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Assessment of an active industrial exoskeleton to aid dynamic lifting and lowering manual handling tasks

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Abstract

The aim of this study is to evaluate the effect of an industrial exoskeleton on muscle activity, perceived physical exertion, measured and perceived contact pressure at the trunk, thighs and shoulders, and subjective usability for cyclical lifting and lowering. Twelve male participants lifted and lowered a box of 7.5kg and 15kg, respectively, from mid-shin height to waist height, five times, both with and without the exoskeleton. The device significantly reduced muscle activity of the Erector Spinae (12%-15%) and Biceps Femoris (5%). Ratings of physical exertion in the trunk region were significantly less with the device (9.5%-11.4%). The measured contact pressure was highest on the trunk (91.7kPa-93.8kPa) and least on shoulders (47.6kPa-51.7kPa), whereas pressure was perceived highest on the thighs (35-44% of Max LPP). Seven of the users rated the device usability as acceptable. The exoskeleton reduced musculoskeletal loading on the lower back and assisted with hip extensor torque during lifting and lowering. Contact pressures fell below the Pain Pressure Threshold. Perceived pressure was not exceptionally high, but sufficiently high to cause discomfort if used for long durations.

1 Introduction

Manual handling activities are associated with high rates of Work-Related Musculoskeletal Disorders (WMSDs) (Zurada, 2012, Collins and O'Sullivan, 2015). Despite the widespread use of robots, automation, mechanisation and work-related interventions in industry, many tasks are still performed manually by workers. In some jobs, workers are necessary to perform the work when it comes to observation and decision-making, and in other instances tasks benefit from human precision, skill and movement capabilities (Bos et al., 2004; Zurada, 2012, de Looze et al., 2015). Hence, despite increased automation, many jobs still require workers to perform manual handling tasks.

There is a growing interest in industry towards the use of wearable sensors and robotics technoloiges, including exoskeletons, to assist workers with performing manual handling activities (de Looze et al., 2015). The principle of an exoskeleton is to add mechanical power to the human body, thereby reducing the biomechanical load and reducing risk of WMSDs. Exoskeletons are typically classified as active or passive. Active systems comprise of one or more actuators to augment the human's power, whereas passive systems use material compliance to provide gravity compensation, and spring/elastic members to store and release energy during movements to assist workers to perform physical movements (de Looze et al., 2015; Matthew et al., 2015). Exoskeletons are also defined based on the fit and resemblance to the human body limbs. Anthropomorphic exoskeletons have joints with rotational axes aligned with the rotational movements of the major human joints, which is not the case with non-anthropomorphic types (de Looze et al., 2015).

Commercially available exoskeletons have been predominately developed for rehabilitation purposes, where the devices are aimed to support and assist physically weak, injured or disabled people with prescribed exercises and activities (Viteckova et al., 2013). A relatively small number of exoskeletons have been designed for military applications to enhance muscular strength and physical carrying capacity of soldiers (Anam and Al-Jumaily, 2012; Yan et al., 2015). Active industrial exoskeletons are remain mainly at research and development stage while passive exoskeletons have already entered the market. It is necessary for these technologies, particularly active exoskeletons, to demonstrate efficacy and safety in order to support their commercial opportunity and uptake in industry (de Looze et al., 2015).

Manual lifting has been well established as an occupational risk factor for back WMSDs (Zurada, 2012). While the objective of an industrial exoskeleton is to provide assistive power to the worker to reduce the risks in the work, the device must also have sufficient usability to be comfortable to use, so that workers accept and are willing to adopt the technology. Studies on exoskeleton prototypes have shown that they do not always achieve their objectives initially, by failing to meet the needs of the end users or stakeholders (Almenara et al., 2017). Nonetheless, the basic principle of providing biomechanical assistance has been proven, but sometimes with increased loading elsewhere in the body. For instance, the BNDR, HappyBack and Bendezy exoskeletons have been demonstrated to reduce erector spinae muscle activity by 21-31% but increase leg muscle activity (Barret and Fathallah, 2001).

A key factor affecting exoskeleton acceptance is local discomfort caused by the force applied to the body at the exoskeleton interface (contact pressure). If not carefully designed, the user may experience significant discomfort and possibly injury, which no doubt will lead lead to reluctance to use the device. There have been few studies of local discomfort and Pain Pressure Treshold (PPT) on exoskeletons.

The purpose of the current study was to perform an ergonomics assessment of an exoskeleton aimed to provide mechanical assistance to the body during lifting tasks to reduce WMSD risk of the back, while also aiming to minimise discomfort and contact pressure. The exoskeleton tested was developed as part of the EU-funded project Robomate (www.robo-mate.eu). Specifically, the objectives were to assess the effect of the exoskeleton on muscle activity, physical exertion, contact pressure, local perceived pressure and subjective usability for short duration cyclical lifting and lowering.

2 Method

2.1 Participants and ethics approval

Twelve healthy male participants with no prior or current injuries/musculoskeletal disorders gave written consent to participate in the study (Means & SD: Age: 27 years ± 2, Mass: 75.38kg ± 10.1, Stature: 1794mm ± 6.56). However, one of these participants was unable to complete the experiment, resulting in the exclusion of these data.

This study was performed in accordance with the Research Ethics Procedures of the Italian Institute of Technology, where the testing occurred.

2.2 Experimental design

The independent variables were LOAD (7.5kg and 15kg) and SYSTEM (with/without exoskeleton). The dependent variables were muscle activity (EMG: Rectus Abdominis, Erector Spinae at level of L3 vertebrae, Biceps Femoris) and perceived physical exertion. Additionally, contact pressure, perceived musculoskeletal pressure and usability were assessed for the 'with exoskeleton' conditions.

There were four treatments (LOAD X 2, SYSTEM X 2) in a full factorial design, which were performed by each participant in a randomised order (for LOAD and SYSTEM). The treatments involved lifting and lowering a box from mid-shin height to waist height five times.

2.3 Procedure

On entering the laboratory, participants were informed of the testing procedure and equipment involved. At that point anthropometric measurements were obtained followed by the preparation and attachment of the EMG electrodes on the muscles. After a detailed explanation, demonstration and setup of equipment (relative to participants' shin and waist) by the lead investigator, participants first practiced the lifting task. Testing commenced once participants were proficient and comfortable with the testing requirements and procedure. The pressure mats were positioned at the three regions whilst the exoskeleton was being placed on the individual for the 'with exoskeleton' conditions.

Each participant performed cyclical lifting and lowering. When they had achieved the required proficiency level in the movements, they performed five cycles as the experimental run for each LOAD and SYSTEM treatment. Once experimentation was completed, the participants were required to perform two MVC measurements per muscle. MVC was conducted at the end to avoid fatigue prior to testing with the exoskeleton. Each muscle was maximally contracted for three seconds, with a one-minute rest period between trials. There was a break of a minimum of five minutes between treatments.

2.4 Equipment

Testing Equipment

A box (L: 43cm, W: 29cm, H: 16cm) and two loads (7.5kg and 15kg) were used. The box with hand-holes was positioned on an adjustable platform set to each participant's mid-shin height. The loads studied reflect a range from moderate to high in industrial tasks, whilst falling within lifting and lowering guideline weights suggested by Pheasant (2006). Similarly, the origin and destination for lift/lower were based on guidelines by Pheasant (2006) and ISO standards (ISO 14738:2008).

Exoskeleton

The exoskeleton is an active wearable type aimed to reduce back loading during lifting/lowering manual handling activities by providing assistive torque at the user's hip. The exoskeleton is attached to the trunk and the thighs and articulated to coincide with rotation about the hip region. The exoskeleton comprises three linked segments: a back unit with two leg units for both thighs (attachment via Velcro straps). The exoskeleton is worn by the user like a backpack (Figure 1). When put on, it is adjusted/aligned on the body via a number of straps on the back unit, and then the attachments at the thighs are secured. The physical assistance is adjusted in real time based on posture (T=Tmax*sin(angle)) No assistance is provided when the user is standing upright. Before testing commenced, starting at 20Nm, each participant could adjust the maximum torque ±5Nm. The adjustability was to assist with comfort and to enable the wearer to vary the power as per their preference. After this adjustment, the selected torque remained constant throughout the testing duration.

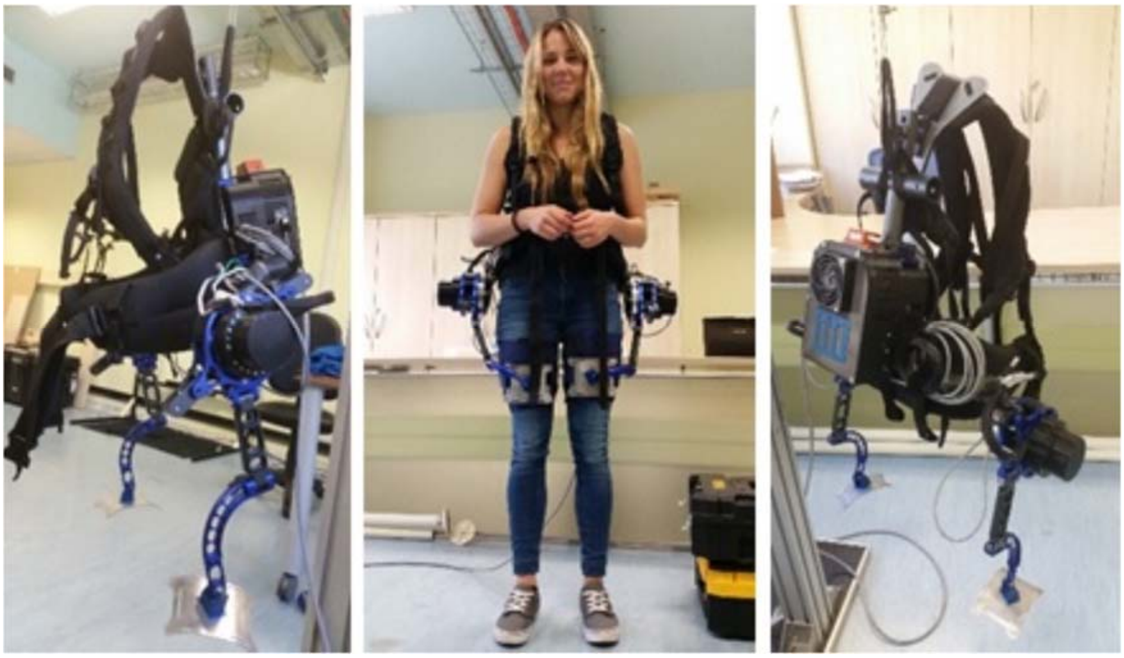

Figure 1 The exoskeleton concept tested

Surface electromyography

Muscle activity of three muscles on the right side of the body was studied: Rectus Abdominis, Erector Spinae at the level of L3 vertebrae and Biceps Femoris. Data were collected using a portable NeXus Mark II EMG system (Sampling rate: 2048Hz) with bipolar electrodes placed over each muscle (inter-electrode distance: 20mm) as per the guidance in the SENIAM protocol (Hermens et al., 2000). Nexus Bio Trace software was used to inspect and analyse the data. A ground electrode was placed on the C7 spinous process. Before electrodes were applied, the skin was shaved, scrubbed and cleaned with alcohol, again in accordance with the SENIAM protocol (Hermens et al., 2000). A digital filter was applied to the signals (IIR Band Pass filter Butterworth 3rd Order, 20-500Hz). The RMS of the EMG data was calculated to determine the signal amplitudes. Participants performed a maximum exertion of each muscle group at the end of the experiment. Maximum amplitude normalised to MVC was determined for the last three lifting and lowering repetitions per treatment. In the end, data from three participants had to be excluded (giving n = 9 for the EMG data set) as the data were contaminated, often because electrodes made contact with the exoskeleton during testing.

Contact pressure

Contact pressure at the interface between the participant and the exoskeleton was measured using BodiTrak pressure measurement mats, and recorded and analysed using the FSA software supplied. Three mats were inserted between the exoskeleton and the body on the left side, one proximal to the shoulder (Shoulder), one at the hip/lower back (Trunk), and one around the upper leg (Thigh). The sensing area, sensor arrangement and sensor quantity for the Trunk mat was 228mmx228mm, 16x16 array and 256 sensors, and for the Shoulder and Thigh mats were 350mmx350mm, 24x24 array and 567 sensors. Pressure was recorded throughout each treatment. Due to signal contamination, pressure data from nine participants are reported.

2.5 Subjective responses

Rating of Perceived Exertion (RPE) was rated using the Borg Category Ratio (CR-10) scale (Borg, 1982). On the left it indicated *zero* (no physical exertion) and on the right *ten* (almost maximal exertion). RPE was assessed for the back and legs separately, for each condition, with and without the exoskeleton.

Perceived musculoskeletal pressure was rated using the Local Perceived Pressure (LPP) method (adapted from van der Grinten and Smitt, 1992). LPP was rated on a scale from *zero* (no pressure at all) to *ten* (extremely strong pressure). It was rated for three areas of the body: Back/Shoulders, Upper Legs and Belly/Hips after each of the two conditions with the exoskeleton.

Usability of the exoskeleton was rated using the System Usability Scale (SUS) (Bangor et al., 2009). This subjective rating scale consists of ten questions rated from *one* (strongly disagree) to *five* (strongly agree). A score over 70 is deemed acceptable. One participant misinterpreted the questions due to the language barrier, thus scores of ten participants were reported.

2.6 Data Analysis

All data were analysed using SPSS Statistics Software Version 21, with significance set at $p<0.05$. Normality of the data was assessed using the Kolmogorov-Smirnov test. Some data violated the assumption of normality, thus, the non-parametric Wilcoxin signed rank test was used to analyze the data. As multiple factorial analysis is not possible with this test, the analysis required multiple separate analyses.

