established under 94/56/EC. Competent Authorities established under 94/56/EC tend to be mostly involved in the investigation of accidents and serious incidents. In Ireland the entity appointed under SI 205/1997 which transposed 94/56/EC into Irish law is the Air Accident Investigation Unit (AAIU).

Currently the Irish State's occurrence reporting obligations are defined in SI 285/2007 which appoints the Irish Aviation Authority (IAA) as the competent authority to "put in place a mechanism to; collect, evaluate, process and store relevant occurrences reported". So as earlier mentioned, persons involved in civil aviation activities are encouraged to report occurrences where the safety of operation was or could have been endangered or which could have led to an unsafe condition.

The taxonomies associated with the designated codes (e.g. Part 145, ICAO Annex 13) are quite broad in their categorisation of causal or contributory factors to an undesired event. Table 2 contains an abbreviated representative example of event categories extracted from the ICAO Annex 13 taxonomy and the AMC 20-8 Appendix. However a common strand amongst many events is the human input. The table below shows some examples of the terms used to categorise the factors that contribute to unwelcome occurrences but maintenance human factor influenced events are not well represented. It should be appreciated that human factor related issues can manifest in a persons degraded performance and the resulting effect not always exposing the cause fully when the event is categorised.

A weakness that may be evident in the reporting system is that actual maintenance human factor causal categories do not appear to be fully considered at mandatory reporting level. This would seem to be one of the reasons that there is a paucity of actual data on human factor driven maintenance related occurrences. Aviation safety is hugely reliant on well executed maintenance. In comparison to other inputs to aircraft operations, under performance relating to maintenance intervention may often be difficult to detect. So there can be latent issues remaining undiscovered for some time until an undesirable event occurs. Mandating the defining, recording, collating and sharing of maintenance related human factor events could yield a very useful source of information that might be applied in support of the new departure to performance based regulatory oversight.

Table 2. Examples of Mandatory Reportable Occurrences

Operational related		
Loss of control – in flight	Undershoot/overshoot	Runway excursion
Occurrences during maint.	Wind-shear or thunderstorm	Laser
Ground handling	Cabin safety events	Unknown or undetermined
Security related	Level bust	Loss of control - ground
Turbulence encounter	Ground collision	Ice
Maintenance and design related		
Damage to or defect of a structural element, which could result in the liberation of items of mass that may injure occupants of the aircraft.		
Defect or damage exceeding admissible damages to a Principal Structural Element that has been qualified as damage tolerant.		
Failure or malfunction of the exclusive function(s) of the system (one system could integrate several functions).		
Any defect in a life controlled part causing retirement before completion of its full life.		

* Source - A representative sample taken from ICAO 13 and EASA AMC 20-8 Appendix..

Where Can It All Go Wrong?

Although unfortunately many lessons have been learned over the years from incidents[4] that contribute to accidents[5], often the same precursors and catalysts exist in some shape or form. Towards the end of the 1980's and into the 1990's, the aviation regulatory authority in Canada

[4] ICAO Annex 13 Aircraft Accident Investigation definition – Incident: An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

[5] ICAO Annex 13 Aircraft Accident Investigation definition – Accident: An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:
a) A person is fatally or seriously injured as a result of
- being in the aircraft, or
- direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
- direct exposure to jet blast, **except** when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew: or
b) the aircraft sustains damage or structural failure which:
- adversely affects the structural strength, performance or flight characteristics of the aircraft, and
- would normally require major repair or replacement of the affected component,
except for engine failure or damage. when the damage is limited to the engine, its cowlings or accessories: or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin: or
c) the aircraft is missing or is completely inaccessible.

(Transport Canada) identified twelve factors that could lead to a persons degraded performance and thereby could contribute to an accident or incident. These twelve factors (Table 3) became known as the 'dirty dozen' and have been adopted in the industry as the base line for discussing human factors and their impact upon aircraft maintenance.

Table 3. The 'dirty dozen' common contributors to human factor issues

Distraction	Pressure	Norms
Lack of knowledge	Lack of resources	Lack of awareness
Complacency	Fatigue	Stress
Lack of communication	Lack of teamwork	Lack of assertiveness

The factors confronting staff involved in aircraft maintenance operations are often not unique to that domain. However alone or in combination, the factors listed above have huge potential to do harm if not sufficiently identified and managed correctly. Lack of resources can be a major constraint when it comes to providing adequate levels of appropriately qualified competent staff. Pressures exerted upon existing staff in a dynamic industry sector to absorb additional workload can of course have a detrimental effect on safety. Competent and available supervision of maintenance and inspection staff is a core requirement of the quality mission in aviation operations. In many regions the maintenance requirements stipulate a process whereby all staff must meet qualification criteria and be deemed competent before unaccompanied work can take place. As mentioned earlier the overall aim of occurrence reporting is to proactively discover and manage the factors that may contribute to incidents and accidents and help fortify the maintenance system against errors. A main tenet of this reporting system in organisations is the ability to report any error or potential error in a 'free and frank' way. This philosophy is intended to be supported by what is termed a just culture, where the outcome for the individual is not based on punitive measures or being inappropriately punished for reporting or co-operating with occurrence investigations. The occurrence reporting system is intended to be a 'closed-loop' system where feedback is given to the originator and actions are implemented within the organisation to address potential or looming safety hazards. The extension of the current guidance taxonomy to include maintenance driven human factor events and the ultimate use of this data will have a certain undisputable value in terms of its predictive ability in relation to identifying trends that could uncover latent undiscovered degraded maintenance input performance.

Today experience might indicate that even the incumbent occurrence reporting system if it had been mandated at the time of many well publicised accidents it may well have helped to proactively identify and address many of the human focused contributory factors. Certainly issues such as deviation from approved data, lack of assertiveness, knowledge, resources, awareness, pressure and complacency to name a few may have been effectively addressed in advance of the events.

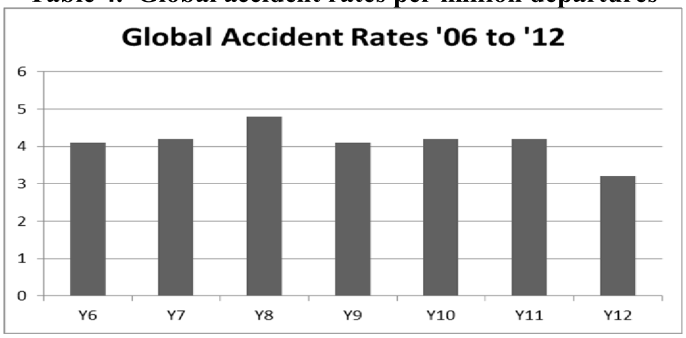
Maintenance Related Human Factors, Where Does It Fit In?

The globally recorded accident rates based on scheduled commercial operations involving aircraft having a maximum take-off weight (MTOW) above 2250 kg can be seen in table 4. These accidents are classified in accordance with the standard ICAO taxonomy[6]. Over the

[6] The ICAO/CICTT Aviation Occurrence Taxonomy is designed to permit the assignment of multiple categories as necessary to describe the accident or incident. Since 2001, the Safety Indicator Steering Group (SISG) has met annually to assign CICTT occurrence categories to the prior year's accidents.

period covering the aggregated rates shown below, the average rate per million departures worldwide is 4.11. The years 2010 and 2011 saw a very slight increase in the accident rate. According to the 2013 ICAO safety report, 2012 saw the lowest recorded rate of 3.2 since ICAO began recording this data.

Table 4. Global accident rates per million departures



* Source – Adapted from data presented in the 2013 ICAO Safety Report.

One might ask the question, "Where do maintenance related human factors come into all of this?" In Europe currently the system for ensuring aviation safety is mainly based on a set of regulations that are overseen by the European Aviation Safety Agency's (EASA) competent authorities. These regulations overtime have matured and have been a major component which has successfully augmented aviation safety system performance. Of course aircraft designs continue to be improving and hence design and operational reliability is continuing to evolve. However as aviation in general is becoming more complex, ICAO recognise that regulation based oversight alone will not be effective enough in the future.

Table 5. An extract collated from the USA NTSB accident investigation web-site

	Event	Date	NTSB report	Probable cause
1	Crash on take-off of Gulfstream Aerospace Corporation G-IV	13 May 2014	ERA14MA271	(Preliminary report) Currently under investigation
2	Boeing 737-300 passenger flight	01 April 2011	AAB-13-02	Human factor at manufacture
3	Crash Following Loss of Engine Power Due to Fuel Exhaustion, Eurocopter AS350 B2	26 August 2011	AAR-13-02	Human Factor crew/Human Factor procedures
4	Loss of Control Eurocopter AS350-B2, N37SH	07 December 2011	AAR-13-01	*Human Factor maintenance
5	Re-fuelling Services flight crash	18 May 2011	AAB-13-01	*Human Factor maintenance
6	Crash During Experimental Test Flight, Gulfstream Aerospace Corporation GVI (G650),	02 April 2011	AAR-12-02	Human Factor manufacture

7	Pilot/Race 177, P-51D	16 September 2011	AAB-12-01	*Human Factor maintenance
8	Runway Overrun Boeing 757-200	29 December 2010	AAR-12-01	Human Factor crew/Human Factor procedures
9	Loss of control while manoeuvring Pilatus PC-12/45	22 March 2009	AAR-11-05	Human Factor crew
10	Crash After Encounter with Instrument Meteorological Conditions during take-off from Remote Landing Site Agusta S.p.A	09 June 2009	AAR-11-04	Human Factor crew

The table above shows a view of 10 accidents (2009 – 2014) that have been or are under investigation by the USA's National Transport Safety Bureau. Like Europe the USA has a mature aviation safety oversight system. It is interesting to note that approximately 30% of the featured incidents appear to have some form of maintenance human factor aspect attributed to them. Indeed considering the impact of continuously evolving systems in maintenance and operations and the resulting impact of organisational factors on the 'human', anticipating and proactively mitigating against all potential safety risks would appear to be a prudent approach.

One development that has the potential to support mandatory occurrence reporting is the advent of industry based Safety Management Systems (SMS). In brief, a well-designed SMS proactively identifies hazards, assess the risks posed by the hazards and supports actions to reduce the risks so that an acceptable level of safety can be achieved. In theory the SMS is a proactive management system that continues to measure the effectiveness of the mitigating actions already embodied in concert with managing new hazards and risks. Although the implementation of SMS is not yet mandatory for all maintenance organisations, many operators with their own maintenance capability have introduced the requirement in harmony with operational requirement obligation.

One of the challenges once associated with occurrence management in the industry was deciding if the severity or potential of the occurrence or incident is such that it could be managed internally or if it had to be reported to the 'Authorities'. As reporting systems and procedures mature, this challenge appears to be manageable when a company has a positive ethos embedded in its culture and the system is formally managed by an appointed individual or group. It is hoped that the outputs from SMS will be an important input to occurrence reporting and therefore proactively inform actions that identify and address degraded performance, for example in the areas of aircraft maintenance and management operations.

Conclusion

It might be considered a reasonable assumption by many that passenger numbers and the related aircraft movements will increase in unison with economic development over the coming years, as will the challenges to remain safe. Although the performance of aviation is strongly related to the efficacy of the systems that are in place, it must be said that it is totally dependent on the proficiency and professionalism of the various teams and individuals that enable operations. Of course actions require judgements and decisions to be made in concert with the various forms of communication that are necessary. Ironically this may invariably expose those decision makers to the risk of inadvertently contributing to error inducing events as they discharge their duties. The advent of SMS is intended to implement mitigating actions that support these actors.

The training of aviation professionals has come a long way over the last few decades. Of course new sources of error and causation factors will continue to evolve and be present. Initiatives such as the implementation of the ICAO's Safety Management System[7] (SMS) requirement and European Human Factors Advisory Group[8] (EHFAG) outputs will continue to define structure and strategies to support human factor development and performance across civil aviation professions and activities. However a more visible endorsement of 'Safety Health' measurement programmes amongst maintenance and operational strands would be a major leap towards the establishment of a 'real-time' view of safety indicators that encapsulate the human factor.

Conventional compliance audit programmes are of specific value when it comes to measuring the degree of compliance with regulatory requirements. Additionally it should be considered as Thomas (2001) notes; "A low accident rate, even over a period of years, is no guarantee that risks are being effectively controlled….This is particularly true in organizations where there is a low probability of accidents but where major hazards are present. Here the historical record can be an unreliable or even deceptive indicator of safety performance". Unfortunately the data that originates from the 'compliance effort' is often unable to give an insight into issues such as the safety culture or climate within a maintenance setting for example. Lagging indicators such as accident or incident data can often be a poor source of how vulnerable an organisation is for example to the impact of degraded performance that might result from issues rooted in human factor deficiencies.