Study of exoskeleton effect on body loading

Maximum %MVC (Rectus Abdominis, Erector Spinae L3, Biceps Femoris) and mean RPE (Legs and Trunk) were assessed for both SYSTEM and LOAD.

User assessment of the exoskeleton

Maximum contact pressure (Trunk, Shoulder, Thigh), mean LPP and SUS scores were assessed. Statistical analysis was only performed on contact pressure data where LOAD was one factor and AREA the second.

3 Results

3.1 Study of exoskeleton effect on body loading

3.1.1 Muscle activity

Erector Spinae and Biceps Femoris muscle activity was significantly lower ($p<0.01$) with the exoskeleton, but not for the Rectus Abdominis (Table 1, Figure 2). Erector Spinae activity was reduced by 12% for the 7.5kg load and by 15% for the 15kg load, whereas Biceps Femoris activity was reduced by 5% for both loads. Erector Spinae and Bicep Femoris muscle activity was significantly higher for the heavier load compared to the 7.5kg load (Table 1, Figure 2). This was also noted for the ‘without exoskeleton’ condition for the Rectus Abdominis.

Table 1: Statistical analysis of maximum %MVC EMG activity for lifting and lowering with and without the exoskeleton for both loads

Effects		**Conditions**					
		Rectus Abdominis		ES L3		Biceps Femoris	
		7.5kg	15kg	7.5kg	15kg	7.5kg	15kg
SYSTEM	Z	-0.866	-0.255	-2.701	-2.803	-2.701	-2.803
	P	0.386	0.799	**0.007**	**0.005**	**0.007**	**0.005**
		Rectus Abdominis		ES L3		Biceps Femoris	
		W-ES	ES	W-ES	ES	W-ES	ES
LOAD	Z	-2.701	-1.784	-2.803	-2.803	-2.395	-2.701
	P	**0.007**	0.074	**0.005**	**0.005**	**0.017**	**0.007**

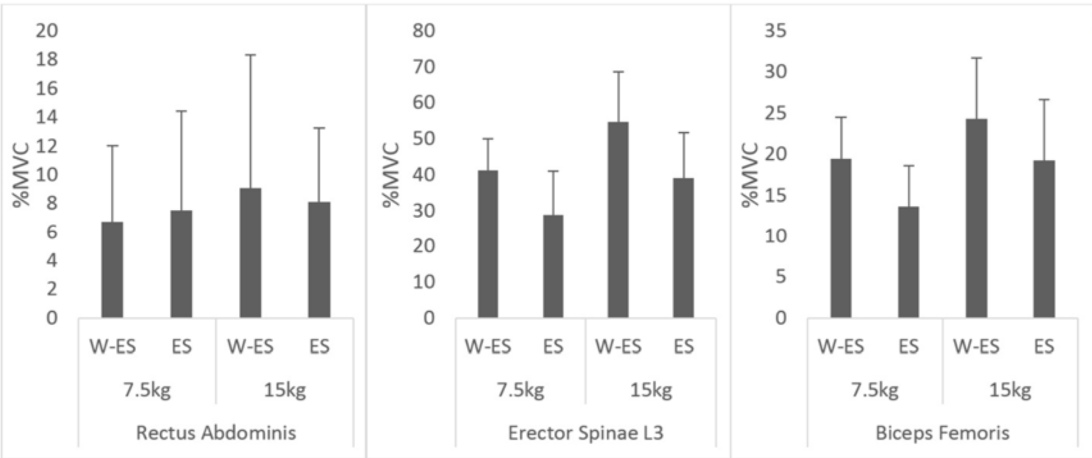

Figure 2 Maximum percentage MVC for the Rectus Abdominis (left), Erector Spinae (Middle) and Biceps Femoris (right) for lifting and lowering with (ES) and without (W-ES) the exoskeleton for both loads

3.1.2 Rating of Perceived Exertion

The exoskeleton reduced the RPE scores of the trunk by 9.5%/11.4%, and of the legs by 4.5%/8.1% for the 7.5kg/15kg load respectively (Table 2, Figure 3). This effect was only significant for the trunk RPE scores ($p<0.01$,). Perceived exertion was significantly higher ($p<0.01$) for both body regions for the heavier load).

Table 2: Statistical analysis of perceived physical exertion for lifting and lowering with and without the exoskeleton for both loads

Effects		**Body region**			
		Trunk		Legs	
		7.5kg	15kg	7.5kg	15kg
SYSTEM	Z	-2.154	-2.232	-0.997	-1.309
	P	**0.031**	**0.026**	0.319	0.191
		Trunk		Legs	
		W-ES	ES	W-ES	ES
LOAD	Z	-2.714	-2.699	-2.555	-2.308
	P	**0.007**	**0.007**	**0.011**	**0.021**

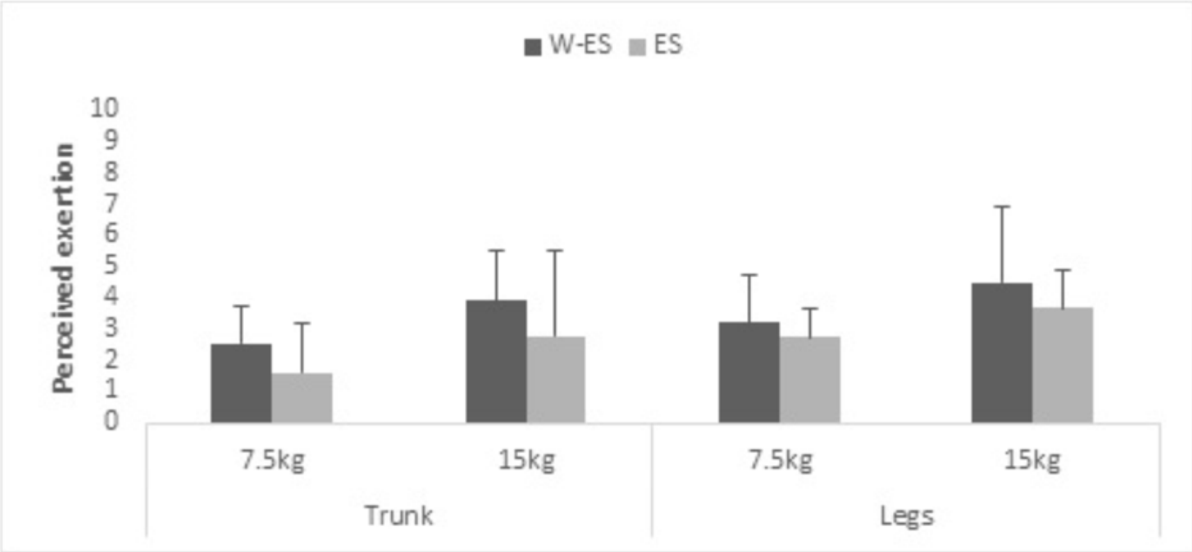

Figure 3 Mean perceived physical exertion for lifting and lowering with (ES) and without (W-ES) the exoskeleton for both loads

3.2 User assessment of the exoskeleton

3.2.1 Contact pressure

The exoskeleton applied highest pressure to the Trunk region and least on the Shoulder (Figure 4). Pressure was significantly higher for the thighs and trunk compared to the shoulders (Table 3, Figure 4). Additionally, Shoulder and Thigh pressure was significantly higher for the heavier load. The pressure applied to the trunk and thighs was on average 91.6kPa /93.6kPa and 69.1kPa/81.2kPa for the 7.5kg/15kg loads respectively. Contact pressure on the shoulder was approximately 47%/44% and 30%/36% less than the trunk and thigh pressure for the 7.5kg/15kg loads respectively, where pressure was on average 48kPa/51.9kPa.

Table 3: Statistical analysis of maximum pressure applied to the human body by the exoskeleton during lifting and lowering for both loads.

Effects		**Conditions**					
		Trunk		Shoulder		Thigh	
LOAD	Z	-0.59		-1.960		-2.197	
	P	0.953		**0.05**		**0.028**	
		Trunk vs. Shoulder		Trunk vs. Thigh		Shoulder vs. Thigh	
		7.5kg	15kg	7.5kg	15kg	7.5kg	15kg
AREA	Z	-2.380	-2.100	-1.352	-0.507	-2.201	-2.201
	P	**0.017**	**0.036**	0.176	0.612	**0.028**	**0.028**

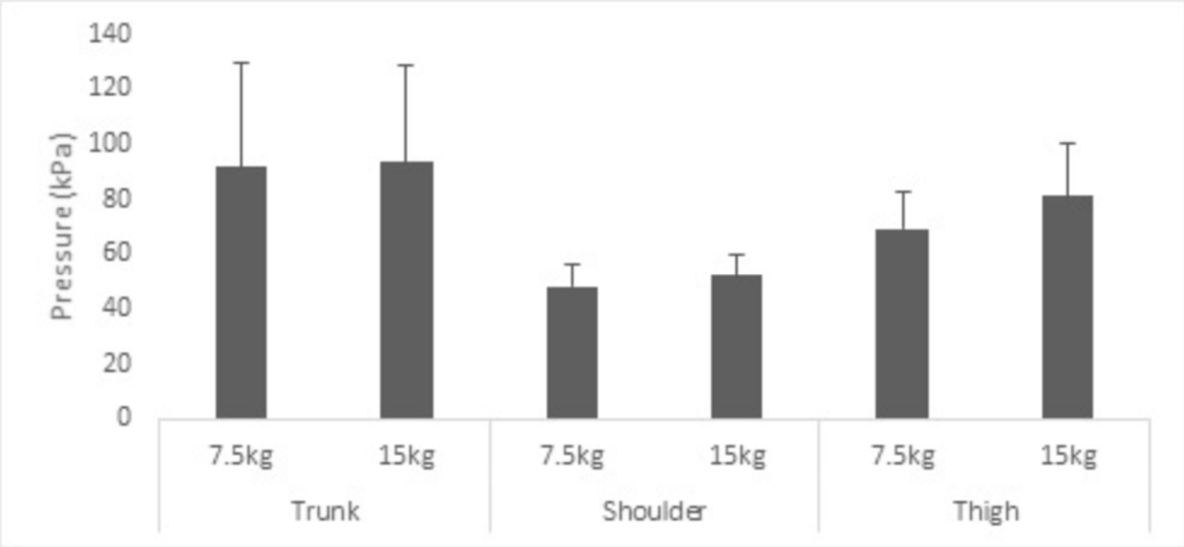

Figure 4 Maximum pressure exerted at the trunk, shoulder and thigh by the exoskeleton during lifting and lowering, for two loads

3.2.3 Local Perceived Pressure

Perceived pressure was higher for the 15kg load than 7.5kg on average across all body regions (Figure 5). The Upper Legs were rated the highest, with average ratings ‘Somewhat Strong’ (35%/44% of Max LPP for 7.5kg/15kg). The Back/Shoulder and Belly/Hips were rated as ‘Light’ pressure (Figure 5): 25%/28% and 24%/27% of maximum LPP for 7.5kg/15kg respectively.

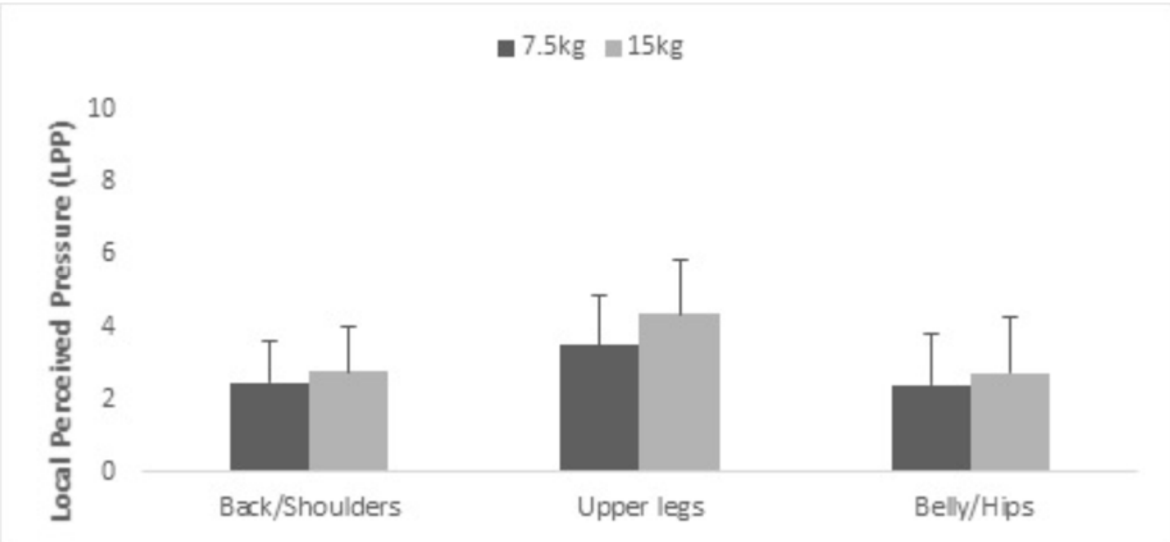

Figure 5 Mean local perceived pressure (+/-1sd) for lifting and lowering with the exoskeleton for two loads

3.2.4 Usability

The System Usability Scores are detailed in Figure 6. Six of the ten participants rated SUS scores above the criterion for acceptable usability.

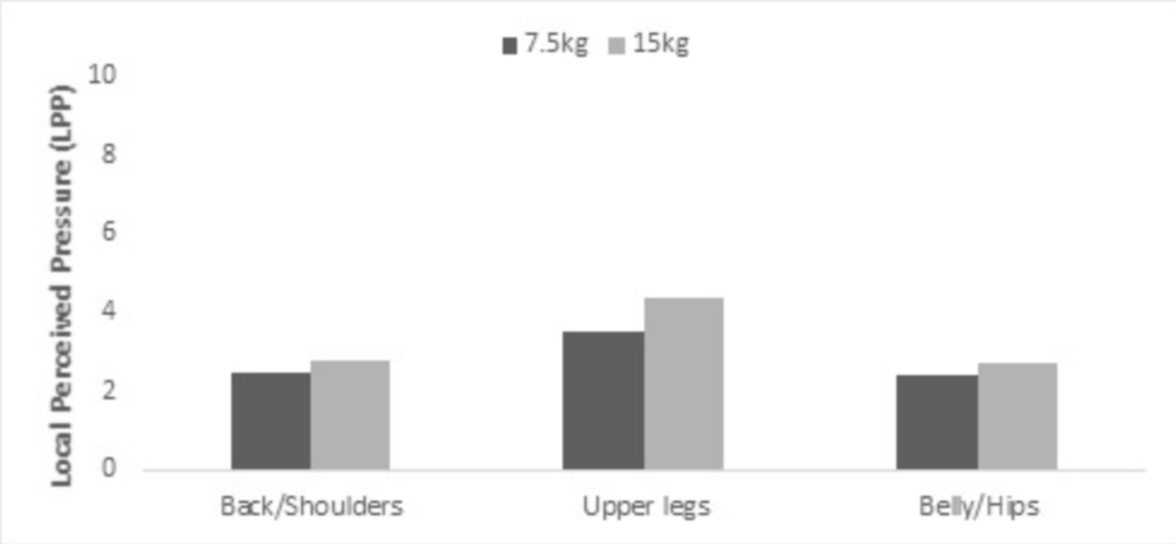

Figure 6 Participant SUS ratings of the exoskeleton

4 Discussion

Study of exoskeleton effect on body loading

The key finding of this study was the reduction in muscle activity of the main trunk extending muscle group in the lower back region, which was in line with the other finding of reduced perceived trunk exertion. Thus, the exoskeleton reduced musculoskeletal loading on the lower back during the simulated industrial lifting task. Erector Spinae peak muscle activity at the lumbar level was reduced by 12-15%, with a greater reduction in activity for the higher load lifted. As peak muscle activity and trunk RPE is reduced, the worker's endurance increases and muscle fatigue decreases, reducing the risk of developing LBD. Granata et al. (2004) suggests that lower back injuries occur when spinal loads exceed injury tolerance. In this case the load has been reduced, thereby indicating an improvement in the user's injury tolerance, which should in turn help protect spinal structures and stability.

The results demonstrated that the exoskeleton significantly reduced muscle activity of the Bicep Femoris by 5%. Thus, the exoskeleton had a large effect on back muscle activity and a marginal effect on hip extensor activity. Similar findings were previously noted for two passive exoskeletons: PLAD and Laevo (Bosch et al., 2016).

It was unclear at the outset what the overall net effect on the body would be, especially for the legs/thighs considering the mass of the exoskeleton and the torque applied at those points. The results indicated the exoskeleton did not have an effect on perceived leg exertion for either load. Thus, participants rated the effort of the legs to be similar with and without the exoskeleton, which is interesting considering the added weight on the user. Furthermore, while RPE was not significant for the lower limbs for both loads, perceived exertion of the legs was on average less wearing the exoskeleton than without. This, in conjunction with the reduced Bicep Femoris muscle activity, indicates the exoskeleton has preferable lower body loading than other exoskeletons, such as BNDR, HappyBack and Bendezy, which have indications of high lower body loading during use (Barrett and Fathallah, 2001; Ulrey and Fathallah, 2013).

User assessment of the exoskeleton

The exoskeleton applied highest pressure to the trunk, followed by the thighs, and the least on the shoulders. Additionally, pressure on the thighs and shoulders increased for the heavier load. This trend was also observed in the LLP scores for all three body areas. This result was likely due to the increased moment and muscle circumference generated by the user to lift the heavier load.

Pain is a warning sign of damage caused by excessive contact pressure, and likewise a good indicator of potential cell damage and death (Fransson-Hall and Kilbom, 1993). The point at which a user begins to feel pain and develops lesions is often referred to as the Pain Pressure Threshold (PPT), which has been measured as occurring at around 280kPa - 480kPa (Pons, 2008; Tamez-Duque et al., 2015). The maximum pressure observed in this study was 93.6kPa, which falls below the PPT levels, suggesting the device does not pose a problem to workers with regards to pain sensation and tissue damage, at least in the short-term (Tamez-Duque et al., 2015). This was also supported in the LPP scores where the highest pressure was rated as *Somewhat Strong* (44% of maximum) for the Upper Legs and *Light* for the Back/Shoulders and Belly/Hips. However, it should be noted that LLP was only measured over five lifting cycles. Unlike contact pressure, we would expect LPP to increase with longer duration use as would be the case in industry.

In contrast to contact pressure, LLP scores were highest for the upper legs (*Somewhat Strong*). This was also observed for the Hybrid Assistive Limb exoskeleton (Nilsson et al., 2014). For both of these devices, some participants pointed out that the connection cuffs at the thighs were too tight during use. The circumference of the thigh expands during muscle contraction. This could explain the increased LPP scores for the thighs. One might expect that we could simply loosen the cuffs. However, this is not currently feasible with this anthropomorphic exoskeleton as the circumference of the thigh will continually change during movement and it needs to be securely attached to the thighs. Thus, at certain stages during the activity the cuffs could be too slack allowing them to alter their position on the thighs. If this occurs, the force applied to the leg would produce an instability, thereby resulting in decreased assistance and potential risk of injury. Alternative materials and attachment solutions should be explored to consider this design challenge.

Even though the LPP scores were not considered excessive, over a longer duration of use they are expected to increase. Dispersing pressure over a larger area is a common approach to reducing discomfort in exoskeleton design (Pons, 2008) but this does not entirely resolve the compression issue and design solutions should again explore ways to also address this challenge. For instance, the current attachment cuffs comprise single elastic Velcro straps positioned in the middle of the thigh. Proximal and distal ends of muscles do not expand nearly as much as the central belly. An alternative could be to have two separate smaller cuffs at either end of a larger cuff with greater flexibility in the mid-section. It should be noted that the skin on the upper inner thigh is highly sensitive, thus this design may cause discomfort if the skin is pinched. Alternatively, the cuffs could comprise of soft pads. This was implemented on the DGO exoskeleton to prevent pressure sores (Colombo et al., 2000). Soft pads will, in theory, accommodate muscle size fluctuations during movement.

Backpacks are a common accessory used by individuals daily. This could explain the conflicting results between contact pressure and LPP scores, as users are familiar with the pressure being exerted on the back compared to pressure being applied around the thighs. Additionally, the straps of the back unit comprised soft pads to minimize discomfort. As detailed above, the skin on the inside and upper thighs is more sensitive than the skin on the trunk, thus pain or discomfort would be perceived higher (Pons, 2008).

A majority of the participants rated the exoskeleton as having acceptable usability. The users, which rated the device below the required criterion, found it to be either complex to use, or that at times the movements were not always completely consistent with their natural movements. From a design perspective, these factors need to be addressed both through the mechanical and sensor design, and also in the system software controls, which control the fluidity of the movements.

Limitations

Due to safety precautions, only five lifting cycles were recorded as the main treatments. This is not a true reflection of an industrial working day. Now that we know the exposures with the current design, future testing can include longer duration testing. This will allow for a more accurate assessment of the interaction between user and device, especially LPP scores. A larger sample size including experienced manual handling workers is necessary to ascertain the usability of the device for the working population. Furthermore, females should be assessed, as their body sizes and capabilities differ to those of males. The assessment of additional muscles, particularly of the lower limb, should be considered to inform a more complete understanding of the risks. The task performed was conducted in the sagittal plane. However, in industry, the task may include asymmetric twisting and walking.

5 Conclusions

The exoskeleton significantly reduced back muscle activity (12%-15%) and perceived trunk exertion (9.5%-11.4%), implying reduced lower back loading. Additionally, the exoskeleton assisted with hip extensor torque as evidence of the significantly decreased Biceps Femoris muscle activity (5%). To our knowledge, this exoskeleton is possibly the first active exoskeleton indicating a statistically significant reduction in Erector Spinae muscle activity in addition to hip extensor assistance for dynamic lifting and lowering tasks. There was no evidence of increased body loading, in fact the exoskeleton appears to have preferable lower body loading. Contact pressure values fell below the PPT, where both discomfort and usability are approaching acceptable levels. In the near future, wearable sensor and robotics devices, such as this and next generation exoskeletons, have the potential to be useful tools to assist workers with industrial lifting tasks, especially if assistive torque is further increased. This study demonstrates the need for strong emphasis on design ergonomics to ensure such technologies are comfortable and have high usability through their design, in order to ensure they are suitable and desirable for workers to use.

6 Acknowledgements

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The application of 3D printing to create high-fidelity anatomical models for physical surgical simulators

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Abstract

There is relatively little research on the use of 3D printing to support ergonomics in healthcare innovation. This current study uses 3D printing to improve the realism of usability testing during medical device design. Currently, usability testing of prototype surgical medical devices is often, at best, limited to studies with basic hollow silicone anatomical models, which are of a single material, and not a direct resemblance of actual diseased state anatomies. The aim of this research was to develop an anatomical simulator for early stage usability testing of endovascular surgical devices using direct replicas of real diseased anatomies from patient scans, rather than off the shelf basic idealised models. We performed a case study to recreate a patient's Abdominal Aortic Aneurysm (AAA) from CT scans. A protocol was developed to digitally recreate anatomically accurate compound models of the AAA, to include aortic thrombus and calcifications. The anatomical models were 3D printed in a range of soft and hard materials, to mimic patient tissues. They were subsequently integrated into a portable pulsatile flow simulator comprising real-time haemodynamic monitoring and a simulated fluoroscopy imaging for usability testing.

1. Introduction

The ultimate goal of any medical device is to improve the well-being of the person receiving treatment (Sharples et al. 2012). However, medical technologies often fail to deliver their intended benefits when they are inadequately designed to match the needs of the intended users (Fairbanks and Wears 2008). A hospital-based review by Sarker and Vincent (2005) found that patients were unintentionally harmed in up to 4% of hospital admissions. Of that cohort, 48% were associated with a surgical intervention and 54% of these adverse events were deemed preventable. Early stage Usability Testing (UT) to design robust, safe and effective medical devices has become a significant focus to reduce the potential for human error.

Measuring and fulfilling user requirements during medical device development results in successful products that help improve patient safety, improve device effectiveness and reduce product recalls and modifications (Jennifer et al. 2006). To achieve this, UT is applied from the earliest opportunity through to validation testing prior to market launch (Alley 2014, FDA 2011). Validation of medical devices should include laboratory testing to evaluate device efficacy, reliability, safety and performance before clinical testing begins (Weinger et al. 2010). Early stage UT relies heavily on simulation using anatomical models under use conditions to explore worst case scenarios, complex failures and environmental interactions, while validating medical devices (Browne and O'Sullivan 2012).

Patient simulators are now routinely used to teach medical skills, such as respiratory physiology and cardiovascular haemodynamics, and also some advanced clinical skills, such as airway management. There are several augmented reality simulators for minimally invasive endovascular surgery that are commercially available, including the Mentice Vist G5 and the Angio Mentor. These provide little to no haptic feedback during testing / training, despite the high cost of the systems. Computer-based simulators are generally unsuitable for medical device design evaluation as they cannot test physical prototypes, which is necessary for design testing purposes.

Endovascular surgery is an example of a branch of medicine that commonly uses minimally invasive medical devices. Such devices are delivered primarily into and through the vascular system. While the devices are minimally invasive, it is pertinent that they are designed to ensure safety during use. For endovascular device evaluation, the most described physical simulators include silicone anatomical models used in pulsatile flow rigs (Doyle et al. 2008, Ene et al. 2011, Lynch et al. 2013, Poepping et al. 2004, Chong et al. 1998). A key objective in the design of patient simulators is to achieve a 'suspension of disbelief' by the operator (Halamek et al. 2000). Farmer et al. (1999) defined 'fidelity' as the extent to which the appearance and behaviour of the simulator/simulation matches that of the desired system. Allen et al. (1991) proposed two dimensions of fidelity: 'Structural Fidelity' (how the simulator appears) and 'Functional Fidelity' (what the simulator does). Structural fidelity is the degree to which the simulator or environment replicates the physical characteristics of the real task. For surgical procedures and medical device testing, structural fidelity is of very high importance for the task (e.g. when interacting directly with tissue or anatomies). Functional fidelity is the degree to which the skills in the real task are captured in the simulated task. The level of functional fidelity required is dependent on the type of task and the level of training of the user. Silicone anatomical models used in pulsatile flow simulator, exhibit high functional fidelity in their ability to reproduce physiological conditions, but offer a low level of structural fidelity.

The objectives of the current research were to create replicas of real diseased patient-specific anatomies to achieve high functional fidelity, and to then integrate these into a pulsatile flow rig to achieve a physical simulator that could be used for early stage testing of endovascular medical devices. To achieve this, we A., recreated anatomical models from patient scans, B., recreated the models using multi-material 3D printing, and C., developed a portable usability test bed that uses the anatomical models and includes real time haemodynamic monitoring and simulated fluoroscopic imaging.

2. Anatomical segmenting in preparation for 3D printing

Anatomical segmentation is the process of isolating anatomical structures from medical imaging in order to produce 3D digital models. Compound anatomical models differ from basic hollow silicone anatomical models in that they can include elements such as thrombus or calcifications to enhance the structural fidelity during medical device testing or training. To create a compound anatomical model, it is necessary to segment the individual structures from a set of medical images to prepare the individual structures reassembled as a single compound model for 3D printing . The individual isolated parts of the anatomical structures can then be printed with different material properties. Efforts have been made previously to segment compound anatomical models in the literature for FEA computer simulations (Wang et al. 2002), however these models contained only two elements.