McDonald et al (2000) in the introduction to their study featured in the paper entitled 'Safety Management Systems and Safety Culture in Aircraft Maintenance Organisations', make a very important point when they state; "To understand the human contribution to major accidents and disasters, organisational and management factors have to be taken into account". Even still despite all of the perceived 'redundant' safety layers required in aviation, it appears that the links between organisational cultural deficiencies and the components of safety in this domain are not fully appreciated or understood. Therefore it could be reaffirmed that in order to understand and measure safety cultures with a view to helping safety in aircraft maintenance and management to continue to evolve, the most basic element that has to be considered is that people have certain capabilities (physical & mental) that in turn define their abilities to operate in diverse working environments. Proactively managing the notion of a safety culture coupled with the support of a view of the real hazards that exist could certainly be realised with the help of a clearer focus on the potential of data arising from maintenance driven human factor issues.

References

Brookhuis, K.A., van Driel, C.J.G., Hof, T., van Aremb, B. and Hoedemaeker, M. 2008, Driving with a congestion assistant: mental workload and acceptance. Applied Ergonomics, 40, (1019 - 1025)

[7] ICAO Document 9859
[8] Further information can be accessed at; http://www.easa.europa.eu/node/15714

Demagalski, J., Harris D., Salmon, P., Stanton, N., Marshall, A., Waldmann, T. and Dekker, S. 2002, Design Induced Errors on the Modern Flight Deck During Approach and Landing. American Association for Artificial Intelligence (173 – 178)

EASA website. www.easa.europa.eu (Accessed 14th April 2014)

European Aviation Safety Agency Annual Safety Review 2013. EASA 2014.

EU Commission Regulation no 2042/2003. http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:315:0001:0165:EN:PDF (Accessed 14th April 2014)

EC Council Directive 94/56/EC http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994L0056:EN:HTML (Accessed 20th July 2014)

EC Council Directive 2003/42/EC http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994L0056:EN:HTML (Accessed 20th July 2014)

ED Decision 2003/012/RM – AMC 20-8 http://easa.europa.eu/system/files/dfu/decision_ED_2003_12_RM.pdf (Accessed 20th July 2014)

S.I. No. 205/1997 http://193.178.1.79/1997/en/si/0205.html (Accessed 20th July 2014)

S.I. No. 285 of 2007 http://www.irishstatutebook.ie/pdf/2007/en.si.2007.0285.pdf (Accessed 20th July 2014)

Regulation (EU) No 376/2014 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014R0376 (Accessed 20th July 2014)

FAA website. www.faa.gov (Accessed 14th April 2014)

Human Factor Guidelines for Aircraft Maintenance Manual, (Doc 9824) First edition, 2003, International Civil Aviation Organisation.

ICAO Human Factors Training Manual (Doc 9683), First edition, 1998, International Civil Aviation Organisation.

ICAO Human Factors Guidelines for Air Traffic Management (ATM) Systems (Doc 9758) First edition, 2000, International Civil Aviation Organisation.

ICAO Human Factors in Civil Aviation Security Operations (Doc 9808) First edition, 2000, International Civil Aviation Organisation.

ICAO Convention on International Civil Aviation (Chicago Convention) (Doc 7300) Ninth edition, 2006, International Civil Aviation Organisation

ICAO website, http://www.icao.int/Pages/default.aspx (Accessed 14th April 2014)

IATA website, http://www.iata.org/Pages/default.aspx (Accessed 14th April 2014)

Irish Aviation Act, 1946, http://www.irishstatutebook.ie/1946/en/act/pub/0023/index.html (Accessed 14th April 2014)

McDonald, N., Corrigan, S., Daly, C. and Cromie, S. 2000, Safety Management Systems and Safety Culture in Aircraft Maintenance Organisations, Safety Science. 34 (151 – 176).

National Transportation Safety Board (NTSB), http://www.ntsb.gov/index.html (Accessed14th April 2014)

Perrow, C. 1999, *Normal Accidents: Living with High-Risk Technologies,* New York: Princeton University Press.

Rouse, W.B. and Cody, W.J. 1998. On the Design of Man-Machine Systems: Principles, Practices and Prospects, Automatcia. 24, No. 2, (227 -238)

Transport Canada Aviation, http://www.tc.gc.ca/eng/civilaviation/menu.htm (Accessed 14th April 2014)

UK Civil Aviation Authority website, www.caa.co.uk (Accessed 14th April 2014)

IRANIAN TRANSPORTATION SAFETY STRATEGY FOR REDESIGN OF TRAFFIC REGULATIONS AND INCREASING ROAD SAFETY BY THE IMPLEMENTATION OF NEW TECHNOLOGIES

Mahnaz Sharafkhani[1], Farzad Naghdali[2]

[1] Department of Industrial Engineering, Azad University of Nour, Iran
[2] Centre for Innovative Human Systems, Trinity College Dublin, Ireland

Abstract
In this paper authors will present a picture of the Iranian Traffic Police to increase safety of roads before and after the implementation of the new strategy which was introduced in 2006. After describing the new strategy the results caused by the changes will be discussed. The data compares before and after the intervention project. The Special mission of March 2014 of Traffic Police will be described briefly and the most recent information regarding road accidents will be analysed. In general the statistical analysis shows a significant reduction of number of accidents and the consequent reduction in the total number of fatalities. However this trend was not observed in mortality rate of accidents and yet the severity of accidents remained high. The paper does not cover the strategies that are aiming to provide medical and emergency services but the reader should consider that the time interval from the report of an accident till presence of emergency teams at the scene has been reduced by relevant authorities by another project parallel to the Traffic Police's project. The project changed the driving culture but did not succeed in reduction of severity of accidents. There are no reliable data regarding the cause of the high fatality rate of accidents but authors pointed out possible issues in the paper that can help official authorities to improve road safety. This paper attempts to provide an insight regarding the importance of the human factor in transportation and its crucial role for the future and provides a tangible knowledge of the safety of road transportation in Iran.

Introduction: A Summary of the Situation

In 1997 based on the United Nation's report Iran had the world's highest rate of fatalities in car accidents. Over speeding was the main cause of accidents and not using the seat belt was the main cause of death in the accidents (United Nations, 1997). Road Transportation serves as the major method of transportation for goods and passengers in Iran and a report in 2008 indicates that 90 % of people travel on roads (Jamejam News, 2008). Size (1,648,000 square kilometres) (National Geographic, 2014) and the population (77352373 People) (World Population Review, 2014) of country contribute to the busyness of the road infrastructures. On the other hand, Iran's culture is based on the family as the core of social activities and road trip is one of the favourite hobbies of people. Low fuel price, availability of inexpensive vehicles in the market and long vacation periods in official calendar, motivate people to use the car as the first choice of transportation means. Figure 1 categorises the accidents by the road users in 2005 and as it can be seen, cars are the largest group of road users involved in crashes (Global Burden of Road Injuries, 2011). Pedestrians and moped are at the second and third place respectively. The issue regarding pedestrians and motor cycles is not in the scope of this paper but the Traffic Police of Iran considered them in the overall project, and new regulations were introduced to protect these groups and control them as well. Country's weather condition during winter introduces new challenges and risks.

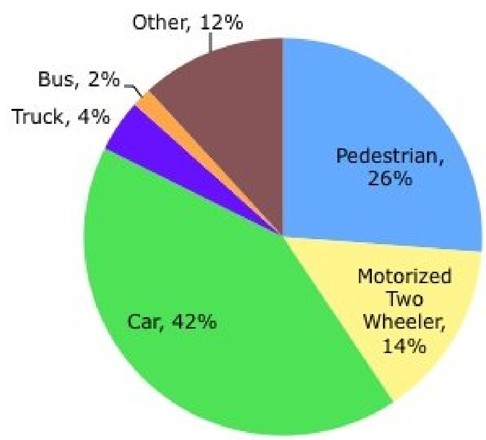


Figure 6- Involvement of Road users' in accidents by categories (Global Burden of Road Injuries, 2011)

Due to the differences in culture and regulations between Ireland and Iran; driving while under the alcohol effect is not a big issue regarding the drivers' misbehaviour but driving while unconscious due to sleepiness is a major cause of deviation from the road and causing accident. To control this issue the traffic police introduced new limitation for the hours of driving specially for truck drivers and bus drivers. In order to control this, heavy vehicles drivers have a notebook and they are obliged to present it at all the checkpoints along the road to the traffic police. Therefore the police forces can constantly monitor the route and hours of driving of drivers. The GPS system is a secondary control measure that records speed, route and time as well, so they can be compared with each other and the data can be validated (Jahannews, 2014).

Criticisms from public media have helped to raise the public's attention towards this problem. But this has led to the wrong conclusion that low quality, vehicle reliability and poor road condition are the causes of the high fatality rate in traffic accidents. Further research revealed that although the vehicles' design can contribute to the high fatality rate of the accidents but the main factor is the drivers themselves.

Innovation: Looking for a Solution

As previously discussed Iran is a vast country with harsh weather conditions in some parts of the country and therefore the road infrastructure developments will face many difficulties. The Ministry of Road and Transport (this ministry was merged with the ministry of City and

Construction affairs in 2011) conducted a research (Jamejam News, 2008) to prioritize development programs. The results of the study showed that the first and last 30km of the roads connecting cities have the highest rate of accidents. The findings of this study resulted in a road development project that was considered to resolve the issue of dangerous locations in roads. The study stated that during the first 30km of roads drivers are not fully aware of entering motorways and they might still feel driving in the city and they are prone to error. On the other hand, the last 30km of the road might be the end of a long journey and therefore the driver's fatigue and frustration for arriving at the destination may result in driving while feeling tired and drowsy. The study recommended an increase of the driver's awareness of these facts during the training courses and increasing control on the drivers' hours of driving. However the ministry of Road and Transport decided to apply prevention measures and change the road conditions to reduce the error prompt parallel to reduce the consequences of probable accidents.

Traffic police also issued changes in the speed limit and increased control on these two critical points of the road. The speed limit was reduced and the Highway Patrol of Road Traffic Police was announced to be responsible for this road section. This means that the Police forces have more power to respond to any deviation of the regulations. The details of the Highway Patrol law enforcement capabilities will be described in the next chapters. The other part of the project regarding the use of mass media (TV, Radio, Social Media, etc.) is still going on and a new department in Traffic Police was established which is called intangible (undercover) traffic control forces and they will remain in place as the modern wing of Traffic Police. This paper will attempt to describe the new rules and regulations and also their enforcement mechanisms in detail and will provide statistics data from both National and International organization regarding the effectiveness of the implementation of the new safety strategies and a discussion regarding the future projects of Police Traffic to future improve the road safety.

Experts of Traffic Police of Iran had already pointed inefficient law enforcement mechanises but public opinion was against any increase of fines or penalties. Even though the traffic police was aware of the fact about the inefficient regulations, the change of the regulations was not permitted till the high fatality rate caught the attention of high rank officials. Therefore, this time the Traffic police developed new regulations. This new regulations was not focused on increasing the fines and penalties but changing the training system and driving licences. Even though this project was designed to improve the behaviour and the penalties was not the main method of improving the behaviour, the mass media criticised on the increased fines and penalties. The Chief of Traffic Police of Iran warned the public media that this criticises might result in misunderstanding and creates difficulties for Traffic Police to achieve the expected goals

Before the Sun-Rise: The Changes and Implementation

Eight years ago in response to the high rate of road accidents and consequent fatalities, the Traffic Police of the Islamic Republic of Iran lunched a new project to redesigning the rules and regulations of road transportation and also to implement of new technologies and new preventive mechanisms to improve the driving culture and increase the control on the situation.

The project changed two main aspects of the system. First and the most important aspect of this new project was redesigning the rules of road and driving regulations. In this regard the Traffic Police increased the fines for any deviation and mainly the over speed and some other dangerous behaviours during driving. Additionally the law enforcement mechanism was also redesigned and the new mechanisms were put in place such as disposal of the driving licence, suspending the vehicle in Police parking and deduction of the driving licence point and etc. Considering the fact that one of the main groups of vehicles in the accidents was public buses and trucks. In order to have more effective monitoring on this group of vehicles, the second aspect of this project that is a GPS system was used in heavy vehicles (trucks, public buses) to track their speed and route and monitor these vehicles all the time. It even went further in details and resulted in redefining the minimum requirements for car's manufacturing standards. This particular aspect of the project resulted in prohibition of importing number of cars and stopped production of a certain group of cars in the country and the Traffic Police suspended registration for the cars that weren't meeting the minimum requirements. Also they changed the law enforcement strategy and new mechanisms were defined to encourage the derivers to respect the rules and drive in the pre-defined criteria using public media.

These changes resulted in a considerable reduction of the number of accidents and fatalities. Also the driving culture in the country changed positively.

After the Sun-Set: Effects and Results

Figure 2 and figure 3 present the statistical data regarding the road traffic fatalities and accidents from 2004 to 2010.