In the current research we used Mimics software (Research Version 17, Materialise, Belgium) to create the 3D models of the patient's anatomy. Anonymised CT scans of a patient with an Abdominal Aortic Aneurysm (AAA) and another with a healthy aorta were used to create the 3D anatomical models. The local research ethics committee approved use of the anonymised patient scans.

By way of example, the AAA model was created in four separate parts: 1. The true lumen, 2. Aneurysm sac, 3. Calcifications, and 4. Aortic wall. The individual parts were then combined to create a full model of the internal volume of the AAA, as illustrated in Figure 1. In addition to creating the compound anatomical models, modifications were made to the models in the Mimics sister software package 3Matic to attach rigid end ports to join the models to piping in the UT test bed (Figure 2).

The need for compound anatomical models is demonstrated in Figure 3, where the path of the true lumen is considerably more tortuous in the lower model, which includes thrombus. Basic hollow silicone anatomical models are not a true representation of the actual anatomy. The sharply angulated AAA neck, as shown in Figure 3(arrow), would be considered challenging to navigate with a 16French endovascular device.

3. 3D Printing anatomical models for simulation and training

Traditionally, aortic models for use in pulsatile simulators were made from silicone using the lost wax method (Doyle et al. 2008). This is a labour intensive method that requires extensive machining of multiple aluminium moulds. There is a significant time requirement to create the wax core, mount the core in a secondary mould, and then fill the cavity between both parts with silicone. Furthermore, the moulding approach is highly susceptible to defects such as air bubbles and uneven wall thickness.

Recent advances in 3D printing present opportunities to create replicas of human anatomies in materials with varying durometers from rigid to pliable. There are numerous 3D printing technologies available today. These include Stereolithography (SLA); curing acrylic or epoxy-based resins using a high intensity energy source; Selected Laser Sintering (SLS); laser fusing of fine grade polymer or metallic powder, Fused Deposition Modelling (FDM), which uses extruded thermoplastics, and Polyjet printing technology, which is a modified inkjet printing method.

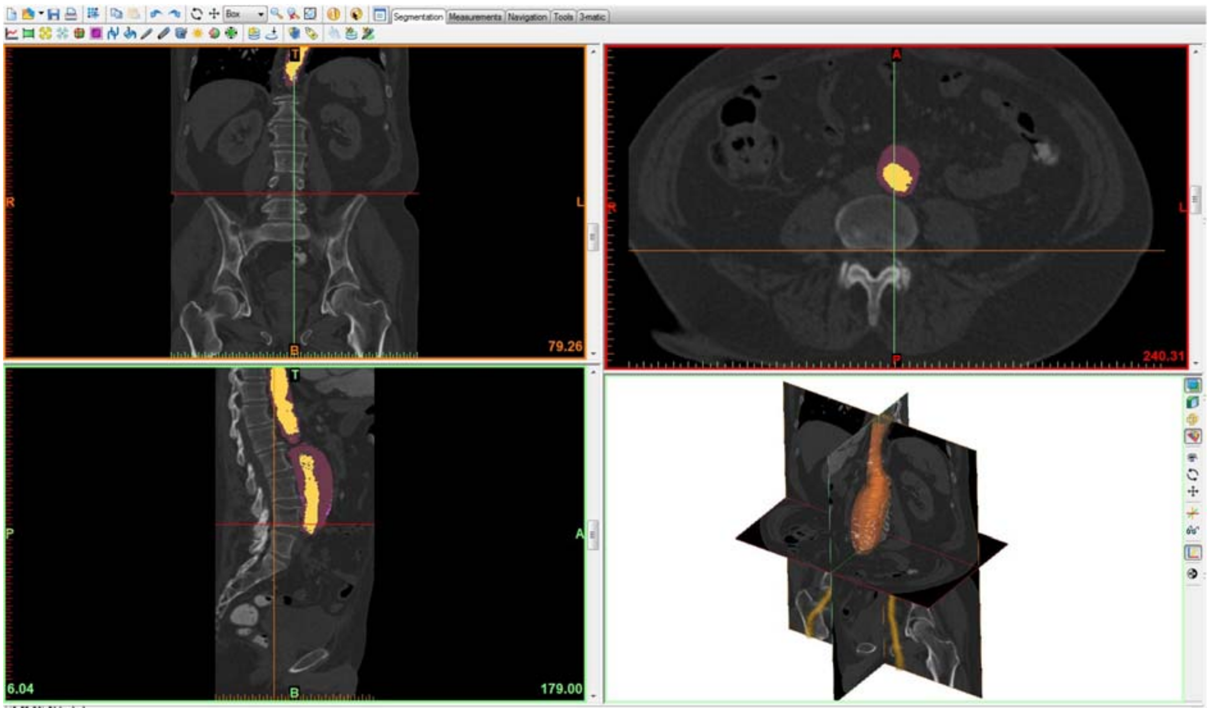

Figure 1: The user interface in the Mimics software while segmenting the model of the Abnormal Aortic Aneurysm, including the generation of the 3D model (bottom right)

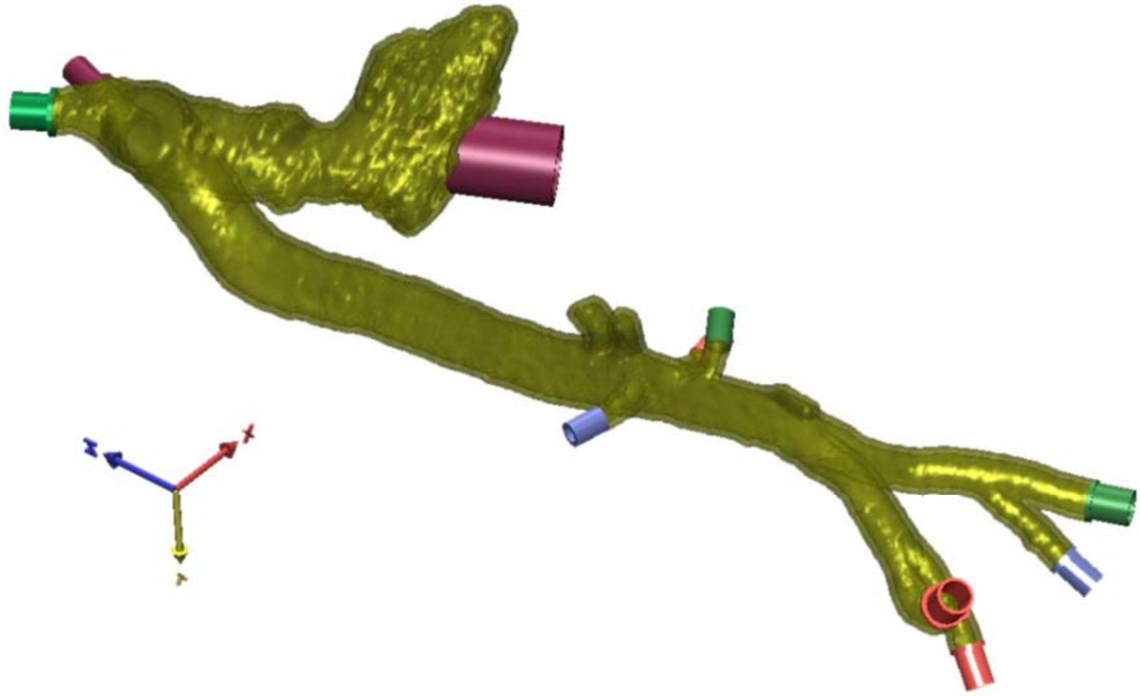

Figure 2 Model of an aorta attached with rigid connection ports for 3D printing

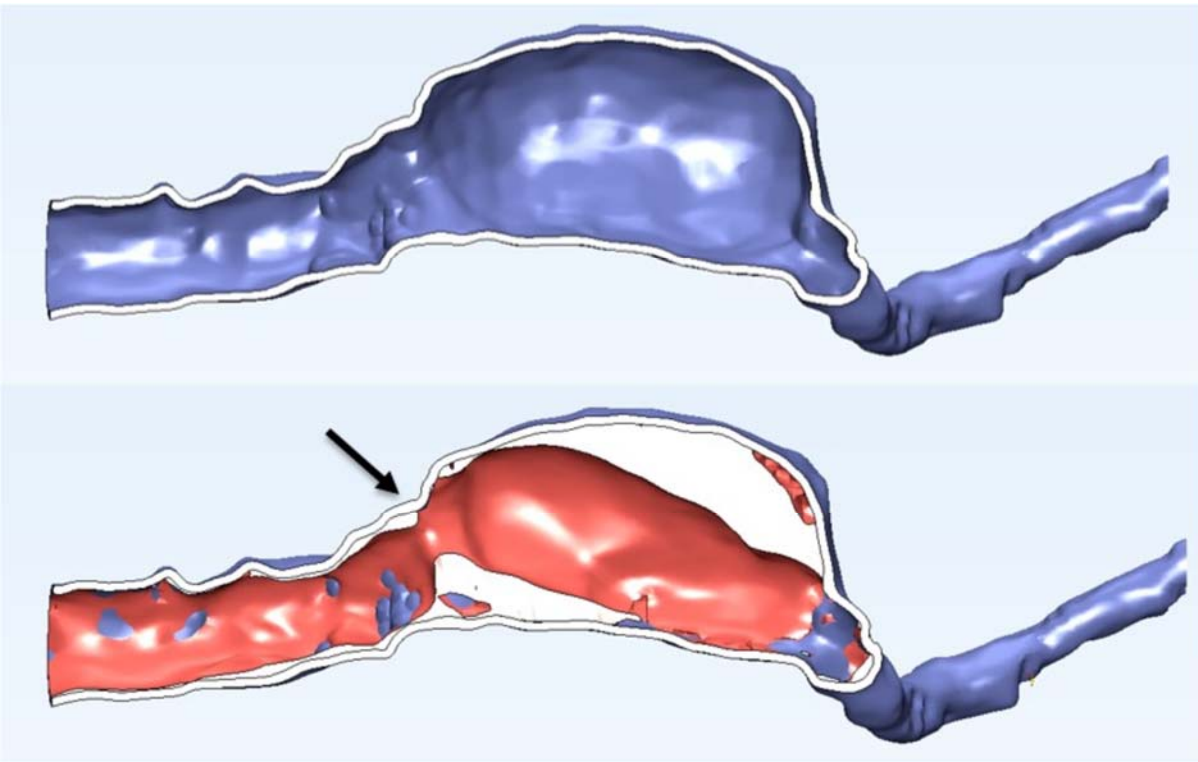

Figure 3 Cross section of the 3D model of the AAA showing the aorta wall on its own (top) and including the thrombus (bottom)

Polyjet printing is amongst the most advanced 3D printing platforms available. It works similar to a traditional inkjet printer in that two or more materials (inks) can be combined to create a multitude of secondary materials. The materials can be soft rubber like, rigid and mixed durometer, all within a single model. The Connex 500 is a polyjet 3D printer that uses two base materials (acrylic monomer resin) and a water soluble support material cured using high intensity UV light. The two base materials can be combined to create 14 digital materials with varying mechanical properties. The ability to print several materials in a single model is ideally suited to this research.

We took the compound anatomical model as shown in Figure 1 and used the Connex digital material DM_9760 for the aortic wall, TangoPlus for the thrombus and VeroWhite for the calcifications. The flexible material was based on research indicating it may be a suitable analogue for aortic tissues (Cloonan et al. 2014). Figure 4 shows the digitally segmented 3D AAA model (top) and the finished, cleaned 3D printed model (bottom).

A cross section of the digital and printed models demonstrates the material differences. Figure 5 shows the 3D model including the location of the cross section in the middle of the aneurysm (left), the digital image of the aneurysm cross section (middle), and the cross section of the 3D printed model showing the arterial wall, thrombus and calcifications (right).

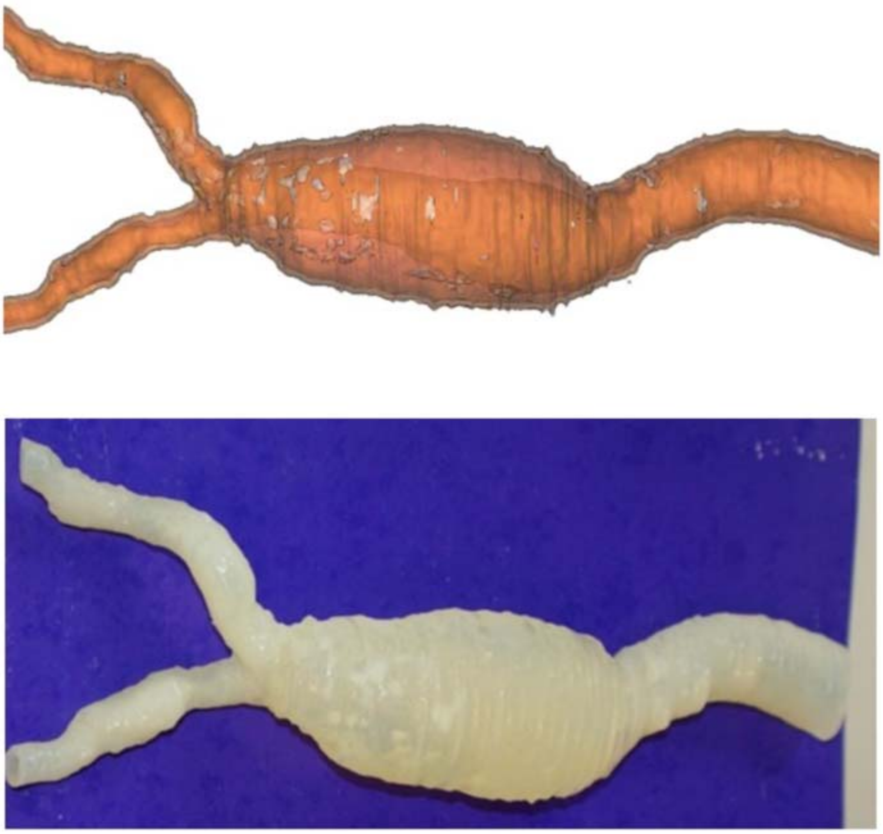

Figure 4 The computer 3D Model of AAA (top) and the 3D Printed Model (bottom)

Figure 5 The 3D Model of the AAA (L), a cross section of AAA model showing the aortic wall, thrombus, calcifications, and true lumen (R), and a section of the corresponding 3D printed model

4. Pulsatile flow simulator and vision system

A pulsatile flow simulator was designed into which 3D printed anatomies could be attached for usability testing or training with endovascular medical devices. A system level diagram for the simulator is shown in Figure 6. The simulator is a closed loop, to approximate the human cardiovascular system. The flow loops from a pump through the anatomical model and pressure control valve back to a heated reservoir. The heart rate and cardiac output (rate of flow) are digitally controlled through an integrated interface.