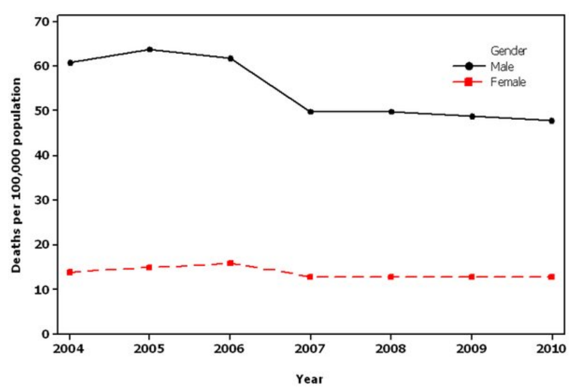


Figure 7 - Fatality rate by gender (Bahadorimonfared et al, 2013)

MR/1000 accidents	MR/10,000 vehicles	MR/100,000 populations	Year
51.1	38.4	38.2	2004
48.2	32.2	39.9	2005
38.2	26.3	39.1	2006
34.1	18.3	32.0	2007
35.2	16.3	32.2	2008
44.9	14.0	31.2	2009
56.1	12.4	31.1	2010*

MR: Mortality rate.
*Including data until March 2011.

Figure 8 - Fatality rate and accidents rate based on years (Bahadorimonfared et al, 2013)

A simple conclusion of these data can be that the new project achieved reduction in fatalities and accidents. It can be considered small reduction, however if we add the fact that Vehicles per Capita in Iran in 2004 was estimated to be around 70 and increased to 200 by 2012, this means the number of cars was tripled but the accidents frequency was reduced. Providing a number for the achieved reduction is difficult due to the growth of public access to cars and a general conclusion needs a more detailed statistical analysis. This great achievement is not only due to the law enforcement and monitoring modifications, but also training system and driving licence changes.

Although the total number of accidents reduced but the mortality rate of accidents still remained high. The high mortality rate of accident can be understood by considering the fact that public transport is highly dependent on buses, and bus accidents will expose nearly 40 passengers to danger of fatal injuries. This was the main motivation for the mandatory GPS installation on all buses and trucks. Although this system enhanced the Traffic Police to monitor the speed and route of all the public buses, and therefore improved the behaviour of bus drivers, yet the buses are exposed the danger of being involved in an accident the same as other road users regardless of driving behaviour of the bus drivers.

The other Side of the Coin: Challenges and Social Impact

The emphasis on increasing fines by mass media affected the public opinion about the project and during early stages of the project initiation the changes of the regulations were negatively regarded. However since 2010 the national television and radio organization started a close collaboration with traffic police. In this step of the project the traffic police started to produce TV shows that show real footage of the drivers' misbehaviour. These TV shows ask people to drive carefully and safely. The national television and radio organization also collaborate during the peak seasons of road traffic to provide information for public. There is no study that evaluates the effectiveness of this approach by implementation of social of media in Iran. The next priority for Iranian authorities is to build more highways and resolve issues about dangerous point of the roads.

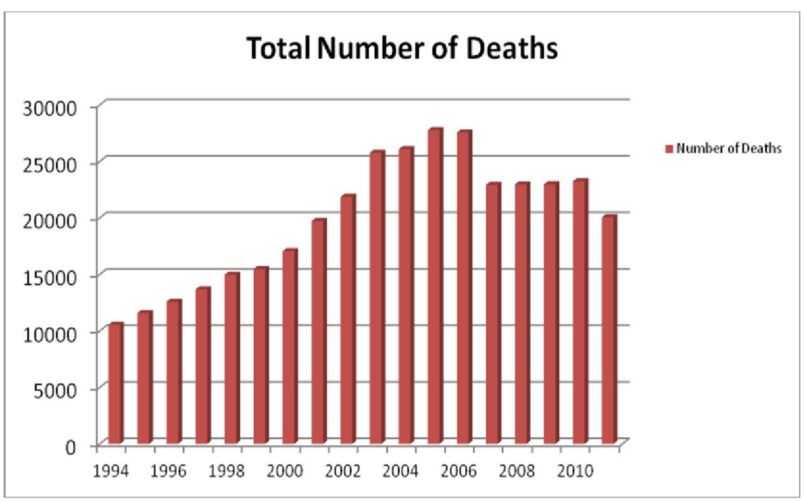


Figure 9 - Total number of fatalities caused by road accidents per year between 1993 and 2011 (Haraa News, 2013)

Latest Available Data: Nowroz 93 Special Mission and a Picture of the Future

The Police Chief of Iran: General Ahmadi Moghadam announced the end of special mission in Nowroz 93 (Tasnim News, 2014) during his press conference in April 2014 and he described:

> "Nowroz 93 (March 2014) special mission of Traffic Police of the Islamic republic of Iran was started 5 days prior to the Nowroz holidays and lasted till the last day which is 20 days. During this mission 500,000 personals of traffic policed remained on high alert and due to service. On Nowroz 1393, 180 million passages were recorded in Iran's road infrastructure which shows 3% increase with respect to Nowroz 1392 (March 2013). In March 2014 per hour 397 vehicles passed through traffic cameras in Iran's roads which were 387 during March 2013. This also shows 3% increase in road usage with respect to last year. The analysis shows that the mean speed of vehicles was reduced to 77km/h from 81 km/h from the previous year. This resulted in consumption of 1.5 billion litters of petrol during the first 15 days of the New Year in March 2014." (Tasnim News, 2014).

The Traffic Police chief during in the press conference after the end of Nowroz 93 mission did not mention the total number of fatalities during Nowroz 93 and only pointed the 12% reduction of immediate deaths at the scene. Some experts suggested the total fatalities reductions are estimated to be 5% with respect to previous year which means a new record in the reduction of road accidents and fatalities. (Tasnim News, 2014)

Statistical analysis reveals a reduction of the fatalities but yet the total number of fatalities remains high and critical. Although the Traffic Police still remains focus on speed reduction and, the slow trend of fatalities reduction can raise the question that maybe the speed is not the main cause and the real issue is still hidden and does not receive enough attention. Mass media still points the poor quality of cars as the cause but there is no evidence to show a mechanical failure or bad design of the vehicle is the main contributing factor to the series of incidents that lead to the accidents.

Iranian authorities did a considerable modification by redesigning the rules and regulations and the new system reduced the number of road accidents and fatalities, but police traffic needs to continue their work and find latent errors in the culture, training system and law-enforcement mechanisms to bring the situation more under control and near international standards. Iranian driving culture is still considered as one of the world's most dangerous cultures and people should understand their duty in this regards to improve the reputation of Iranian road safety.

References

Bahadorimonfared A., Soori H., Mehrabi Y., delpisheh A., Esmaili A., Salehi M., Bakhtiyari M., (2013), *Trends of Fatal Road Traffic Injuries in Iran* (2004- 2011), Phase One, downloadable at: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0065198

Global Burden of Road Injuries, (2011), *Incidents of Road Injuries in Iran*, downloadable at: http://roadinjuries.globalburdenofinjuries.org/iran

Haraa News, (2014), *Road Fatalities during the last 19 years (in Persian)*, report number: 3244, downloadable at: http://www.haraa.ir

Jahannews, (2014), *GPS is Mandatory for all Public vehicles (Miniter of Transportation interview) (in Persian)*, report number: 353686, downloadable at: http://jahannews.com/vdcivpapqt1awq2.cbct.html

Jamejam News agency, (2008), *New Year's Special issue, Iran's Roads (in Persian)*, report number 100933771493, Jamejam Online, download able at: http://www1.jamejamonline.ir/papertext.aspx?newsnum=100933771493

National Geographics, 2014, *Iran Facts*, downloadable at: http://travel.nationalgeographic.com/travel/countries/iran-facts/

Tasnim News, (2014), *Two sides of the Coin (in Persian)*, report number: 328205, downloadable at: http://www.tasnimnews.com/Home/Single/328205

United Nations, (1997), *Asia-Pacific road accident statistics and road safety inventory*, New York, USA

World Population Review, (2014), downloadable at: http://worldpopulationreview.com/countries/iran-population/

POST-WORK RECOVERY AND PSYCHOLOGICAL DETACHMENY IN ACADEMIA: RESULTS FROM A SEVEN DAY DIARY STUDY

Victoria Hogan[1], Michael Hogan[2] and Margaret Hodgins[1]

[1] *School of Health Sciences, National University of Ireland Galway, Ireland*
[2] *School of Psychology, National University of Ireland Galway, Ireland*

Abstract
The Effort-Recovery Model (Meijman & Mulder, 1998) suggests that long working hours do not leave sufficient time to recover from the demands of the day and chronic lack of recovery has been proposed as one potential causal mechanism linking long working hours to ill-health (Härmä, 2006). Thus, post-work recovery has been identified as an important process which aids in maintaining well-being and preventing fatigue. Research shows that academics engage in long working hours, with Irish academics working the longest hours across Europe (Kwiek & Antonowicz, 2013). Achieving adequate recovery and psychological detachment from work is regarded as highly important, particularly for those with heavy workloads and highly engaged workers, such as academics. The aim of this study was to examine the post-work activities of academics and their ability to psychologically detach and recover from work. Data was collected from 44 university lecturers, 27 females and 17 males across two Irish universities. They each completed a pre-diary questionnaire and seven daily diaries over the course of a week. Quantitative analyses revealed a number of gender differences in post-work activities and identified the post-work activities with the strongest positive effects on post-work recovery. Qualitative analyses revealed that academics struggled to consistently achieve recovery after work and a number of barriers to recovery and psychological detachment were also identified. The findings suggest that changes in post-work recovery activities may be warranted in an effort to increase recovery and promote long term well-being among Irish academics.

Introduction
According to Gambles et al., (2006) workers in control of their own working hours, with the ability to work flexibly (as in the case of academics) are under most pressure and tend in fact to work more hours rather than less. Indeed, the extant literature across numerous countries has shown that academics engage in long working hours. For example, the average working week for American academics is estimated to be 55 hours (O'Laughlin & Bishchoff, 2005). Research has found that Irish academics work the longest hours (47 hours per week) in comparison with academics in 11 other European countries (Kwiek & Antonowicz, 2013). Long working hours are of concern because research shows a negative relationship with health and well-being (Härmä, 2006).

Both the Conservation of Resources Model (Hobfoll, 1989) and the Effort Recovery Model (Meijman & Mulder, 1998) propose that having sufficient time to recover from work is essential in order to prevent occupational stress and adverse effects on health and well-being. These two theories therefore underpin recovery and respite research. The Conservation of Resources model states that workers try to protect and retain their resources (e.g. energy) and if resources are threatened that stress can result. Working very long hours can threaten resources as there is insufficient time to replenish a valued resource such as energy. The Effort Recovery Model employs a work-rest cycle and proposes that long working hours do not leave sufficient time to recover from the demands of the day. Lack of recovery is most likely where the same psycho-physiological systems are used both during work and non-work time e.g. worrying about work and / or engaging in further work (Brosschot, Pieper & Thayer, 2005).

Relatively little research attention has been given to date as to how academics recover and psychologically detach from work. Post-work recovery has been defined as process of restoration or recuperation (Sonnentag, Binnewies & Mojza, 2008), while psychological detachment has been defined as "the individual's sense of being away from the work situation" (Etzion, Eden & Lapidot, 1998, p. 579). Detaching from work involves disengaging from both the negative and positive aspects of work, because if an employee is thinking about work (be it positive or negative) they remain cognitively aroused (Cropley, Dijk & Stanley, 2006). Post work recovery and psychological detachment from work are inter-related, as it is assumed that full recovery cannot take place without some degree of psychological detachment.

It has been noted that academics may struggle to detach from work due to a number of factors. For example, the open-ended and vocational nature of academic work (Gornall & Salisbury, 2012) and the propensity for academics to become absorbed in their work (Bailyn, 2003) may impede detachment. By investigating post-work recovery and psychological detachment in academics, we can gain greater insight into this complex and multifaceted issue and increase our understanding of the role of cognitive detachment in relation to recovery and well-being in academia. Specifically, the study aimed to examine post-work activities of academics and the extent to which they were perceived as facilitating recovery. In addition, barriers to recovery and detachment from work were also examined.

Methodology

The study consisted of a seven day diary completed by a sample of Irish academics. An email requesting diary participants was sent to all academics working in two Irish universities. In total, 70 academics agreed to participate and fully completed diaries were returned by 45 academics, however, one diary was unusable. Within the sample there were 17 males and 27 females, the majority of whom worked full time (N=43). Over half of the sample was aged between 36-45 years of age. The majority (N=34) were married and over half of participants had children.

Prior to completing the diaries, each participant completed a pre-screening questionnaire, designed to elicit demographic information and the self-rated propensity of diarists towards work rumination. The diary instrument contained a combination of quantitative and qualitative measures. The diary elicited information on work patterns each day, i.e. hours worked and perceived level of work intensity. In addition, participants were asked to indicate how much time they spent after work in five activity categories i.e. work, household/childcare, low effort activities (e.g. watching television), physical activities (e.g. walking) and social activities (e.g. meeting friends). Respondents were also required to indicate the degree to which they managed to switch off from work during each of these activities. Likert scale response formats were used for the recovery and detachment measures. All measures employed in both the pre-screening questionnaire and diary were previously used in recovery and detachment research and were proved to be valid and reliable.

The diary instrument and pre-screening questionnaire were piloted prior to data collection. Ethical approval for the study was obtained from the NUI Galway Ethics Committee (29/02/2008) prior to data collection. In addition, permission was granted by the two participating universities allowing staff to be contacted via email.

Results

Self- reported average weekly working hours among the participants revealed that only 20% (N=9) worked less than 40 hours per week, while the remaining 80% (N=34) worked over 40 hours per week. A 5 (Activity) x 7 (Day) repeated measures ANOVA was conducted to determine trends in the post-work activities engaged in by the participants over the course of a week There was a main effect of Activity, $F(4,160)=11.780$, $p<.0001$, partial $\eta^2 =.228$, with participants reporting more household activity relative to work, physical activity, and social activity.

A Gender x Activity interaction effect $F(4, 156), = 4.73$, $p <.005$, partial $\eta^2 =.105$ was also found. While men showed no difference in levels of work, household and passive activity, they devoted more time to passive activities relative to physical activities $F(1,39) = 16.45$, $p<.0005$, significantly more work activity relative to physical activity $F(1,39) = 8.07$, $p<.005$, and significantly more passive activity relative to social activity $F(1, 39) = 8.09$, $p<.01$. Women did significantly more housework relative to all other activity types. Women also did more housework relative to men $F(1,39) = 4.74$, $p <.05$. Conversely, men engaged in more work related activity in the evening relative to women $F(1,39) = 10.33$, $p<.005$. Men and women did not differ significantly across passive, physical and social activities.

Another research question sought to determine which post-work activities were perceived as most beneficial in aiding recovery from work. The main effect of Activity on Recovery Experience Rating ability was significant, $F(3,60)= 3.241$, $p<.05$ partial $\eta^2 =.139$. Post hoc pair-wise comparisons revealed that participants recovered more when engaging in physical and social activities relative to household activities ($p<.01$ for both comparisons), with no difference in recovery associated with household and passive activities.

Qualitative data analysis was employed to address the third research question on the barriers to successful recovery and detachment for academics. In addition to identifying barriers, academics were also asked to describe their recovery after work. There was a large degree of variability across the participants in the levels of reported recovery during the working week (i.e. Monday-Friday). Barriers to recovery and detachment from work were analysed and grouped into categories. The three most frequently cited barriers were: having to work in the evenings and at weekends, preoccupation with work and general workload.

Discussion

Consistent with trends in the international literature, the Irish academics in this study tended to work long hours. In addition, the analysis of post-work activities over the course of seven days also revealed that working in the evenings at home and working on weekends was routine for a substantial number of academics. This pattern of work may have long term implications, as research to date shows that having sufficient time to achieve recovery after work is important in order to protect and promote well-being and productivity.

Overall the results indicated that female academics spent greater time in household/caring activities after work, while the male academics spent greater time in either work or passive activities. This finding is consistent the extant literature on gender differences in time usage in full time workers (Lee et al., 2007). However, the academics rated social and physical activities as most conducive to recovery. Therefore, although the academics may have been aware that certain activities were more beneficial in aiding recovery, finding the time and/or energy after a long working day combined with home demands, may have been too difficult for many of the participants. Perhaps in the face of long working hours, engaging in non-demanding activities such as watching the television may be considered preferable to more demanding activities (i.e. physical and social).

Inconsistent findings across occupational groups and sectors have been observed in recovery and respite research; therefore, it is important to examine recovery processes in different sectors. There is strong and consistent evidence in the extant literature showing that engaging in physical activity in the evenings results in improved recovery outcomes (cf. Demerouti et al., 2009), therefore, the findings from this study are in line with this general trend. However, the findings to date on engaging in social activities and recovery are mixed. Research suggests that social support given by family and friends is strongly associated with general health and well-being (Ayman & Antani, 2008) therefore; the relationship between recovery and social activities deserves further research attention.

Strengths and Limitations

The study had several limitations including the use of self-reported data and a poor response rate to the initial request for participants. Despite these limitations, the diary method allowed the dynamic nature of post-work recovery, detachment and related variables to be explored both within and between subjects. By designing a mixed method diary, the data elicited provided rich details on post-work recovery and detachment issues. Furthermore, the study responded to calls within the extant literature to use more innovative study design methods.

Conclusions

The findings suggest that the work-rest cycle adhered to by workers and the nature of post-work activities is an important consideration with regard to employee health and well-being in academia. In the face of increasing stress levels and higher work intensity across the academic sector, interventions designed to improve recovery practices could aid workers in maintaining their well-being. Promotion of physical activity, in particular should be investigated in light of the current study findings and previous research which notes that physical activity is especially important for employees engaged in mentally demanding occupations (Zijlstra & Rook, 2009).

References

Ayman, R., & Antani, A. (2008). Social support and work-family conflict. In K. Korabik, D. S. Lero & D. L. Whitehead (Eds.), *Handbook of Work-Family Integration: Research, Theory and Best Practices*. Amsterdam: Elsevier.

Bailyn, L. (2003). Academic Careers and gender equity: Lessons learned from MIT. *Gender, Work and Organization, 10*(2), 137-153.

Brosschot, J. F., Pieper, S., & Thayer, J. F. (2005). Expanding stress theory: prolonged activation and perseverative cognition. . *Psychoneuroendocrinology, 30*, 1043-1049.

Cropley, M., Dijk, D. J., & Stanley, N. (2006). Job strain, work rumination and sleep in school teachers. *European Journal of Work and Organizational Psychology, 15*, 181-196.

Etzion, D., Eden, D., & Lapidot, Y. (1998). Relief from job stressors and burnout: Reserve service as a respite. *Journal of Applied Psychology, 70*, 314-328.

Gambles, R., Lewis, S., & Rapoport (2006). *The myth of work-life balance; the challenge of our time for men, women and societies*. Chicester: Wiley.

Gornall, L., & Salisbury, J. (2012). Compulsive working, 'hyperprofessionality' and the unseen pleasures of academic work. *Higher Education Quarterly, 66*(2), 135-154.

Härmä, M. (2006). Work hours in relation to work stress, recovery and health. *Scandinavian Journal of Work, Environment and Health, 32*(6), 502-514.

Hobfoll, S. E. (1989). Conservation of resources: A new attempt at conceptualizing stress. *American Psychologist, 44*(3), 513-524.

Kwiek, M. & Antonowicz, D. (2013). Academic work, working conditions and job satisfaction. In U. Teichler & E.A. Höhle (Eds.), The Work Situation of the Academic Profession in Europe: Findings of a Survey in Twelve Countries. Dordrecht: Springer

Lee, S. H., McCann, D., & Messenger, J. C. (2007). *Working Time Around the World: Trends in working hours, laws and policies in a global comparative perspective.* London: Routledge.

Meijman, T. F., & Mulder, G. (1998). Psychological Aspects of Workload. In P. J. D. Drenth, H. Thierry & C. J. de Wolff (Eds.), *Handbook of Work and Organisational Psychology: Volume 2 Work Psychology* (Vol. 2, pp. 5-33). Sussex: Psychology Press.

O' Laughlin, E. M., & Bischoff, L. G. (2005). Balancing parenthood and academia: Work/family stress as influenced by gender and tenure status. *Journal of Family Issues, 26*, 79-106.

Sonnentag, S., Binnewies, C., & Mojza, A. J. (2008). Did you have a nice evening? A day level study on recovery experiences, sleep and affect. *Journal of Applied Psychology, 93*, 674-684.

Zijlstra, F. R. H., & Rook, J. W. (2009). The weekly cycle of work and rest: A diary study. In R. A. Roe, M. J. Waller & S. R. Clegg (Eds.), *Time in Organisational Research*. London: Routledge.

EFFECTIVE DESIGN OF TOTAL WORKER HEALTH™ INTERVENTIONS FOR LONE WORKERS EXAMPLES AND IMPLICATIONS FOR THE IRISH CONTEXT

Denis O'Hora[1] and Ryan Olson[2]

[1] *School of Psychology, National University of Ireland Galway, Ireland.*
[2] *Oregon Health & Science University, Portland, ON, USA.*

Abstract
Workplace safety does not exist in a vacuum. Individuals come to work with a variety of advantages and disadvantages derived from their off-work activities. Extra-workplace behaviors and attitudes are likely to have greater impact for lone workers because such workers typically operate under less formal and informal oversight and receive less workplace support. The Total Worker Health™ (TWH) approach, advocated by the National Institute for Occupational Safety and Health (NIOSH) in the USA, integrates traditional safety and health protection within a broader health promotion focus that acknowledges interactions between health and well-being and workplace injuries. The current paper outlines features of the TWH approach and summarizes TWH interventions recently developed for truck drivers and home care workers. With this background, opportunities for the development of TWH interventions for Irish lone workers are considered.

Introduction

Since 2004, the National Institute for Occupational Safety and Health (NIOSH) in the USA has sought to bring together the diverse range of expertise in occupational safety and health and worksite health promotion with a view to producing comprehensive solutions to workplace health and safety. This initiative culminated with the development of the Total Worker Health™ (TWH) approach: a research, practice, and policy agenda related to integrated worker health protection and health promotion (Pronk, 2013). TWH interventions interventions are multidisciplinary and operate at multiple levels of the workplace, including the personal, group, organizational, and environmental level. Typical aims at the personal and group levels include education of individual workers in an attempt to build social norms supportive of worker health, for example through educational classes or one-on-one training programs. Interventions at the environmental/organizational level of influence aim to modify the work environment or organization in support of worker health outcomes (National Institute for Occupational Safety and Health [NIOSH], 2012). The integration of interventions across these levels is intended to allow mutual facilitation of worker health and safety through positive feedback and support.

Lone workers have diminished exposure to social and organizational factors that promote healthy lifestyle behaviors, such as supportive supervision, organizational training, and peer social modeling, support, and reinforcement. Moreover, the structure of lone working is such that hazards are more likely and, when they occur, they are more dangerous. Risky hazards are more likely because lone workers typically receive minimal occupational safety support and, while their attention is focused on work tasks, they do not have a second pair of eyes that might identify imminent hazards. Hazardous outcomes are more dangerous because, for example, threats to health that might be mitigated by the presence of another (e.g., the effects of falls, inhaling noxious gases) may be enhanced through the incapacitation of the lone worker.

As mentioned above, lone workers are at increased risk to workplace hazards. Partially, this is due to charactersitics of the jobs that lone workers do, but partially it is due to the limited support provided to lone workers on the job. TWH interventions are explicitly designed to address safety risks at both the personal and organisational levels and so seem particularly suitable for lone workers. The current paper outlines two recent TWH interventions for lone workers developed in the USA. The first intervention, SHIFT, was designed for truck drivers, a predominantly male group, with a high proportion of sedentary activity. The second intervention, COMPASS, engaged home healthcare workers, a largely female group with more variable job requirements. Following description of these interventions, the application of TWH interventions in the Irish context is considered.

Study 1: Safety & Health Involvement for Truckers (SHIFT)

Background

Truck drivers experience unacceptably high levels of fatalities, injuries, and lifestyle-related health problems relative to other occupational groups. In the USA, truck drivers account for 15% of all work-place fatalities and consistently rank among the top three occupations in total nonfatal injuries and illnesses (Bureau of Labor Statistics, 2007, 2008). In Ireland, the Transportation and Storage sector had the highest rate of injuries (51 per 1000) in 2011-2012 and accounted for 12.3% of all workplace injuries and illnesses (Health and Safety Authority, 2013). Injury rates rates have been consistently high in recent years and there were fatalities in the sector every year from 2008 to 2012.

The organization of the haulage industry exposes truck drivers to increased health and safety risks. In the USA, long-haul drivers may spend up to 11 hours of driving and 14 hours on-duty per day, and up to 70 total driving hours in an 8-day period (Federal Motor Carrier Safety Administration, 2005). Spending so long driving limits opportunities for exercise, and limited roadside food options (e.g., Truck Stops) encourage diets high in saturated fat and calories and low in fruits and vegetables. Long-haul truck drivers sleep approximately two hours less than typical adults (Mitler, Miller, Lipsitz, Walsh, & Wylie, 1997), due to long work days, sleeping away from home in sleeper berths that can be noisy and hot/cold, and variable schedules that can disrupt circadian rhythms. Moreover, sleep deficiencies interact with lifestyle factors. Sedentary lifestyle is associated with increased risk of sleep disorders, and in laboatory studies, sleep restriction to four hours resulted in a 20% increase in calorie consumption on the following days. With these factors in play, truck drivers have an obesity rate that is more than twice that of the general population in the US (Sieber et al, 2014). Obesity and associated conditions such as diabetes and sleep apnea increase crash risk (Laberge-Nadeau et al, 1996; Stoohs et al, 1995; 1994), likely through causal pathways associated with fatigue and attentional lapses during long work periods.