The interface simultaneously displays real-time pressure, flow, and temperature data, as well as a simulated ECG signal. A second monitor displays a simulated fluoroscopic image. The fully assembled simulator was built into a padded flight case for portability and can be transported readily by car.

Pulsatile flow is an essential component of any system to be used in the evaluation of endovascular devices to recreate the mechanical stresses found in the body. A reciprocating piston pump was used based on the work of Morris et al. (2013). A steel direct drive rack and pinion is powered using a stepper motor. Two one-way valves installed in opposite directions to the piston pump manifold create unidirectional flow. The length of the piston stroke determines the volume of fluid displaced, creating the required cardiac output. The piston stroke (cardiac output) and frequency (heart rate) can be adjusted digitally in real time. Systolic pressure is generated by the cardiac output (approx. 80ml/beat) while the diastolic pressure is controlled using the viscoelastic properties of the system. The anatomical model, tubing, and control valve (distal to the aortic bifurcations) generate sufficient compliance.

Figure 7 shows a full size 3D printed healthy aortic model in the pulsatile flow simulator (detailed below). The model includes the left ventricle, aortic arch, descending and thoracic aorta and bifurcation. All of the main branches of the aorta are included and can be selectively occluded depending on the devices being tested.

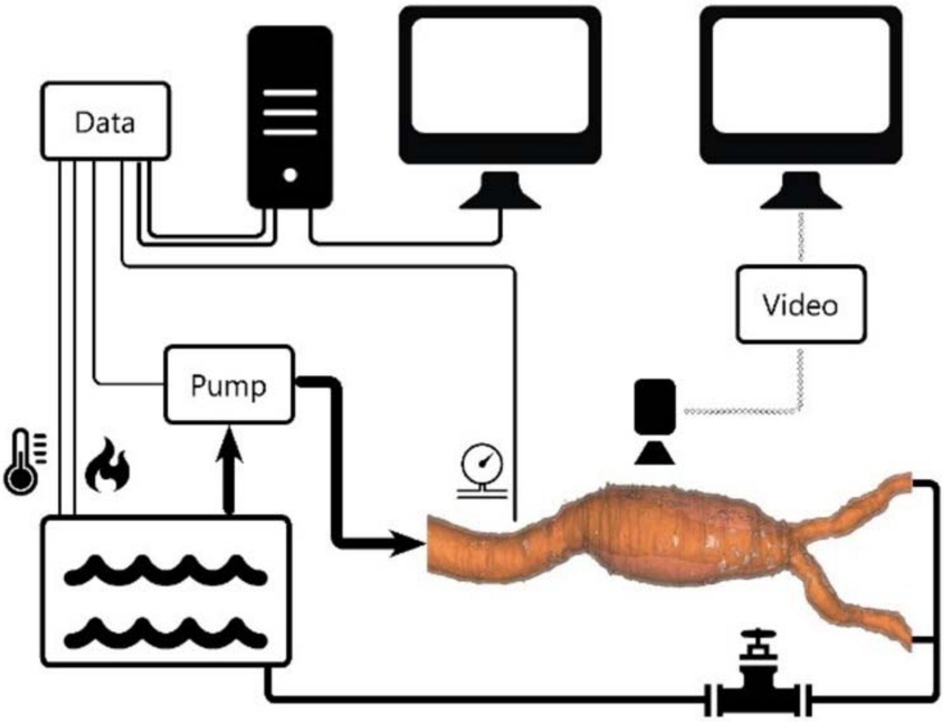

Figure 6 Schematic drawing of the pulsatile simulator

Pressure in the simulator is measured at multiple locations and displayed on the interface. To enhance the functional fidelity of the simulator while manipulating devices, a blood analogue comprising a glycerol and water mix (~44:56 ratio) with sodium chloride (~0.9%) was used (Yousif et al. 2010). Normal body temperature is maintained at a constant 37°C (+/- 0.5°C) by means of a heated reservoir and thermistor control loop.

The simulator is controlled using a combination of LabView and Arduino platforms. A Virtual Instrument (VI) was created as the interface to visualise both the input parameters (pump controls) and output haematological measurements (Figure 8: left screen). The VI was designed to approximate a typical monitoring screen found in the cath lab. The VI allows adjustment of the input parameters and monitoring of the outputs in real time.

Simulated fluoroscopy imaging was achieved using a CCD camera, converted to black and white format and the contrast / brightness adjusted to approximate the image quality of a fluoroscope. Figure 9 presents a series of on-screen images of the aortic root arteriogram at three phases of injecting contrast (black dye) to demonstrate the visualisation.

4. Discussion

3D printing in healthcare has become a useful tool for both visualising complex conditions and surgical planning (Rengier et al. 2010). The work presented here is a novel use of multi-material to improve medical device usability to reduce errors and enhance surgical treatment. A protocol to digitally segment compound anatomical models was successfully developed and patient-specific models were created, which were successfully recreated using multi-material 3D printing. While the segmenting of anatomical models is not novel, the segmenting and printing of patient-specific compound models for early stage usability testing does not appear to be previously detailed in the literature.

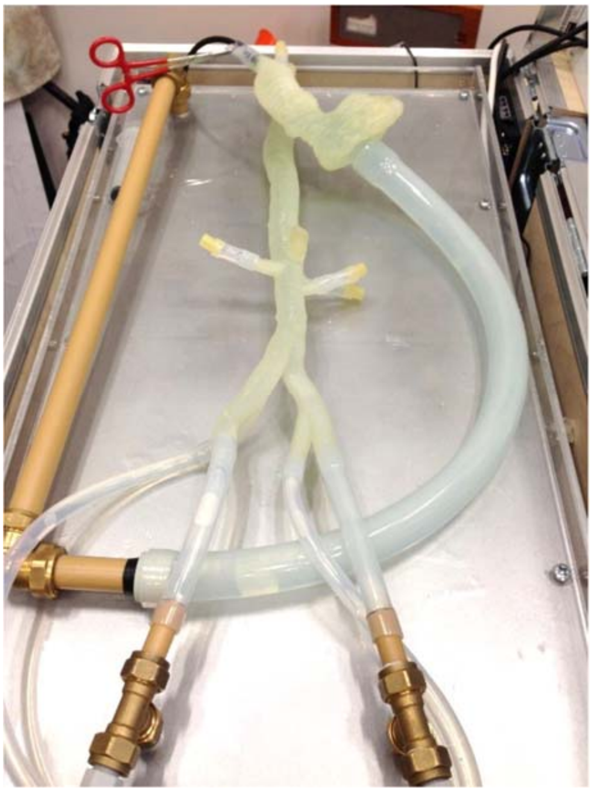

Figure 7 Image of a 3D printed aorta in the pulsatile rig

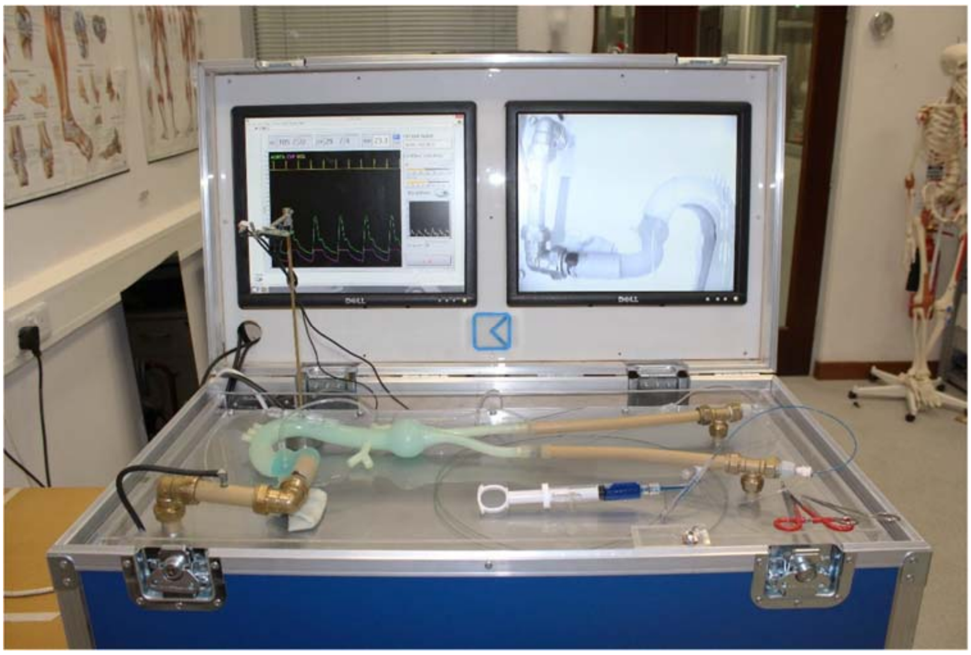

Figure 8 Front view of the endovascular simulator, in this case with a basic silicone anatomical model shown

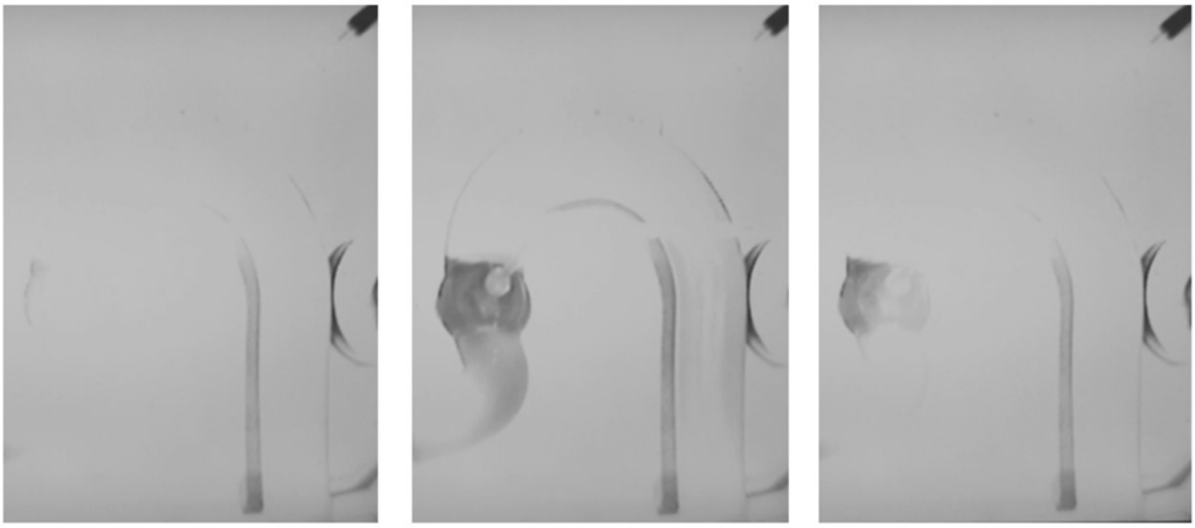

Figure 9 Simulated fluoroscopic image on the simulated fluoroscope image at three stages of injecting simulated contrast into the aortic root

Several important use case criteria are omitted when testing prototypes in basic hollow anatomical models, and this in turn can impact the validity of the simulated use testing. The reaction of vessels (such as the femoral arteries) to straightening cannot be considered valid if the presence of calcifications is omitted, as in silicone models. The current approach is an important contribution to improving the fidelity of these models and will advance the realism of usability testing.

The design and use of pulsatile flow simulators is well discussed in the literature (Chong et al. 1998, Doyle et al. 2008, Morris et al. 2013, Cloonan et al. 2014) but few have been developed for the purposes of early stage usability testing. Current simulators are generally specific to anatomical models or disease states. They are generally not portable, are inflexible for use with various anatomical models, and/or do not physiologically resemble the cardiovascular blood flow. A portable simulator, as presented, is advantageous as it can be transported to surgical experts with ease of setup on-site for testing sessions. Another advantage of the current simulator is the ease of exchange of multiple anatomical models.

Other advantages of 3D printing anatomical models, over lost wax casting, relate to time and cost. Due to the large size of the print bed on the Connex 500 3d printer, three patient specific AAA models were manufactured in a single 26-hour build period. While the polyjet technology is relatively expensive, with each model costing circa €500 - €800 in raw material, the costs are not dissimilar to commercially available hollow silicone models.

The use of real-time haemodynamic monitoring is novel in the current work over previous pulsatile flow rigs. Experimentally focused pulsatile flow rigs often measure pressure, flow and temperature. However, these are often logged rather than presented in real time. The monitor interface, as created in this work, resembles those in traditional cath-lab monitoring equipment, and as such, contributes to the structural fidelity.

Limitations

There are some limitations to the 3D printed materials presented here. As with most 3D printed materials, there can be weaknesses between the printed layers, which can lead to delamination and splitting. The TangoPlus material is slightly hydroscopic and overtime absorbs water. This leads to opacification of the material, and in thin sections, can lead to failure as the material swells and delaminates. For this reason, the use of pure TangoPlus for the aortic wall, as proposed by Cloonan et al. (2014), is inappropriate for prolonged use in contact with water. There are also issues with the longevity of polyjet materials. As the materials are UV-cured, they can degrade with time when exposed to daylight. Experiments are underway to investigate coating the finished 3D printed models to reduce this.