Despite the foregoing personal costs to truck drivers and consequent financial costs to haulage companies, effective health and safety interventions for truck drivers are scarce. Education-based health promotion interventions for truck drivers have been limited in effectiveness (Holmes et al, 1996; Roberts and York, 1999). In the main, such interventions have relied upon passive training and have not provided significant motivational support. And while some more engaging approaches such as health counseling can produce better health outcomes for drivers (Kukkonen-Harjula et al, 2013), we are not aware of any interventions that integrate injury and crash prevention with health promotion for truck drivers. To address these research gaps, Olson and colleagues developed and evaluated the SHIFT (Safety and Health Involvement For Truckers) program through a pilot study (partially funded by NIOSH grant #5 T42 OH008433-02) and now a randomized controlled trial (ongoing, funded by NHLBI grant #1R01HL105495)

Participants and Setting

In the SHIFT pilot study (Olson et al, 2009) truck drivers (N=29) were recruited from four trucking carriers based in the Pacific Northwest region of the United States. Participants had a mean age of 48.4 (SD = 10.1), a mean BMI of 38.9 (SD = 7.1), and were predominantly White (n = 28) men (n = 23).

Intervention

The SHIFT project incorporated several proven intervention tactics that are well suited for isolated workers, but that had not been adapted for or evaluated with truck drivers. These included weight loss and safe driving competition, computer-based training (in eating, safety [including sleep], and exercise), behavioral self-monitoring (BSM), and motivational interviewing (MI).

Results

Attrition was relatively low with 75% of the sample completing the post-intervention health assessment (22 of 29). Pre and post scores on a series of health indicators are provided in the Table 1. Mean weight loss (t_{22} = 3.17, p = 0.005, d = 0.68) and reduction in BMI (t_{22} = 3.01, p = 0.005, d = 0.61) were statistically significant. Effect sizes were large and reductions were clinically significant, with drivers losing an average of about one unit of body mass index. Ninety percent of participants lost weight, with 55% losing 5 or more lbs during the intervention. Moreover, in a follow-up study 30 months post intervention the majority of drivers reported further weight loss post intervention (Wipfli et al, 2013).

Table 1 Body measurements pre and post SHIFT intervention

Measure	Pre	Post
Body weight (lbs)	271.25	263.46*
Body mass index	38.85	37.89*
Waist-to-hip ratio	0.94	0.92
Waist circumference (cm)	118.55	115.14*
Neck circumference (cm)	47.09	41.71

* Asterisk denotes significant difference between pre and post ($p<.05$)

These health improvements stemmed mainly from changes in dietary behaviours (see Figure 1). For example, the frequency of drinking sugary drink dropped from “5 or 6 times a week” to “1 or 2 times a week” (p = 0.01, d = 0.50); eating sugary snacks dropped from “1 or 2 times a week” to “1 to 3 times in the past 4 weeks” (p = 0.03, d = 0.60); and eating fast food dropped from “1 or 2 times a week” to “1 to 3 times in the past four weeks” (p = 0.03, d = 0.47).

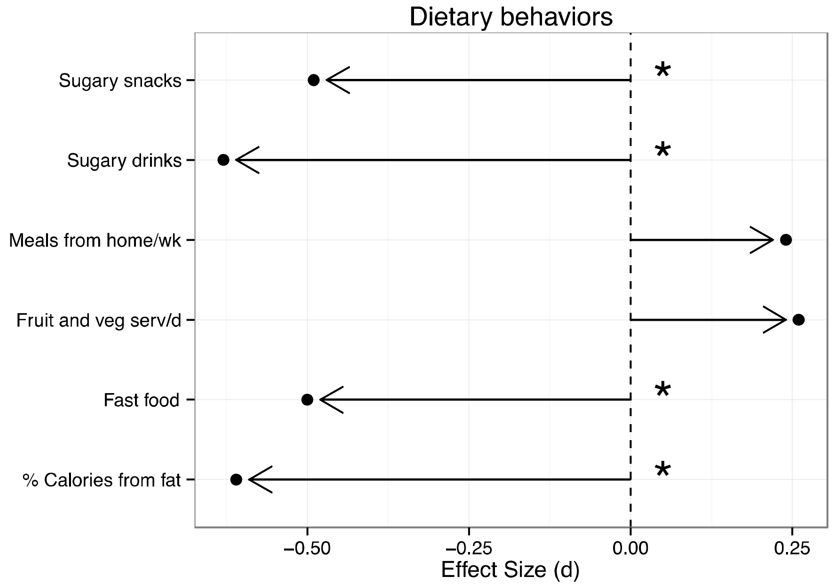


Figure 1. Dietary behaviours post-intervention as a percentage of baseline pre-intervention levels
* Asterisk denotes significant difference between pre and post (p<.05)

A number of elements of safe driving were targetted in training and the competition aspect of the intervention. Two of the companies provided safe driving indices from prior to the intervention. From these values, z scores were calculated (Baseline = 0). Hard brakes per 10,000 miles driven reduced from 0.00 to -0.61 ($t_9 = 2.78$, $p = 0.02$, $d = 0.88$). Drivers' percent time overspeed reduced from 0.00 to -0.92 ($t_{10} = 1.65$, $p = 0.13$, $d = 0.50$). For further details of study results, the reader is directed to Olson, Anger, Elliot, Wipfli and Gray (2009), and to Wipfli, Olson and Koren (2013) .

Study 2: Community of Practice and Safety Support for Home Care workers (COMPASS)

Background
It is well documented that health care workers, especially those who lift and move patients, are at high risk for musculoskeletal injuries and symptoms (Magora, 1970). Rates of such injuries have systematically increased and, recently, the high prevalence of back injuries in health care workers has been described as an "epidemic" (Galinsky, Waters, and Malit, 2001). In Ireland, the Healthcare and Social Support sector has above average illness and injury rates, with the fourth highest sector rates in both measures in 2012 (Health and Safety Authority, 2013).

Within the healthcare sector, home care workers are at even greater risk of occupational injury. Home care workers are predominantly female, older than 40 and they assist the elderly and disabled with self-care and mobility in private homes. They are often not very well paid, being self-employed or employed by their client, which raises stressful line management issues (Olson et al, 2014). As a consequence, they mainly operate as lone workers and lack supervision and typical organizational support structures, such as safety committees or health promotion programs. The job can be lonely and extremely demanding.

In the USA, the injury rate for home care workers is nearly four times higher than that of the average worker and they are at elevated risk for mental and physical health problems (Bureau of Labor Statistics, 2010). In addition to manual handling and healthcare-related risks, home care workers face many and varied hazards that stem from operating in private homes. In a Northern Irish context, Taylor and Donnelly (2006) noted that such hazards include access issues, hygiene and infection, manual handling, aggression and harassment, domestic and farm animals, infestation (e.g., fleas, vermin) and safety of home equipment.

Participants and Setting
Nineteen workers (18 female, 13 Caucasian) were recruited from home care workers serving clients in publicly funded programs in the Portland Oregon metropolitan area. Participants have an average age of 57.3 yrs (SD=7.4), body mass index of 28.3 (SD=8.4), and 20.1 weekly work hrs (SD=13.9). Eighty-nine percent (n=17) of workers reported musculoskeletal pain interfering with work or living activities during past 3-months.

Intervention
A considerable number of supportive interventions have been developed and tested for family home caregivers (see Sorenson et al., 2002 for a review). These interventions have not included home care workers (e.g., paid caregivers) and have primarily focused on improving wellbeing and knowledge of caregivers, without addressing illness and injury prevention. The COMPASS (Community of Practice and Safety Support) intervention is ongoing and organizes workers into neighborhood-based teams that meet regularly for education and social support. It integrates health promotion and protection topics, and uses scripted peer-led education methods (Elliot et al., 2007) and social support groups for caregivers (Toseland et al., 1990).

Results
Process measures recently obtained suggest that the intervention was enjoyable and produced behavioral change. Average attendance was 81%, mean favorability rating was 4.2 on a 5 point scale (SD=0.2), and the average knowledge gain (pre/post meeting) was 17.6% (SD=3.0). Sixty-three percent (SD=18.7) of participants reported making behavior changes between meetings. Baseline levels of primary outcomes show room for improvement post-intervention. Self-reported experienced community of practice averaged 44.2 (SD=7.1) on a 60-point scale (60 = highest/best score), and physical and mental well-being averaged 9.3 and 9.2, respectively, on 14-point scales (14 = highest/best score). The sample averaged 2.6 (SD=1.4) days per week with 30 min of moderate exercise, 6.8 (SD=4.9) daily servings of fruits and vegetables, and 29.7% (SD=5.9) dietary calories from fat. Self-reported safety compliance averaged 4.3 (SD=0.7) on a 5-point scale (5=best). When asked to report new safety practices in the past 6 months, 16% (n=3) had adopted a new tool for lifting or transferring clients, 26% (n=5) adopted a new tool for housekeeping, 42% (n=8) talked with a client about safety, and 47% (n=9) corrected a hazard in a client's home.

TWH interventions for Irish lone workers

As mentioned previously, Irish truck drivers and home healthcare workers are at increased risk of illness and injury in the workplace relative to the average worker. Indeed, at the European Union level, there is recognition of the importance of truck driver safety. Legislation has imposed regulations (EU 3820/85 and 3821/85) on the trucking industry to improve driver safety. For example, these regulations limit the amount of time truckers are allowed to work during a 24 hour-period to a maximum of 9 hours per day, with the possibility of working 10 hours per day 2 days a week (Phillip, 2005). Perhaps the most obvious application of Total Worker Health^{TM} interventions to the Irish context, however, is to the farming sector.

Internationally, agriculture is a very dangerous occupation (Von Essen and McCurdy, 1998). Farmers are exposed to a broad range of risks, ranging from using complex heavy machinery, animal handling, working with noxious chemicals, enduring prolonged exposure to hazardous weather conditions, and working in difficult terrain and physical circumstance. These risks can and do interact to create even more challenging working conditions. In the USA, the Farming, fishing, and forestry sector has the highest fatality rate of all occupational sectors (23.3 per 100,000; Bureau of Labor Statistics, 2014), and is approximately 50% higher than the next most fatal sector, Transportation and material moving (14.0 per 100,000).

In Ireland, farming is a highly valued occupation that is central to our national conscience and yet, farmers are by far the most likely occupation to die at work. Since 2008, the Agriculture, forestry and fishing sector has consistently had the highest rate of fatalities, with a rate of 29.2 per 100,000 in 2012 (Health and Safety Authority, 2013). This was four times higher than the Construction sector, which was the next most fatal (6.9 per 100,000) and fifteen times higher than the remaining sectors (all lower than 2 per 100,000). The figures for this sector include fisherman and foresters, but the majority of fatalities in this sector stem from farmers (e.g., 21 of 28 in 2012). The Agriculture, forestry and fishing sector also had the highest rates of illness in 2012 (48.7 per 1000), but the rate of injuries in the sector was relatively low in 2012 (18.7 per 1000). This relatively low injury rate seems out-of-step with the fatality rate and it is worth noting that injury rates in the farming sector have been underreported in previous years (e.g., 2010, see Osborne et al 2013). Indeed, Osborne and colleagues (2010) reported that 56% of a sample of Irish farmers reported musculoskeletal disorders in the previous year, which is line with research on farmers in Kansas (60%; Rosecrance , Rodgers and Merlino, 2006).

A number of features of the farming occupation and farmer demographics in Ireland suggest that TWH interventions are appropriate in this context. As outlined earlier, TWH interventions are particularly suited to lone workers. The overwhelming majority of Irish farmers (95%) are self-employed or family workers (Connolly, 2007). In such contexts, lone working is often the norm, which makes hazards more likely and the effects of hazards more extreme. In addition, the number of farms and those employed on farms have declined steadily since the 1990s. Farm size has increased by almost 20%, but farming activities now provide a much smaller proportion of gross household incomes than 20 years ago. Such tightening of resources increases financial stress, which negatively affects mental health directly (Peirce, Frone, Russell, and Cooper, 1996) and indirectly encourages unsafe decisions (e.g., “cutting corners”).

In addition to developing and encouraging safe practices, TWH interventions focus on increasing overall worker physical and mental health and, thus, worker capacity to deal with occupational hazards. For example, enhancing social support is a common feature of TWH interventions and one that directly addresses aspects of lone working. Social support directly addresses mental heath challenges (Pierce et al, 1996), enables safe practices to be transmitted through networks of lone workers and enables safety services to be provided more efficiently (e.g., providing a critical mass of workers for safety training). Such safety support initiatives would be facilitated by strong casual and formal networks of support that Irish farmers have traditionally maintained.

The demographics of farming in Ireland constitute an increasing safety challenge. In 2011, the average age of a farm-holder was 54.4 years, ranging from 49.7 years in dairy farming to 64.6 in Tillage (Teagasc, 2012). A significant portion of farmers, 20.6%, receive a pension, indicating that they are older than 65. For such a physically demanding job, increased age is a risk factor for serious injury and fatality. Of the 28 fatalities in the Agriculture, forestry and fishing sector, 20 (71%) were suffered by individuals over the age of 45 and 9 (30%) were over 65 years old (Health and Safety Authority, 2013). The focus of TWH interventions on physical health makes them especially useful for dealing with age-related hazards. Exercise and diet are the most effective defences against age-related deficits on cognitive and physical function (Park and Reuter-Lorenz, 2009; Rowe, and Kahn, 1987). By enabling farmers to improve their physical and cognitive fitness, TWH interventions will reduce the effect of aging and enhance and extend the voluntary working lives of farmers.

Conclusion

Total Worker Health interventions broaden the focus of safety intervention from identifying hazards and developing safe procedures to a focus on positive physical and mental health outcomes that empower workers to deal with workplace hazards. TWH interventions have already been developed for truck drivers and home healthcare workers, two lone worker populations that endure high illness and injury rates in Ireland. Finally, Irish farmers constitute a lone worker population who are exposed to very hazardous environments, and, for whom TWH interventions seem particularly appropriate.

Acknowledgements

The authors wish to thank John McNamara and Patricia Murray for their helpful advice. The work described in this paper was partially funded by NIOSH grant #5 T42 OH008433-02 and by NHLBI grant #1R01HL105495.

References

Bureau of Labor Statistics, 2007. *Nonfatal occupational injuries and illnesses requiring days away from work, 2006*. Available from: http://www.bls.gov/iif/osh_nwrl.htm

Bureau of Labor Statistics, 2008. *Nonfatal occupational injuries and illnesses requiring days away from work, 2007*. Available from: http://www.bls.gov/iif/osh_nwrl.htm

Bureau of Labor Statistics, 2010. *Nonfatal occupational injuries and illnesses requiring days away from work, 2009*. Available from: http://www.bls.gov/iif/osh_nwrl.htm

Bureau of Labor Statistics, 2014. *Census of Fatal Occupational Injuries Charts, 1992-2012* Available from: http://www.bls.gov/iif/oshwc/cfoi/cfch0011.pdf

Connolly, L., 2007. Overview of the changing structure of Irish agriculture monitored by the national farm survey. *Proceedings of the Annual Conference of the Agricultural Economics Society*, Athenry, Ireland.

Elliot D. L., Goldberg, L., Kuehl, K. S., Moe, E. L., Breger, R. K. R., and Pickering, M. A., 2007. The PHLAME (Promoting Healthy Lifestyles: Alternative Models' Effects) firefighter study: Outcomes of two models of behavior change. *Journal of Occupational and Environmental Medicine,* ***49***(2), 204-13.

Federal Motor Carrier Safety Administration, 2005. 49 CFR Parts 385, 390, and 395 hours of service of drivers, Final rule. Federal Regulations. 70.

Galinsky, T., Waters, T., and Malit, B., 2001. Overexertion injuries in home health care workers and the need for ergonomics. *Home Health Care Services Quarterly,* ***20***(3), 37–41. doi:10.1300/J027v20n03

Health and Safety Authority, 2013. *Summary of Workplace Injury, Illness and Fatality Statistics 2011-2012.*

Holmes, S. M., Power, M. L., & Walter, C. K., 1996. A motor carrier wellness program: development and testing. *Transportation Journal*, **35**, 33-48.

Kukkonen-Harjula, K., Puhkala, J., Mansikkamaki, K., Aittasalo, M., Hublin, C., Olkkonen, S., Partinen, M., & Fogelholm, M. (2013). Lifestyle counseling to reduce overweight in professional male drivers. *Proceedings of the International Society for Behavioral Nutrition and Physical Activity*, Ghent, Belgium.

Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K., & Wylie, C. D., 1997. The sleep of long-haul truck drivers. *New England Journal of Medicine, 337*(11), 755–761. doi: 10.1056/NEJM199709113371106

Laberge-Nadeau, C., Dionne, G., Maag, U., Desjardins, D., Vanasse, C., & Ékoé, J. M., 1996) Medical conditions and the severity of commercial motor vehicle drivers' road accidents. *Accident Analysis & Prevention*, ***28***(1), 43-51.

Olson, R., Anger, W. K., Elliot, D. L., Wipfli, B., and Gray, M., 2009. A new health promotion model for lone workers: Results of the Safety & Health Involvement For Truckers (SHIFT) pilot study. *Journal of Occupational and Environmental Medicine / American College of Occupational and Environmental Medicine*, ***51***(11), 1233–46. doi:10.1097/JOM.0b013e3181c1dc7a

Olson, R., Wipfli, B., Wright, R. R., Garrigues, L., Nguyen, T., and López de Castro, B., 2014. Reliability and validity of the Home Care STAT (Safety Task Assessment Tool). *Applied Ergonomics*. doi:10.1016/j.apergo.2014.02.004

Osborne, A., Blake, C., Meredith, D., Kinsella, A., Phelan, J., McNamara, J., and Cunningham, C., 2013. Work-related musculoskeletal disorders among Irish farm operators. *American Journal of Industrial Medicine,* ***56***(2), 235–242. doi:10.1002/ajim.22092.

Magora, A. (1970). Investigation of the relation between low back pain and occupation. *Industrial Medicine and Surgery,* ***39***(11), 46 and 39 (12), 504-510.

National Institute for Occupational Safety and Health [NIOSH], 2012. *Research Compendium: The NIOSH Total Worker Health™ Program: Seminal Research Papers 2012*. Washington, DC: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2012-146, 1-214

Park, D. C., and Reuter-Lorenz, P., 2009. The Adaptive Brain□: Aging and neurocognitive scaffolding. *Annual Review of Psychology*, ***60***, 173–196. doi:10.1146/annurev.psych.59.103006.093656

Peirce, R. S., Frone, M. R., Russell, M., and Cooper, M. L., 1996. Financial stress, social support, and alcohol involvement: A longitudinal test of the buffering hypothesis in a general population survey. *Health Psychology*, ***15***(1), 38.

Philip, P., 2005. Sleepiness of occupational drivers. *Industrial Health*, ***43***(1), 30-33.

Pronk, N. P., 2013. Integrated worker health protection and promotion programs: Overview and perspectives on health and economic outcomes. *Journal of Occupational and Environmental Medicine*, ***55***(12 Suppl), S30–7. doi:10.1097/JOM.0000000000000031

Roberts, S., York, J., 1999. *Technical Memorandum Number Three: Pilot Test Results and Marketing Plan.* Washington, DC: Federal Motor Carrier Safety Administration.

Rowe, J. W., and Kahn, R. L., 1987. Aging□: Usual and successful. *Science*, ***237***(4811), 143–149.

Rosecrance J, Rodgers G, Merlino L. Low back pain and musculoskeletal symptoms among Kansas farmers. Am J Ind Med 2006;49:547–556.

Sieber, W. K., Robinson, C. F., Birdsey, J., Chen, G. X., Hitchcock, E. M., Lincoln, J. E., Nakata, A. and Sweeney, M. H. (2014). Obesity and other risk factors: The National Survey of U.S. Long-Haul Truck Driver Health and Injury. *American Journal of Industrial Medicine.* doi: 10.1002/ajim.22293.

Sörensen, S., Pinquart, M., and Duberstein, P., 2002. How effective are interventions with caregivers? An updated meta-analysis. *The Gerontologist.* ***42***(3), 356-72.

Stoohs, R. A, Bingham, L. A., Itoi, S., Guilleminault, C., and Dement, W. C., 1995. Sleep and sleep-disordered breathing in commercial long-haul truck drivers. *Chest*, ***107***(5), 1275–82.

Stoohs, R. A., Guilleminault, C., Itoi, A., & Dement, W. C., 1994. Traffic accidents in commercial long-haul truck drivers: the influence of sleep-disordered breathing and obesity. *Sleep*, ***17***, 619-619.

Taylor, B. J., & Donnelly, M., 2006. Risks to home care workers: Professional perspectives. *Health, Risk & Society,* ***8***(3), 239–256. doi:10.1080/13698570600871695

Toseland R.W., 1990. Long-term effectiveness of peer-led and professionally led support groups for caregivers. *Social Service Review*, ***64***(2), 308-27.

Von Essen, S. G., and McCurdy, S. A., 1998. Health and safety risks in production agriculture. *Western Journal of Medicine*, ***169***(4), 214.

Wipfli, B., Olson, R., and Koren, M., 2013. Weight loss maintenance among SHIFT pilot study participants 30-months post-intervention. *Journal of Occupational and Environmental Medicine*, ***55***(1), 1–3. doi:10.1097/JOM.0b013e31827db848

THE EFFECT OF AUTOMATED MANUFACTURING ENVIRONMENTS ON EMPLOYEE HEALTH

Fiona Wixted and Leonard O'Sullivan

Department of Design and Manufacturing Technology, University of Limerick, Ireland

Abstract

A review of the literature was conducted which revealed that psychosocial work factors such as job content, job control, workload, workplace, role, interpersonal relationships and equipment are prevalent stressors in automated manufacturing environments. The repetitive, monotonous and often highly paced work along with aspects of human-automation interaction have the potential to impact on employees mental, muscular and cardiovascular health.

Introduction

The working environment and type of work are important influences on employee health (Stansfeld et al. 2006). According to the EU Labour Force Survey 2007 on health and safety at work, approximately 14 % of those with a work-related health problem experienced stress, depression or anxiety as the main health problem (Romans and Preclin 2008), which infers that stress, depression or anxiety was the second most frequently reported work related health problem in the EU after musculoskeletal disorders. Occupational factors that give rise to stress are diverse and have been termed "occupational psychosocial factors". These factors are defined by Cox and Griffiths (1995) as 'those aspects of work design and the organisation and management of work, and their social and environment contexts, which have the potential for causing psychological, social and physical harm'. Psychosocial risks are also known as stressors which cause work-related stress. Work-related stress is the response people may have when presented with work demands and pressures that are not matched to their knowledge and abilities and which challenge their ability to cope (WHO 2003). Psychosocial risks have been demonstrated to have possible adverse effects on workers' physical, mental and social health (Bonde 2008); (Hanson et al. 2009); (Bosma et al. 1998); (Stansfeld and Candy 2006); (Wieclaw et al. 2008), (Nieuwenhuijsen et al. 2010).

Psychosocial factors which have the potential for causing psychological or physical harm can be grouped under the following headings: job content, workload and pace, work schedule, environment and equipment, job control, organisational structure and function, interpersonal relationship at work, role in the organisation, career development and home-work interface (ESENER 2012). Many of the aforementioned emerging psychosocial hazards identified by ESENER 2012 can be linked to the international phenomena of globalisation and technological advancements. Developments as a result of globalisation are seen in the form of changes in equipment and production processes, automation/robots, information technology, and manufacturing (Bamberger 2013).

Automation is when a computer can carry out functions that a human would normally perform (Parasuraman 2000). Research has shown that automation changes human activity and behaviour, resulting in new demands on the human operator (Woods 1996), (Parasuraman and Riley 1997). As automation technology becomes more sophisticated and designers have the ability to automate more processes and operations than ever before, increased automation in manufacturing industries is likely to impact on some of the emerging psychosocial factors identified by ESENER2012 such as job insecurity, increased work intensification, lean production and increased worker vulnerability.

There is evidence that automating tasks can add to the existing psychological demands and stressors within a manufacturing environment (Wall and Jackson 1995, Mital and Pennathur 2004). Operators' responses to technological demands can be physiological such as heightened blood pressure and musculoskeletal disorders (Carayon et al. 1999), or psychological (Corlett 1982). Automation can result in increased workload demands, reduced control over tasks and reduced skills, increased work pace and electronic performance monitoring pressures, reduced social interaction, higher psychological/cognitive demands, increased supervisory control and job insecurity (Carayon et al. 1999).

In spite of the widespread implementation of automation, its adoption is not always successful. The problems usually stem from the human interaction with the automation and the lack of consideration for human performance and limitations in the design of the automated systems (Parasuraman 2000). Automation use in human-machine systems depends on a complex interaction of factors that include mental workload, situation awareness, trust in automation, self-confidence, and risk (Lee 2006). In theory, automation should reduce operator workload and improve operator performance. In practice, automation generally reduces the physical workload, but may increase the cognitive workload of the employee. Bainbridge (1983) remarked on the irony of the fact that the more advanced the control system is, the more important the contribution of the human operator.

While human factor deficiencies in relation to automated environments have long been highlighted in the literature, research to date has not looked at the psychosocial stressors that arise as a result of these shortcomings. The following is a review of the literature pertaining to the psychosocial factors that are most relevant to modern automated manufacturing environments. These psychosocial stressors contribute to further health effects such as mental health problems, cardiovascular diseases and musculoskeletal problems, which are briefly summarised at the end of the review.