The quality of CT - DICOM scan images used dictates the quality of the models. For example, the segmentation of the aortic wall can be difficult for a number of reasons. The wall itself has comparable properties and density to surrounding tissues and the wall is only 1.3 – 2mm thick, making it difficult to identify. This challenge can be partly addressed using high resolution scans.

One obvious limitation of the current work is the quality of simulated imaging. The inherent difficulties of replicating X-ray imaging is a long standing challenge (Chong et al. 1998). While the quality of the simulated imaging presented here is inferior to VR simulators such as the Angio Kit or Mentice Vice, the primary purpose for UT is to avoid 'direct visualisation' of the device being tested in the anatomical model.

A further limitation of the simulated imaging system presented here is that it is continuously live. In a clinical setting the fluoroscope is only activated briefly at a time to limit the exposure of ionising radiation. Future development of the current work should include the addition of a foot pedal to start/stop the 'fluoroscopic' image as occurs in the practice.

6. Conclusions

The current research successfully demonstrated the replication of patient-specific anatomical models, including the use of 3D printing with multi-materials, to resemble the mix of hard and soft aspects of the tissues. These anatomically accurate models advance the realism and therefore fidelity of usability test simulators.

Any usability test bed for use with endovascular surgical devices should mimic physiological conditions as closely as possible. Pulsatile flow, physiological pressure and temperature are important for representative testing of such medical devices. The simulator presented is anatomically accurate relative to specific disease states, and also physiologically resembles blood flow, pressure and temperature. The portability of the current simulator, coupled with physiological and anatomical resemblance to the human anatomy, is an improvement on contemporary simulator designs. It can be used for UT and also medical device training.

3D printing using Polyjet multi-materials represents a new paradigm for the production of anatomical models for usability testing of medical devices. While the work presented here is primarily focused on usability testing, use of this new approach could extend further into surgical training, surgical planning, demonstration and other medical experimental applications.

7. Acknowledgements

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Carpal Tunnel Syndrome's Cyberpsychological Advancement

Stella Marie Rostkowski, Ph.D.

Abstract

Research for this study was aimed at learning how the effects of being socially ostracized at work by co-workers for having Carpal Tunnel Syndrome (CTS) affected an employee with CTS ability to complete an employer-sponsored Return to Work (RTW) program. Through the use of semi-structured interviews, open-ended interviews, and observations, 12 employees with CTS in three separate companies described the influence and impact their co-workers bullying efforts had physically, socially, psychologically and psychosomatically in their workday and brought individuality to the effects CTS has socially in the workplace. When seen through an interpretivist lens, the stories and recollections from the 12 participants in this study brought an undiscovered insight and individuality to the effects CTS has socially in the workplace.

Introduction

Current research on CTS considers the employees from either a case study perspective or a phenomenological perspective. Research has shown that case studies surrounding CTS centered on one of two aspects of the disease. First, a case study may concentrate on what CTS is and what the employees did in order to contract CTS (Atroshi, Lyren, & Gummeson, 2009; Giersiepen, & Spakkek, 2011; Hammond, & Harriss, 2012). The second approach involves measuring how fast the employees returned to work and how effective they were at their jobs once they returned (Baldwin & Butler, 2006; Butler, 2002; Fevre, Robinson, Lewis, & Jones, 2013). Phenomenological studies emphasized the employees' fear of the unknown and how they contended with their fear (Brotheridge & Lee, 2010; Cano, Leong, Heller, & Lutz, 2009; Cho, Zunin, Chao, Heiby, & Mckoy, 2012; Dae-seok, Gold, Kim, 2012). Research showed that employees' fears centralized around future employability prospects and meeting financial obligations (Brotheridge & Lee, 2010; He, Hu, Yu, Gu, & Liang, 2010; Jenkins, Watts, Duckworth, & McEachan, 2012; Koh, Moate, & Grinsell, 2009).

Personal feelings were evident in research, which showed that CTS places stress on both the employee and the employer. Employee stress involves the employee's balancing a combination of multiple fears while trying to regain a semblance of their former life back (Dale et al., 2003). Multiple fears for the employee occur in a cycle, which starts and ends with the fear of job loss and also includes job satisfaction and future employment opportunities. Encompassed in the employee's fear circle is the impact that the job loss, loss of job satisfaction, and future employment opportunities will have on their private life (Dale et al., 2003).

Studies have also shown that employees who felt pressured into returning to work have sabotaged their employer's efforts in RTW programs in what is known as "worker comp return-to-work drama" (Butler, 2002, para. 6). According to Butler (2002), this is a direct "psychological impact" para. 17) imposed by CTS, because employees feel helpless against their injury. Employees are afraid to return to work, because they are afraid that their injury will return, and that their careers will end (Pransky, Benjamin, Hill-Fotouhi, Fletcher, & Himmelstein, 2002). The employees now associate their injury with their employer and their place of work. Employees inflicted with CTS encounter disease-inflicted limitations. As a direct result of these limitations, employees with CTS work twice as hard to prove their self-worth to their employers and co-workers (Brouwer et al., 2009; Cöté & Coutu, 2010; Gravel et al., 2010; Heijbel, Josephson, Jensen, Stark, & Vingard, 2006). In the employees' minds, they have to prove to everyone, including themselves, that they can still do their jobs (Pransky et al., 2002).

Employers experience stress from a financial perspective. Research showed that CTS claims cost employers “over $4,000 per claim” (Faucett, Blanc, & Yelin, 2000, para. 4). Included in this cost is the hiring of temporary personnel to replace the injured worker while they are at home recuperating from their injury (Faucett et al., 2000). Research showed that employer bias against employees with CTS is due to its medically imposed restrictions (Faucett, Blanc, & Yelin, 2000; Vickers, 2009; Welch, Haile, Boden, & Hunting 2010), which are placed on the employee and to which the employer must adhere (Holmgren & Ivanoff, 2007). Holmgren and Ivanoff stated that the reason employers have this type of bias is because they feel trapped by the societal constraints of this disease, which state the employer has to allow the employee with CTS the right to work a reduced work schedule and find tasks that they can perform. In the employer’s mind, this does not make good financial sense while trying to keep their budgets intact.

Literature Review

Musculoskeletal disorders (MSDs) remain a substantial concern at work and result in considerable personal and societal burden” (Wells, 2009, p. 117). The societal burden of CTS and the discrimination against employees with CTS have been well documented and shown to be prevalent in workplaces today. Studies revealed that employers have gotten more sophisticated in their discrimination tactics, and their tactics are deemed socially acceptable because there are no laws that state otherwise (Egan, Bambra, Petticrew, & Whitehead, 2009; Einarsen, Hoel, Zapf, & Cooper, 2011).

However, because of the lack set regulations for return to work programs (RTW), most organizations deem this as another inconvenience associated with this disease and employ various sabotage methods to thwart the employees’ progress in the RTW. Studies showed that this was accomplished through bullying, demoting the employee with CTS, and various humiliation tactics, which increased with intensity over time, such as gossiping, spreading rumors, and mobbing in order for organizations to rid themselves of this inconvenience.

Financial

The financial inconveniences noted by employers included the cost associated with the Workers Compensation claims for the employees with CTS (Theberge & Neumann, 2013) and having to hire temporary workers, who have to be trained to do the injured employee’s job (May, Li, Mencl, & Huang, 2013). Opsteegh et al. (2009) argued that the financial implications, inconveniences, and disruptions brought on by having an employee with CTS in the workplace directly related to the employer’s being predisposed to bias against employees with this disease.

Multiple studies made the argument that because employees spend a good portion of their day at work, any negativity caused by work will eventually manifest itself in symptoms that are felt mentally and exhibited physically in the employee (Gilbreath, 2012; Hasselberg, Jonsdottir, Ellbin, & Skagert, 2014; Nixon, Mazzola, Bauer, Kruger, & Spector, 2011). Mental and physical symptoms directly linked to workplace stress included “gastrointestinal problems and sleep disorders” (Nixon et al., 2011, p. 1), panic attacks (Shoss & Shoss, 2012), increased musculoskeletal injuries (Koukoulaki, 2013; Melin & Harriss, 2010), depression (Koukoulaki, 2013), exhaustion (Hasselberg et al., 2014), anger, frustration, increased sick days (Jacobsen et al., 2014), and higher employee turnover because employees quit from being forced to work longer hours over an extensive time frame (Koukoulaki, 2010; Melin & Harriss, 2010). Because of the continual downward spiral of mental and physical effects, employers were forced to look at other means to maintain their bottom line.

Societal Influence

Societal induced pressures of keeping budgets intact, and minimalizing the appearance of CTS in the workplace in an attempt to maintain the "social model of disability" (Fevre, Robinson, Lewis, & Jones, 2013, p. 288) resulted in the magnification of the predisposition that employers have towards employees with CTS (Opsteegh et al., 2009). Research showed that there was a significant financial commitment from the employer to implement a RTW program into the workplace (Knauf et al., 2014; Stahl, Toomingas, Aborg, Ekbreg, & Kjellberg, 2013), which included paying overtime to employees for working additional hours and hiring an Occupational Rehabilitation specialist. In instances where employees were unable to return to their original positions because of their injury, the employer viewed this as a negative and counter-productive, because in addition to having to retrain, or transfer the employee to do another job, the employer had to permanently replace the employee with CTS and train a new employee. In the employer's mind, the amount of time and effort required to assist one inured employee, versus hiring a new employee was more than they were willing to commit to. Because there was not a significant financial increase and productivity decreased due to the additional effort required by co-workers working additional hours, most employers abandoned their RTW programs before fully giving them a chance to produce the outcome they were looking to achieve.

Multiple studies by Opsteegh et al. (2009), Fevre et al. (2013), Samnani and Singh, (2012), and Wheeler, Halbesleben, and Shanine (2010) argued that because of the pressure employers received from societal influence, employers indirectly work against employees with CTS's healing processes and concentrate their effort towards eliminating employees with CTS from their organizations. Societal influences discussed the lengths employers were willing to take in order to avoid having CTS in their workplace, which included hierarchal bullying.

Hierarchal Bullying

Hierarchal bullying is an "abuse of power" (Schumann, Craig, & Rosu, 2014, p. 846), which is directly aimed at forcing the employer's will onto the employee by getting the employee to submit to what the employer wanted through psychological mind control and manipulation (D'Cruz & Noronha, 2010; De Cuyper, Baillien, & De Witte, 2009; Einarsen et al., 2009; Einarsen et al., 2011; Finne et al., 2011; Schumann et al., 2014). Hierarchal bullying "encapsulates a series of systematically negative acts that derive into social, psychological, and psychosomatic problems for the victim" (Montes, Muniz, Leal-Rodrguez, & Leal-Millan, 2014, p. 2659). Research showed that employer bullying starts with the first bullying action of public and private humiliation (Finne et al., 2011; Gumbus & Lyons, 2011; Hauge et al., 2010). Once the employer had successfully humiliated the employee, efforts were increased to sabotage the employee's work and discredit the employee with co-workers (Hoefsmit et al., 2013; Hogh et al., 2011; Idris et al., 2014; Law et al., 2011).

Public and private humiliation begin with employers degrading the employee at work in front of other co-workers and colleagues in order to discredit the employee in front of their co-workers and make them uncomfortable around the employee (Agervold, 2009; Idris et al., 2014; Law et al., 2011). This enables the employer to isolate the employee (Armstrong, 2011; Atkinson, 2014; Baillien et al., 2011) and prevent them from gaining support or sympathy from their co-workers (Baillien et al., 2011), which could later be used to sabotage the bullying managers' efforts.

Several studies showed that employers sabotage employees' work by interfering in its progress (Agervold, 2009; Roscigno et al., 2009a), being overly critical of the work (Atkinson, 2014; Roscigno et al., 2009a; Rugulies, 2012), and giving the employee an assignment that they know the employee will not finish on time (Roscigno et al., 2009a; Selenko & Batinic, 2013). The employer does this in order to create and show a pattern of the employees' work performance, which can be used to maintain control over the employee through denying vacation, or sick days, promotions, or allowing the employee to transfer to another department (Selenko & Batinic, 2013; Sloan, Matyiok, Schmitz,

& Short, 2010). Studies showed denying employee transfers to other departments was one of the severest of manipulations and bullying tactics on the employers part because it invoked helplessness, desperation, and made the employee feel that they had no control over the situation. Research showed that the employee felt hopeless and stuck in their position (Sloan et al., 2010; Stojanova, 2014; Tracy, Lutgen-Sandvik, & Alberts, 2006; Vie, Glasø, & Einarsen, 2010; Wheeler et al., 2010).

Managers have also sabotaged an employee's work efforts in order to discredit the employee with their co-workers (Idris et al., 2014; Law et al., 2011). The manager starts by talking behind the employee's back to other co-workers about the employee's performance and uses key buzz words or phrases to invoke a negative response from the employee's co-workers. Research showed that this sabotage removes any chance of the employee gaining support or sympathy from their co-workers when the bullying intensifies (Idris et al., 2014; Law et al., 2011; Vickers, 2009; Wiedmer. 2011).
Studies showed that hierarchal bullying exists in the workplace today, because this type of management style has been engrained into the organizational culture and is now accepted as the norm (Roscigno et al., 2009b; Vickers, 2009). Employees who are bullied at work by their managers are often isolated, because other employees fear the same reprimand or fate from management and engage in the bullying efforts in order to avoid being victimized as well (Agervold, 2009; Spielberger & Rehiser, 2009). According to the Workplace Bullying Institute (2014), hierarchal bullying exists and thrives in the workplace because of fear:

> Fear of being the next target; fear of not helping correctly and botching it; fear of being the only one from a group to act; fear of retaliation by the bully; fear of loss of one's job and income. Thus, for coworkers as well as targets themselves, the workplace becomes a fear-plagued environment. (para. 7)

Studies also showed if the employee complained to upper management or human resources, the employee was viewed as "anti-organizational" (Vickers, 2009, p. 262) and their claims were dismissed. Employees who complained about being bullied at work to upper management or those who attempted to file complaints against their managers were subjected to increased bullying efforts by their managers, which included "intimidation and threats of physical violence" (Vickers, 2009, p. 264). Because this is a power struggle from the top down, the employees with CTS are forced to do what their managers want them to do or risk reprimand and termination. The managers continue their bullying efforts until the employees submit (Roscigno et al., 2009b; Samnani, & Singh, 2012; Sloan et al., 2010; Vickers, 2009). In the employees' minds, the only way to get away from this type of persecution is to quit their job (Roscigno et al., 2009a; Sloan et al., 2010).

The effects of hierarchal bullying cause the bullied employee to experience a chain reaction of social, psychological, and psychosomatic symptoms and events in their professional and personal lives (Bartlett & Bartlett, 2011; Glasø, Nielsen, Einarsen, Haugland, & Mattheisen, 2009b; Hauge et al., 2010; Nixon et al., 2011;Tuckey, Dollard, Hosking, & Wienfield, 2009) that were found in numerous studies. Studies showed that employees who were bullied by their managers have a hard time socially trusting co-workers and colleagues in other positions (Bartlett & Bartlett, 2011; Glasø, Nielsen, & Einarsen, Haugland, & Mattheisen 2009b; Hauge et al., 2010; Tuckey et al., 2009) because the employer-employee work ethic was broken (Nixon et al., 2011; Roscigno et al., 2009b; Samnani & Singh, 2012). In the bullied employee's mind, work is supposed to provide opportunities for growth and advancement, not serve as the breeding ground for organized harassment, social injustice and inequities, and make you ill (Nixon et al., 2011).

The effects of being socially discredited and humiliation by their manager and co-workers causes the bullied employees to change their personality and forces them into isolation (Gholipour, Sanjari, Bod, & Kozekanan, 2011; Glasø et al., 2011). Numerous studies stated that because of the repeated abuse and humiliation endured socially for extended periods of time, bullied employees have high amounts of stress, anxiety, appear to be nervous all the time, and are insecure about their job (Gholipour, Sanjari, Bod, & Kozekanan, 2011; Vickers, 2009). Bullied employees were reported to have developed coping mechanisms such as grinding their teeth (Roscigno et al., 2009b; Vickers, 2009), nervous twitches (D'Cruz, & Noronha, 2010; Roscigno et al., 2009a; Vie et al., 2010) and developed dependency on "psychotropic drugs" (Niedhammer, Simone, Degioanni, Drummond, & Philip, 2010, p. 152).

In their personal lives, the continued and constant exposure to being bullied at work causes the employee to pull away from their spouse or partner both physically and sexually because they feared being rejected by them as well (Nielsen et al., 2012; O'Reilly & Aquino, 2011; Rugulies, 2012). In cases where extreme bullying occurred, bullied employees reported having thoughts of suicide because they felt this was the only way out of their oppression (Hinduja, 2009).
Research showed that the combination of psychological and psychosomatic effects of hierarchal bullying were traumatic to the bullied employee. Bullied employees reported developing depression, anxiety, (Murray, 2013; Nixon et al., 2011), irritability (Martin & Martin, 2010; McFarlane, 2013; Murray, 2013), and digestive disorders, such as Irritable Bowel Syndrome (Hogh, Hoel, & Carneiro, 2011; Martin & Martin, 2010). In extreme cases of hierarchal bullying, bullied employees developed Post Traumatic Stress Disorder (PTSD) and had to drop out of the work force because they were not able to distinguish their past experience of being bullied at work from their present job (McFarlane, 2013).

Financial Effects of Bullying
Workplace bullying proved to be a "key ethical problem in the modern workplace" (Boddy, 2011, p. 367) and had the opposite effect of what managers were trying to accomplish by bullying their employees into conforming (Montes et al., 2014). Studies showed that the social, psychological, and psychosomatic effects of employer bullying affected the organization's bottom line because of the waterfall of effects that bullied employees experience socially, psychologically, and psychosomatically (Agervold, 2009; Roscigno et al., 2009b). While minimal literature addressed the exact financial losses organizations experience due to bullying, literature implied that the losses to productivity (Atkinson, 2014; Vickers, 2009), employee turnover, excessive absenteeism, loss of product knowledge, and having to hire new personnel cost organizations between "6 to 36 billion" dollars (Stojanova, 2014, p. 149) annually.
Research also showed that bullied employees were not the only ones isolated and socially traumatized by workplace bullying (Ahlstrom et al., 2013; Dunstan & MacEachen, 2013). Studies showed bullying affects co-workers socially, psychologically, and psychosomatically as well. Employees left behind after their bullied co-worker left reported fear of who was going to be the next bullied target or victim, decreased morale (Beirne & Hunter, 2012; MacIntosh, 2012), increased job insecurity, psychological and physical stress levels (Davidson & Harrington, 2012; Gumbus & Meglich, 2012; Law et al., 2011; MacIntosh, 2012), "job burnout" (Georgakopoulos, Wilkin, & Kent, 2011, p. 5), and eventually they began to experience and exhibit some of the same symptoms and ailments that their bullied co-worker did (Idris et al., 2014). Researchers stated this progression was caused by a combination of viewing their co-worker under stress and the guilt the co-workers felt for not helping the bullied employee (Dunstan & MacEachen, 2013; Idris et al., 2014).

Employer bullying also jeopardized the reputation of the organization (Armstrong, 2011; Gumbus & Lyons, 2011; Hollins Martin & Martin, 2010; MacIntosh, 2012; Wiedmer, 2011) because of numerous lawsuits filed by bullied employees. While research showed that three-fourths of the lawsuits filed against employers for bullying were ruled in favor of the employer, the social effects of the law suit itself caused doubts about the organization with their clients (Appelbaum et al., 2012; Gumbus & Meglich, 2012).

While research leant heavily in favor of enacting an anti-bullying law, it can be argued that bad management is everywhere and some are worse than others. Additionally, it can be argued if the employees are truly miserable at work or feel they are being treated unfairly, they do have the right to seek employment elsewhere. In instances where the employee is socially, psychologically, and psychosomatically damaged, counseling and therapy is recommended to help undo the sociological, psychological, and psychosomatic damage that was done before the employee starts a new job in order to help alleviate the symptoms and put the experience in the past.

Additional research is recommended to learn how much employer bullying does physically cost an organization annually. Research findings can then be used and presented to upper management as an argument for instituting anti-bullying programs within the organization. Because of the devastating effects bullying has caused in the workplace, further research is recommended which would examine the influence other areas of the organization can have on preventing bullying.

Study Purpose

The purpose of this constructivist grounded theory study was to discover how the physical, social, and emotional effects of carpal tunnel syndrome (CTS) affect employees with CTS's ability to complete an employer-sponsored return to work (RTW) program at their place of employment. This was accomplished using a constructivist approach to examine relationships between employees and their managers. The results found in these relationships were compared to the business needs, healthcare needs, and personal needs showing how they compared, contrasted, and coexisted with each other. Participants in this study consisted of 12 employees with CTS in three separate companies who were participating in their employers' RTW programs. The purpose behind using three separate companies was to show the differences and similarities within the study between participants and employers as they relate to CTS.
The guiding question for this study was,
How do the effects of employer's bias towards employees with CTS affect the employee's successful completion rate of a RTW program?

Constructivist Grounded theory provided the methodological framework for investigating the research questions because of the individuality brought to the study through each of the participants' experiences. When seen through an interpretivist lens, the participants' individuality helps to reveal the essence of societal influence towards the shaping of a RTW program for employees with CTS. By using this method, the researcher was able to contrive theories by "learning about the experience within embedded, hidden networks, situations and relationships" (Creswell, 2009, p. 65).

Methodology

Qualitative research does not seek to define social existence. Rather, qualitative research shows how individual social identities exist though the thoughts, feelings, and stories of the participants' social, psychological, and psychosomatic experiences. Though the participants' thoughts, feelings, emotions, and fears, an individual story emerges. Research has shown when multiple individual stories emerge and centralize around one or more ideas, a pattern emerges that can take the researcher to the depths of the participants' most inner thoughts, feelings, fears, and motivations to investigate why they responded or reacted a particular way, in a particular situation, on a particular day (Maxwell, 2012; Merriam, 2009; Ritchie et al., 2013).

This study used a constructivist grounded theory methodology to learn about the participants' individual experiences. Constructivism "asserts that realities are social constructions of the mind, and that there exist as many such constructions as there are individuals" (Guba & Lincoln, 1989, p. 43). Charmaz (2014) argued that data does not provide a window on reality. Rather, reality is discovered from the "interactive process and its temporal, cultural, and structural contexts" (p. 524). Therefore, in the case of this study, bringing individualized morals, values and ethics into the examination of the RTWs will reveal the impact societal influence has in the workplace. Through the use of an interpretivist lens, "mere statements of uniformities of social behavior in responses to social influences" (Guba & Lincoln, 1989, p. 12) can be captured and depicted and used to illustrate the direct influence on the outcome for an employee with Carpal Tunnel Syndrome in a Return to Work program. Because the workplace is made up of "multiple individual realities influenced by context" (Mills et al., 2006, p. 7), these relationships have to be explored to understand why employees with Carpal Tunnel Syndrome think, feel, and react the way they do in an employer-sponsored Return to Work program.

Sampling

The population for this study consisted of 12 people in three separate companies who have been afflicted with CTS and were absent from work for an extended period of time in order for their injury to heal. Participants in this study were either returning to work after their extended absence or had returned to work within the last 45 days and were actively participating in their employer's RTW program. In order for employees with CTS to participate in this study, they had to provide proof of a previous licensed physician's diagnosis of CTS.

Data Collection

Data collection took place over a three-month period. Nine out of 12 participants' interviews took place in person; three of the interviews took place via Skype because the participants could not travel to meet for an interview. Participants in this study answered semi-structured and open-ended interview questions about their experience with CTS in the workplace, how they dealt with having CTS in the workplace, how they were treated in and out of the RTW program by their employer and co-workers, and why they felt their disease had a direct impact on how they were treated by their employer and co-workers. In conjunction with the semi-structured interviews, observations served to confirm or question the participants' responses and shape the open-ended interview questions.

Instrument

Data collection instruments for this study were (a) semi-structured interviews, (b) observations, (c) and open-ended questions. Semi-structured interviews served as the foundation for the creation of open-ended questions. The purpose of the semi-structured interviews was to learn about the initial background of the participants' experience with CTS in the workplace. Observations, in conjunction with the semi-structured interviews, confirmed or supplemented the participants' responses. Observations also suggested open-ended interview questions.

Open-ended questions used for the interviews allowed participants to open up about their experience of how they dealt with having CTS in the workplace, how they were treated in and out of the RTW program, and why they feel they were treated the way they were. Direct questions were only used for clarification purposes. The open-ended questions utilized a conversational style and were intended to make the participant comfortable and at ease discussing their feelings about their injuries and how they felt they were treated at work and within the RTW program.

Semi-structured interviews, observations, and open-ended research questions gave participants the ability to open up about their experiences. This in turn addressed the research questions and illuminated how the effects of the psychological, psychosomatic, and sociological served as the exposition of why a participant acted and reacted the way he or she did within the Return to Work program.

Results and Findings

Data analysis in this study utilized the microanalysis techniques and procedures outlined by Strauss and Corbin (1998). The general framework utilized for data analysis involved open coding, axial coding, and selective coding.

Open Coding

Open coding was conducted in this study by repeatedly comparing the participants' interview responses against their body language during their semi-structured and open-ended interviews. The comparison provided information about meaning and categories for the investigated participants Kantianisms. During Open coding reoccurring groups, themes, or incidents were grouped together and given the same conceptual label. During open coding, 19 concepts were coded; Unwilling Acceptance, Anger, Fear of the unknown, medication, Feeling Different from Co-Workers., Wanting to be treated like they were before, Physical Limitations, Envy, Blame, Envy, Self-loathing, Anxiety, Depression, Physical Pain. Coping Strategies, Denial, Loss of Self-esteem, Loss of Self-worth, Feelings about their Future and their Career, Feelings about CTS.

Axial Coding

Axial coding was used to sort the 19 identified concepts into six categories that repeatedly emerged. The six categories allotted the researchers insight into the psychological, psychosomatic, and sociological effects of CTS within the workplace. Within the six categories, three to five subcategories emerged, and these were used to provide further insight into these effects.

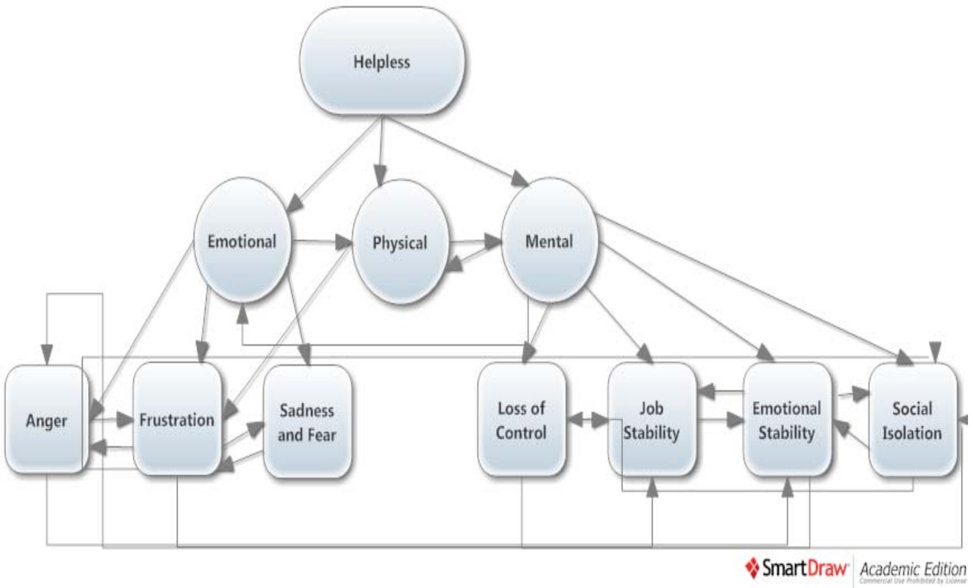

Figure 1. Axial coding: Psychological.