Psychosocial Factors in Automation

Job Content

There are a number of aspects of job content which are relevant to automated manufacturing environments including low value of work, underuse of skills, lack of task variety and repetitiveness in work, uncertainty, lack of opportunity to learn and high attentional demands (Cox et al. 2000, Schabracq and Cooper 2000) .

While automation has broken the monotony of repetitive work such as labelling containers on an assembly line for the duration of a work shift, it has introduced a new monotonous task in the supervision of a process along with removing the 'hands-on' interaction manufacturing operators would have experienced in the past. In this supervisory capacity, the operator may feel they are no longer a significant contributor to the product. Psychologist, Fromm (1995) claimed that a sense of personal productivity, what he terms ‘productive orientation’ is fundamental to a human beings sense of selfworth. Dvash and Mannheim (2001) found that the ‘technological coupling’ or the extent of the interaction between human operators and advanced manufacturing technology is negatively related to overall job satisfaction and to mental health disorders.

Increased use of automation in industry has led some researchers to claim that automating work practices leads to deskilling workers (Gallie et al. 2003, Smith and Carayon 1995). Cooley (1987) reported that the knowledge and skills required by some applications of automation technology are ideally suited to mentally retarded workers, or those with a mental age of 12. Mital and Pennathur (2004) stated that the human operator has become subservient to the technology and the outcome has been deskilling of operators in automated manufacturing environments. Deskilling has been found to have negative health effects with Lee and Ashforth (1996) reporting that higher skill utilisation was related to lower emotional exhaustion and less depersonalisation.

Task variety is defined as the degree to which the job requires that the employee perform a wide range of tasks (Morgeson and Humphrey 2006). Task variety is positively related to job satisfaction and perceived performance (Humphrey et al. 2007). In the context of the automated manufacturing work environment in particular, the job content tends to have low task variety and high levels of repetitiveness and monotony (Warr 2002). Netterstrøm et al. (1988) found that individuals who reported monotony in the job had increased blood levels of stress hormones compared to individuals not reporting monotony at work.

Uncertainty at Work

Insufficient feedback from automated systems is a known human factors problem (Kaber et al. 2000) and it can also be considered as a cause of ‘uncertainty in work’, which is a known cause of stress (Warr 1992). The out-of-loop position of the human operator has been shown to cause numerous problems including manual skill loss and a decreased level of technology understanding as a result of minimal engagement with the automated system. Firstly, automation by its very nature distances the operator physically from the process, reducing feedback and interaction. Secondly, the passive observation of changes in the system required by automation monitoring requires only visual monitoring whereas, the active monitoring involved in manual control allows for propioception and perception of cues like noise, vibration and smells (Proctor and Van Zandt 2011). Thirdly, with automation monitoring, the user can be complacent about monitoring when the automated system is perceived to be reliable, diverting their attentions elsewhere, which can also be a factor in keeping the human out of the control loop (Parasuraman 2000). When the operator is out of the control loop, their understanding of the process and the technology is diminished leaving them with less ability to take manual control of the system when necessary (Endsley and Kiris 1995). This skill loss can also affect the operators’ self-confidence making them less likely to intervene when there is a breakdown (Lee and Moray 1994, Wickens 1992).

Vigilance

High attentional demands were also identified by (Cox et al. 2000)as one of the potentially hazardous aspects of job content. Sustained attention or vigilance can be a large part of the operators’ role in an automated manufacturing environment (Kaber et al. 2000). Vigilance refers to the ability of organisms to maintain their focus of attention and to remain alert to stimuli over prolonged periods of time ((Molloy and Parasuraman 1996). The key findings in vigilance research are that vigilance performance declines over time, generally within 25 to 30 minutes of the task beginning (Teichner 1974) and that humans are simply not good at vigilance tasks (Finomore et al. 2009, Warm et al. 2008, Warm et al. 2008) found that vigilance is difficult mental work for humans and is stressful.

Mental Workload

The term "mental workload" refers to the "fit" or extent of the gap between task demands and a persons' ability, when motivated to cope with these demands (MacDonald 2003). Factors that are commonplace in automated environments such as the number of alternative actions, insufficient or contradictory data, uncertainty about the consequences of actions, time pressure and probability of failure have been identified as issues that may have an impact on the perceptions of mental workload (Meshkati and Loewenthal 1988). Continued advancements in automation technology have been motivated by a desire to reduce human mental workload in spite of the fact that the requirement for human monitoring creates mental workload in itself (Lee 2006).

Jou et al. (2009) compared mental workload levels in operators completing a manual and a semi-automated task in a nuclear power plant control room. This study shows that while automation can effectively reduce the overall workload and improve the operating performance of the operators, it can also lead to lowered mental workload, resulting in lowered attention. If the automation cannot be designed to optimise mental workload, the operator performance cannot be improved relative to manual tasks and there may be an increase in the risk of human error.

Workload and Work Pace

Automated manufacturing processes can potentially lead to work overload and underload. The introduction of automation was expected to reduce operator workload but this has not necessarily turned out to be the case (Proctor and Van Zandt 2011). While many manufacturing tasks can now be automated, designers often leave the operator with the most difficult task because they only have the ability to automate the less complex task. Where easier tasks have been automated, this leaves the operator with less experience and confidence when dealing with more difficult tasks, resulting in a situation where the automation has the effect of both reducing the workload during already low workload periods and increasing it during high workload periods (Lee 2006).

Shultz et al. (2010) found that role overload is more detrimental to both one's physical and psychological health than role underload. Parasuraman and Purohit (2000) found, in certain classifications of workers both role overload and underload can influence psychological health and well-being. McBride et al. (2011) have stipulated that in high workload situations fewer attentional resources may be available for monitoring, potentially resulting in a failure to detect automation errors and also contributing to operator stress.

Work pace is a factor which influences workload and which has been negatively associated with stress. Work pace is an issue in automated production work as the pace is rarely set to 'fit' the needs of the individual. The pace is often too high for the operator putting pressure on the operator to keep up with the process. The fifth European Working Conditions Survey looks at work intensity, which is a term that describes workers' experience of high job demands including high working pace. The survey reveals an overall increase in work intensity in most European countries over the past two decades with 62% of workers reporting working to tight deadlines and 59% report working at high speed (at least a quarter of the time)

(EUROFOUND 2012). The recent Eurobarometer survey on job satisfaction also confirmed an increase in work intensity in Europe over the last five years (EU 2014).

Environment and Equipment

Aspects of the work environment such as poor lighting, excessive noise, inadequate space or equipment have been identified as stressors in the work environment (Cox et al. 2000). One potential psychosocial stressor in the human-automation environment is the human-automation interface itself, usually a computer (Ayyagari et al. 2011). Superior computer interfaces allow users to focus on their task without diverting cognitive resources (attention, knowledge and workload) from the task to the interface (Woods 1996). Human-automation design that considers human affective processes can improve acceptance of the technology and productivity thereafter (Norman et al. 2003). Burkolter et al. (2014) found that there were significantly lower error rates and higher acceptance of the technology when a customised software interface was used where the user could choose individual preferences.

Job Control

The main assumption of the Karasek Job Demands-Resources model of stress is that, job demands in any occupation may trigger a process of energy-depletion leading to health problems, whereas job resources should be more motivating leading to high work engagement and improved performance (Schaufeli et al. 2009). One-third of workers say that they have little or no control over their work (EUROFOUND 2001).Kalleberg et al. (2009) found that autonomy, and consultation with workers reduced stress levels.

In general automated manufacturing has reduced the job control of operators. de Witte and Steijn (2000) found in their study of blue-collar workers that a trend of what they term 'internal differentiation' exists, where automation increases the complexity of a job but decreases the worker autonomy.

One aspect of human-automation interaction that impacts on operator job control is that of 'trust in automation'. If operators' confidence in their own ability to control is greater than their trust in human automation, they tended not to use it. When the reverse was true, they tended not to use automation. Self-confidence is a critical factor in mediating the effect of trust on reliance of the automation in particular (Lee and Moray 1994).

Interpersonal Relationships at Work

Interpersonal relationships at work can sometimes be stressful and have the potential to cause harm. These include social isolation, poor relationships with supervisors and colleagues and lack of support within the organisation. Automation has been described as a cause of "user alienation" (Sheridan and Parasuraman 2005). The automated process tends to remove the individual both physically and cognitively from the process he/she is directing. Some authors have also discussed separation in time from the automation due to the fact that the operators work or decision making is not synchronised with the automated process (Moray 2000). Another aspect of employee isolation is as a result of the worker having less or no contact with the product being manufactured or processed leaving the operator with a lack of ownership over the company's product. Social isolation in highly automated industrial environments is also compounded by the fact that there may be more interaction with computers than with people.

Role in the Organisation

Issues relating to role ambiguity and role conflict have in particular been found to have detrimental effects for the employee. Role conflict is a stressor where employees' role is not clearly defined and there are different role expectations from different members of the organisation (Rosen et al. 2010). Role ambiguity has been defined as uncertainty about the expectations, behaviours, and consequences associated with a particular role (Kozlowski 2012). As discussed previously, within a highly automated manufacturing environment, the role of the human operator tends to be that of a supervisor of the system (Lee 2006). Research has shown us that humans are not suited to such supervisory monitoring roles where high levels of vigilance are required (Parasuraman et al. 1993), and this type of role not only contradicts one of the core teachings of ergonomics that the job should be designed to fit the human but leads to role ambiguity owing to the lack of boundaries between where the automations role ends and that of the human begins. This conflict or ambiguity is often as a result how functions are allocated between the automated system and the human, known as "function allocation".

Health Effects of Poor Psychosocial Organizational Environments

While psychosocial stressors are the trigger for many occupational diseases, three groups of occupational disorders that are commonly linked with stress include mental, musculoskeletal and cardiovascular disorders.

Musculoskeletal Disorders

Psychological stress has been shown to play a significant role in the aetiology of musculoskeletal disorders through a number of different mechanisms. Psychosocial factors can influence the biomechanical load on the person through changes in posture, or exerted forces (Bongers et al. 1993, Kraatz et al. 2013). Psychosocial factors can impact the ability of a person to cope with an illness or change their perception of pain and they may therefore be more likely to report a health problem (Bernard 1997). Automated manufacturing environments have led to new ways of working that may pose sustained low-level mechanical loads on muscle and tendons (Knardahl 2005).

While multiple biological pathways linking psychosocial stress to musculoskeletal disorders exist, three key mechanisms by which psychological stress impacts muscles are muscular tension, muscular activity and muscular fatigue. Psychologically mediated or psychogenic muscle tension is when muscle tension occurs independently of biomechanical forces in response to a mental stressor but may be increased when the muscles are already exposed to a biomechanical loading (Treaster 2003). Roman-Liu et al. (2013) found that increased mental demand was linked with increased muscular tension in the neck/shoulder region in operators carrying out "supervisory control" tasks such as vigilance in automated environments.

Mehta et al. (2012) found that concurrent physical and mental demand resulted in increased muscular fatigue, with an increase in mental demands resulting in a faster rate of muscle strength decline. Studies have also found that psychological stress and elevated mental workload may cause increases in muscular activity (Lundberg et al. 1994, Waersted and Westgaard 1996). In relation to computer work in particular, increases in shoulder muscle activity have been linked to mental demands (Mclean and Urquhart 2002).

Mental/Psychological Disorders

Psychosocial stressors at work have been found to impact certain mental health disorders, the most common of these being anxiety and depression. Mental disorders such as depression and anxiety are recognised as potential occupational diseases in some countries e.g. Sweden. Recent reviews show some associations between poor psychosocial working conditions and depression

(Bonde 2008, Netterstrøm et al. 2008). Stress due to high task demands and poor social interactions at work seem to be important mediating factors in these conditions (Holte and Westgaard 2002). Recently, Becker (2014) found evidence to support a link between a poor psychosocial work environment and an increased risk of dementia.

Cardiovascular Disorders

Cardiovascular diseases such as coronary heart disease, myocardial infarction, heart failure, angina pectoris, stroke and hypertension have all been linked to psychosocial factors in the workplace (Backé et al. 2012). A review by Kivimäki et al. (2006) reported that there was a 50% increased risk of cardiovascular disease among employees who were found to be suffering from work stress. A meta-analysis by Eller et al. (2009) found that high job demands and low social support were risk factors for ischemic heart disease among men.

Conclusions

Through advances in technology and increased globalisation, manufacturing businesses are becoming more automated. Automated manufacturing environments are a potential origin of psychosocial stressors which can impact employees' mental, muscular, and cardiovascular health in numerous ways.

Acknowledgements

This research was co funded under the European Commission supported FP7 project Robomate, Grant number 608979.

References

Ayyagari, R., Grover, V. and Purvis, R. (2011) 'TECHNOSTRESS: TECHNOLOGICAL ANTECEDENTS AND IMPLICATIONS', *Mis Quarterly,* 35(4), 831-858.

Backé, E.-M., Seidler, A., Latza, U., Rossnagel, K. and Schumann, B. (2012) 'The role of psychosocial stress at work for the development of cardiovascular diseases: a systematic review', *International archives of occupational and environmental health,* 85(1), 67.

Bainbridge, L. (1983) 'Ironies of automation', *Automatica,* 19(6), 775-779.

Bamberger, S. G. (2013) 'Globalization, Transformation Pressure, and Psychosocial Work Environment-the Implications of Management on Mental Health'.

Becker, T. (2014) 'The effect of the psychosocial working environment on cognition and dementia', *Occupational and Environmental Medicine,* 71(5), 305-306.

Bernard, B. (1997) 'Work-related musculoskeletal disorders and psychosocial factors', *Work-related musculoskeletal disorders and psychosocial factors*.

Bonde, J. P. E. (2008) 'Psychosocial factors at work and risk of depression: a systematic review of the epidemiological evidence', *Occupational and Environmental Medicine,* 65(7), 438-445.

Bongers, P. M., de Winter, C. R., Kompier, M. A. and Hildebrandt, V. H. (1993) 'Psychosocial factors at work and musculoskeletal disease', *Scandinavian Journal of Work, Environment & Health*, 297-312.

Bosma, H., Peter, R., Siegrist, J. and Marmot, M. (1998) 'Two alternative job stress models and the risk of coronary heart disease', *American Journal of Public Health,* 88(1), 68-74.

Burkolter, D., Weyers, B., Kluge, A. and Luther, W. (2014) 'Customization of user interfaces to reduce errors and enhance user acceptance', *Applied ergonomics,* 45(2), 346-353.

Carayon, P., Smith, M. J. and Haims, M. C. (1999) 'Work organization, job stress, and work-related musculoskeletal disorders', *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 41(4), 644-663.

Cooley, M. (1987) *Architect or Bee?: the human price of technology,* Vintage.

Corlett, E. (1982) 'Machine pacing and occupational stress: G. Salvendy and MJ Smith (Eds) Taylor and Francis Ltd, pp 384,£ 19.75', *Applied ergonomics,* 13(2), 150-151.

Cox, T. and Griffiths, A. (1995) 'The nature and measurement of work stress: theory and practice', *The evaluation of human work: A practical ergonomics methodology. London: Taylor & Francis*.

Cox, T., Griffiths, A. and Rial-González, E. (2000) *Work-related stress,* European Agency for Safety and Health at work.

de Witte, M. and Steijn, B. (2000) 'Automation, job content, and underemployment', *Work, Employment & Society,* 14(2), 245-264.

Dvash, A. and Mannheim, B. (2001) 'Technological coupling, job characteristics and operators' well-being as moderated by desirability of control', *Behaviour & Information Technology,* 20(3), 225-236.

Eller, N. H., Netterstrøm, B., Gyntelberg, F., Kristensen, T. S., Nielsen, F., Steptoe, A. and Theorell, T. (2009) 'Work-related psychosocial factors and the development of ischemic heart disease: a systematic review', *Cardiology in review,* 17(2), 83-97.

Endsley, M. R. and Kiris, E. O. (1995) 'The out-of-the-loop performance problem and level of control in automation', *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 37(2), 381-394.

ESENER, E. R. O. (2012) 'Management of psychosocial risks at work: An analysis of the findings of the European Surveyof Enterprises on New and Emerging Risks (ESENER)'.

EU (2014) *Flash Eurobarometer Report 398 on Working Conditions*.

EUROFOUND (2001) 'Third European Survey on Living and Working Conditions'.

EUROFOUND (2012) 'Fifth European Working Conditions Survey',

Finomore, V., Matthews, G., Shaw, T. and Warm, J. (2009) 'Predicting vigilance: A fresh look at an old problem', *Ergonomics,* 52(7), 791-808.

Fromm, E. (1995) *To Have Or to Be?,* Abacus.

Gallie, D., Felstead, A. and Green, F. (2003) 'Skill, task discretion and new technology', *L'Année sociologique,* 53(2), 401-430.

Holte, K. A. and Westgaard, R. H. (2002) 'Further studies of shoulder and neck pain and exposures in customer service work with low biomechanical demands', *Ergonomics,* 45(13), 887-909.

Humphrey, S. E., Nahrgang, J. D. and Morgeson, F. P. (2007) 'Integrating motivational, social, and contextual work design features: a meta-analytic summary and theoretical extension of the work design literature', *Journal of Applied Psychology,* 92(5), 1332.

Jou, Y.-T., Yenn, T.-C., Lin, C. J., Yang, C.-W. and Chiang, C.-C. (2009) 'Evaluation of operators' mental workload of human–system interface automation in the advanced nuclear power plants', *Nuclear Engineering and Design,* 239(11), 2537-2542.

Kaber, D. B., Onal, E. and Endsley, M. R. (2000) 'Design of automation for telerobots and the effect on performance, operator situation awareness, and subjective workload', *Human Factors and Ergonomics in Manufacturing,* 10(4), 409-430.

Kalleberg, A. L., Nesheim, T. and Olsen, K. M. (2009) 'Is participation good or bad for workers? Effects of autonomy, consultation and teamwork on stress among workers in Norway', *Acta Sociologica,* 52(2), 99-116.

Kivimäki, M., Virtanen, M., Elovainio, M., Kouvonen, A., Väänänen, A. and Vahtera, J. (2006) 'Work stress in the etiology of coronary heart disease--a meta-analysis', *Scandinavian Journal of Work, Environment & Health,* 32(6), 431-442.

Knardahl, S. (2005) 'Psychological and social factors at work: contribution to musculoskeletal disorders and disabilities', *G Ital Med Lav Ergon,* 27(1), 65-73.

Kozlowski, S. W. J. (2012) *The Oxford Handbook of Organizational Psychology,* OUP USA.

Kraatz, S., Lang, J., Kraus, T., Münster, E. and Ochsmann, E. (2013) 'The incremental effect of psychosocial workplace factors on the development of neck and shoulder disorders: a systematic review of longitudinal studies', *International archives of occupational and environmental health*, 1-21.

Lee, J. D. (2006) 'Human factors and ergonomics in automation design', *Handbook of Human Factors and Ergonomics, Third Edition*, 1570-1596.

Lee, J. D. and Moray, N. (1994) 'TRUST, SELF-CONFIDENCE, AND OPERATORS ADAPTATION TO AUTOMATION', *International Journal of Human-Computer Studies,* 40(1), 153-184.

Lee, R. T. and Ashforth, B. E. (1996) 'A meta-analytic examination of the correlates of the three dimensions of job burnout', *Journal of Applied Psychology,* 81(2), 123-133.

Lundberg, U., Kadefors, R., Melin, B., Palmerud, G., Hassmén, P., Engström, M. and Dohns, I. E. (1994) 'Psychophysiological stress and EMG activity of the trapezius muscle', *International Journal of Behavioral Medicine,* 1(4), 354-370.

MacDonald, W. (2003) 'The impact of job demands and workload on stress and fatigue', *Australian Psychologist,* 38(2), 102-117.

McBride, S. E., Rogers, W. A. and Fisk, A. D. (2011) 'Understanding the effect of workload on automation use for younger and older adults', *Human Factors,* 53(6), 672-686.

Mclean, L. and Urquhart, N. (2002) 'The influence of psychological stressors on myoelectrical signal activity in the shoulder region during a data entry task', *Work & Stress,* 16(2), 138-153.

Mehta, R. K., Nussbaum, M. A. and Agnew, M. J. (2012) 'Muscle-and task-dependent responses to concurrent physical and mental workload during intermittent static work', *Ergonomics,* 55(10), 1166-1179.

Meshkati, N. and Loewenthal, A. (1988) 'The effects of individual differences in information processing behavior on experiencing mental workload and perceived task difficulty: A preliminary experimental investigation', *Advances in Psychology,* 52, 269-288.

Mital, A. and Pennathur, A. (2004) 'Advanced technologies and humans in manufacturing workplaces: an interdependent relationship', *International Journal of Industrial Ergonomics,* 33(4), 295-313.

Molloy, R. and Parasuraman, R. (1996) 'Monitoring an automated system for a single failure: Vigilance and task complexity effects', *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 38(2), 311-322.

Moray, N. (2000) *Are Observers Ever Really Complacent When Monitoring Automated Systems?,* translated by SAGE Publications, 592-595.

Morgeson, F. P. and Humphrey, S. E. (2006) 'The Work Design Questionnaire (WDQ): Developing and validating a comprehensive measure for assessing job design and the nature of work', *Journal of Applied Psychology,* 91(6), 1321-1339.

Netterstrøm, B., Conrad, N., Bech, P., Fink, P., Olsen, O., Rugulies, R. and Stansfeld, S. (2008) 'The relation between work-related psychosocial factors and the development of depression', *Epidemiologic reviews,* 30(1), 118-132.

Netterstrøm, B., Danborg, L. and Olesen, H. (1988) 'Glycated hemoglobin as a measure of physiological stress', *Behavioral Medicine,* 14(1), 13-16.

Norman, D. A., Ortony, A. and Russell, D. M. (2003) 'Affect and machine design: Lessons for the development of autonomous machines', *IBM Systems Journal,* 42(1), 38-44.

Parasuraman, R. (2000) 'Designing automation for human use: empirical studies and quantitative models', *Ergonomics,* 43(7), 931-951.

Parasuraman, R., Molloy, R. and Singh, I. L. (1993) 'Performance consequences of automation-induced'complacency'', *The International Journal of Aviation Psychology,* 3(1), 1-23.

Parasuraman, R. and Riley, V. (1997) 'Humans and Automation: Use, misuse, disuse, abuse', *Human Factors,* 39(2), 230-253.

Parasuraman, S. and Purohit, Y. S. (2000) 'Distress and boredom among orchestra musicians: The two faces of stress', *Journal of Occupational Health Psychology,* 5(1), 74.

Proctor, R. W. and Van Zandt, T. (2011) *Human factors in simple and complex systems,* CRC Press.

Roman-Liu, D., Grabarek, I., Bartuzi, P. and Choromański, W. (2013) 'The influence of mental load on muscle tension', *Ergonomics,* 56(7), 1125-1133.

Romans, F. and Preclin, V. (2008) 'European Union Labour Force Survey–Annual results 2007', *Eurostat Data en Focus,* (27).

Rosen, C. C., Chang, C.-H., Djurdjevic, E. and Eatough, E. (2010) 'Occupational stressors and job performance: An updated review and recommendations' in Perrewé, P. L. and Ganster, D. C., eds., *New developments in theoretical and conceptual approaches to job stress.*, Bingley United Kingdom: Emerald Group Publishing, 1-60.

Schabracq, M. J. and Cooper, C. L. (2000) 'The changing nature of work and stress', *Journal of Managerial Psychology,* 15(3), 227-241.

Schaufeli, W. B., Bakker, A. B. and Van Rhenen, W. (2009) 'How changes in job demands and resources predict burnout, work engagement, and sickness absenteeism', *Journal of Organizational Behavior,* 30(7), 893-917.

Sheridan, T. B. and Parasuraman, R. (2005) 'Human-automation interaction', *Reviews of human factors and ergonomics,* 1(1), 89-129.

Shultz, K. S., Wang, M. and Olson, D. A. (2010) 'Role overload and underload in relation to occupational stress and health', *Stress and Health,* 26(2), 99-111.

Smith, M. J. and Carayon, P. (1995) 'New technology, automation, and work organization: stress problems and improved technology implementation strategies', *International Journal of Human Factors in Manufacturing,* 5(1), 99-116.

Stansfeld, S. A., Marmot, M. and Wilkinson, R. (2006) 'Social support and social cohesion', *Social determinants of health,* 2, 148-71.

Teichner, W. H. (1974) 'The detection of a simple visual signal as a function of time of watch', *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 16(4), 339-352.

Treaster, D. E. (2003) *An investigation of postural and visual stressors and their interactions during computer work*, unpublished thesis The Ohio State University.

Waersted, M. and Westgaard, R. (1996) 'Attention-related muscle activity in different body regions during VDU work with minimal physical activity', *Ergonomics,* 39(4), 661-676.

Wall, T. D. and Jackson, P. R. (1995) 'New manufacturing initiatives and shopfloor job design'.

Warm, J. S., Matthews, G. and Finomore, V. (2008) 'Vigilance, workload, and stress', *Performance under stress*, 115-41.

Warm, J. S., Parasuraman, R. and Matthews, G. (2008) 'Vigilance Requires Hard Mental Work and Is Stressful', *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 50(3), 433-441.

Warr, P. (1992) 'Job features and excessive stress', *Prevention of Mental Ill Health at Work. London: HMSO*.

Warr, P. (2002) *Psychology at work,* Penguin UK.

WHO (2003) 'PROTECTING WORKERS'HEALTH SERIES NO 3'.

Wickens, C. D. (1992) *Engineering psychology and human performance,* HarperCollins Publishers.

Woods, D. D. (1996) 'Decomposing automation: Apparent simplicity, real complexity', *Automation and human performance: Theory and applications*, 3-17.