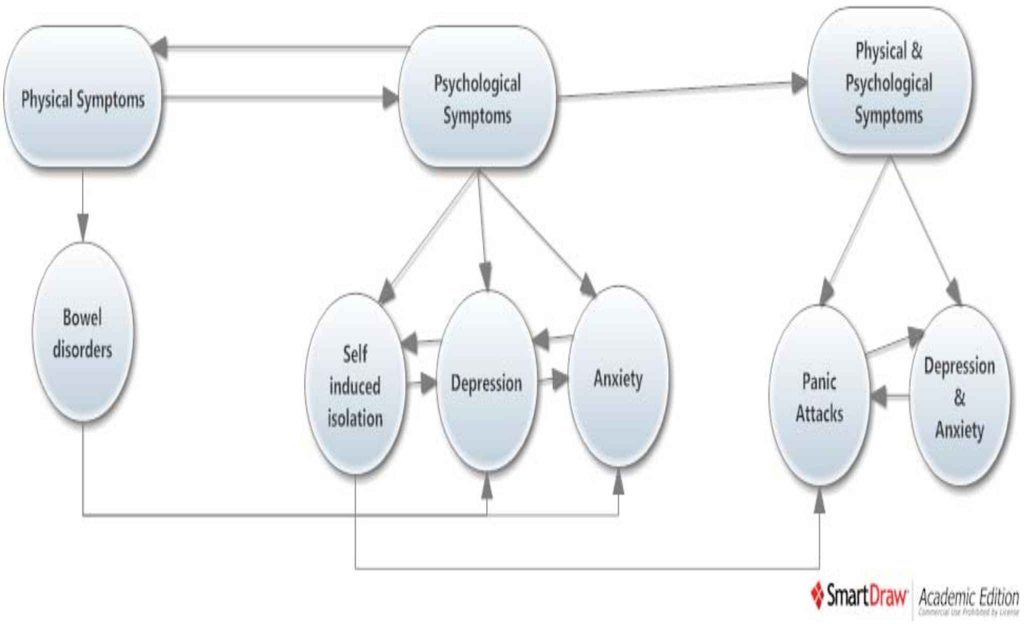

Figure 2. Axial coding: Psychosomatic.

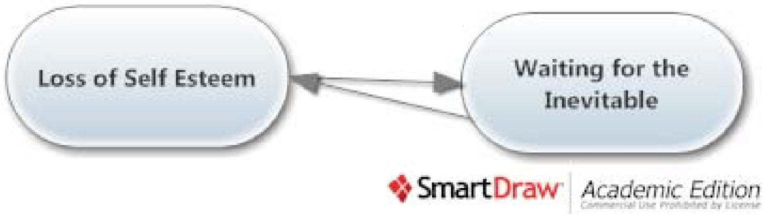

Figure 3. Axial coding: Sociological.

Selective Coding

Through selective coding, the participants' words and actions depicted a story, which revealed an insider's perspective on how CTS affected employees on psychological, psychosomatic, and sociological levels both in and out of the RTW program and within their personal lives. Once the core categories and their relationships to each other were identified, a hypothesis was formed based on the relationships, which revealed the invariable nature societal influence has on this disease.

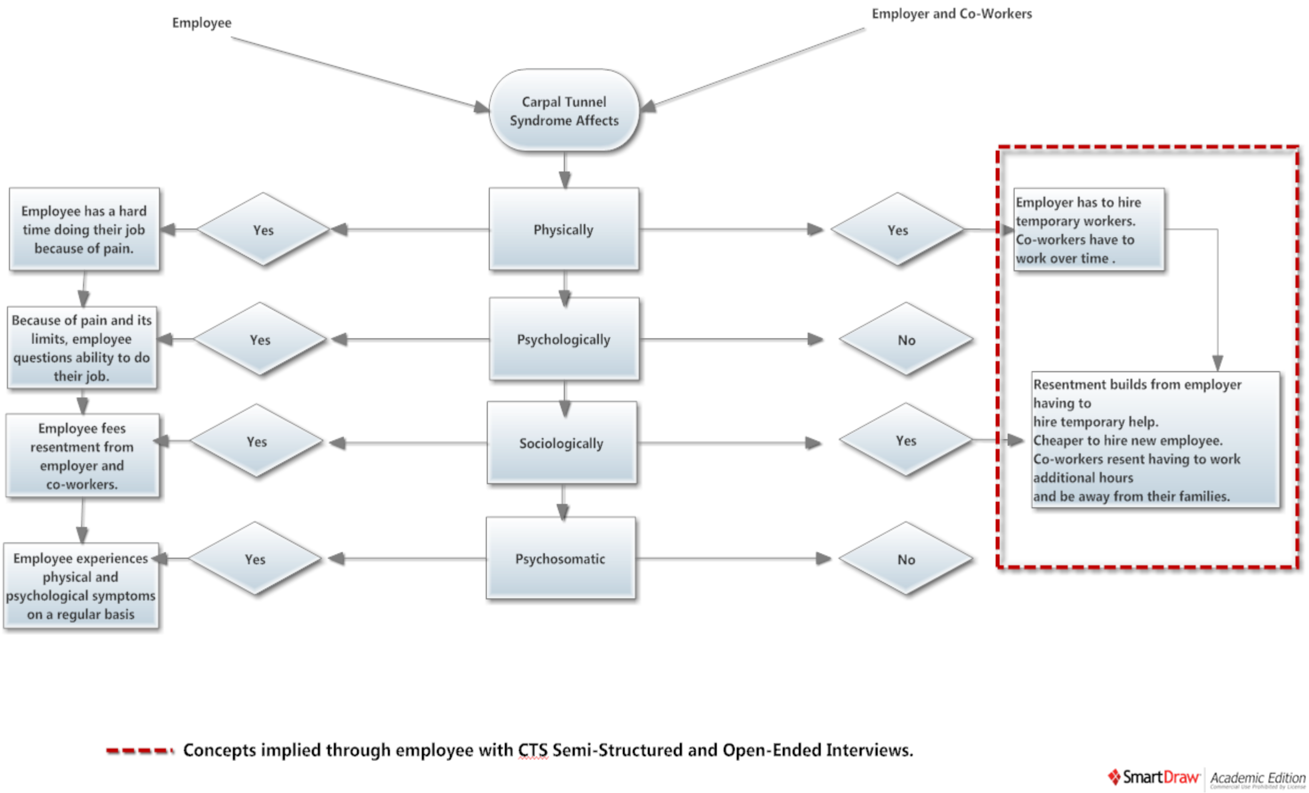

Figure 4. Conditional/consequential matrix.

Conclusions

The purpose of this constructivist grounded theory study was to discover how the physical, social, and emotional effects of carpal tunnel syndrome (CTS) affect employees with CTS's ability to complete an employer-sponsored return to work (RTW) program at their place of employment. Through the participants' recollections and stories, the employees with Carpal Tunnel Syndrome words helped to reveal and depict the essence and influence that the physical, psychological, psychosomatic, and sociological aspects of CTS have on each other and how they influence an employee's day-to-day physical and psychological workplace activities. Findings in this study provided physical, psychological, psychosomatic, and sociological insight into the social existence and non-acceptance of this disease in the workplace.

The core concepts that emerged from this study were consistent with present day literature surrounding this topic in both case studies and phenomenological studies. The six core concepts found in this study, (a) helplessness (Clay & Olitt, 2012; Glasø, Vie, Holmadal, & Einarsen, 2011; Sloan et al., 2010; Stojanova, 2014), (b) physical symptoms (Egan et al., 2009; Nixon et al., 2011; Persson et al., 2014; Shoss & Shoss, 2012; Sullivan et al., 2013), (c) psychological symptoms (Anderson et al., 2012; Banerjee et al., 2014; McFarlane, 2013), (d) physical and psychological symptoms (Koukoulaiki, 2013; Law et al., 2011; Mug Kang et al., 2011), (e) loss of self-esteem (MacIntosh, 2012; Martin & Martin, 2010; Martin, & LaVan, 2010; McCormack et al., 2009; McFarlane, 2013; Miranda et al., 2009), and (f) waiting for the inevitable (Cho et al., 2012; Egan et al., 2009) provided insight into the psychological, psychosomatic, and sociological effects of CTS within the workplace.

Limitations

This study was originally designed to learn and measure how the effects of Carpal Tunnel Syndrome prohibited employees with Carpal Tunnel Syndrome from completing their employers' Return to Work programs by interviewing the employees with Carpal Tunnel Syndrome, their managers, and their co-workers. However, IRB approval was not granted for the original design because the researcher was told that (a) the study would be too large in focus, (b) too difficult to complete in a six-month time frame; (c) too risky because the chance of employers' seeking retaliation against the employees with Carpal Tunnel Syndrome or their co-workers for participating would jeopardize the integrity and credibility of the study. The study was redesigned to include only the employees with Carpal Tunnel Syndrome and their experience. Therefore, it can be argued if employers' and co-workers' experiences could have been accounted for in this study, additional insight and theories could have been generated and used to answer the research questions.

Future Research

Considering the challenges expressed by employees with CTS in this study and the new sociological findings that emerged, additional grounded theory studies are recommended to examine how the effects of CTS financially extend to the employer and co-workers of employees with CTS. The purpose of this study would be to confirm previous claims made in other studies about reducing workers' compensation claim insurance cost.

Additional studies examining the physical, psychological, psychosomatic, and sociological realms CTS has for employers with employees who have CTS and their co-workers are also recommended to examine how this disease affects them in and out of the workplace. Because of the risk of retaliation against employees with CTS, research with different employers and co-workers from separate organizations is recommended. A larger sample size and multiple organizations are also recommended to adequately measure this.

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Observation methods to measure psychosocial work risk factors: A synopsis

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Abstract

Observation methods are commonly used in ergonomic research for the assessment of physical risk factors for health. However the assessment of psychosocial working conditions is almost exclusively reliant on self-report measures. Self-reports on work stressors bear several limitations from an epidemiological research perspective and are commonly influenced by personality, individual coping with stress and mood, hereby leading to bias for associations between psychosocial hazards and health, e.g. work-related musculoskeletal disorders. The method of observational job analysis will be described as an alternative with job analysis methods developed within the theoretical framework of Action Regulation Theory. Job analysis assesses psychosocial work exposures independently of worker appraisal by observation through trained analysts. Applications of these instruments to occupational health studies within different industrial sectors and different types of work (blue-collar, white-collar, transportation, teaching and health care work will be presented.

Introduction

Ergonomics research traditionally focussed on the investigation of physical or biomechanical work exposures as risk factors for health, e.g. work-related musculoskeletal disorders (WRMDSD), such as manual handling, heavy lifting, pulling or pushing, sustained awkward postures or repetitive motions. Research now also identified psychosocial working conditions as relevant in the aetiology of WRMSDs. Psychosocial factors have been shown to contribute to injuries independently of physical exposures (Bernal *et al.*, 2015) and synergistically impact on WRMSDs (Devereux, Buckle, and Vlachonikolis, 1999; Widanarko *et al.*, 2014). Psychosocial exposures have been defined in several ways and are often discussed in the context of job stress. The definition provided by Leka *et al.* will be used here which defines psychosocial hazards as conditions of work rather than as characteristics of the person as '...those aspects of the design and management of work and its social and organisational contexts, that have the potential for causing psychological and physical harm.' (p.2). Examples include high work demands, low control over work, low social support at work, unclear role expectations and many more. Causes for psychosocial hazards can be due to poor work organisation, and inadequate socio-technical or environmental design.

Within the field of ergonomics several observational methods were developed to assess physical exposures that may be detrimental to health. These methods include real-time expert observations during work using, video analyses, photo-based analyses, checklists and other techniques (David, 2005; Takala *et al.*, 2010). The assessment of psychosocial work risk factors is commonly done by self-report, mainly by use of questionnaires. While questionnaires have many advantages in research, such as easy administration hereby allowing for large sample sizes, they bear several limitations when investigating associations between psychosocial risk factors and WRMSDs from an epidemiologic research perspective (Kasl, 1998):

First, the self-report of the exposure, job stressor, may be influenced by the health outcome hereby inflating associations between job stressors and MSDs. For example, people with strong back pain may attribute their pain to job stress or simply report higher stress levels because the pain puts physical and psychological strain on them.

Second, the self-report of job stress is commonly affected by individual characteristics, such as perception, coping styles and personality traits of the respondent, e.g. persons may tend to deny stress, tend to respond in a socially desirable way or may have a tendency to view oneself or the world in negative terms (negative affectivity). If the outcome is also self-reported, e.g. back pain or mental health symptoms, associations between job stress/stressors and health outcomes (e.g. back pain) can be spuriously inflated or deflated depending on the direction of the respective associations of the confounder with the exposure and the outcome (Spector and Brannick, 2009; Spector et al., 2000; Zapf, Dormann, and Frese, 1996).

Third scholars highlighted the phenomenon of common methods variance, a bias that arises because the exposure and the outcome are assessed by the same method self report, hereby inflating associations (Podsakoff, MacKenzie, and Podsakoff, 2012; Spector and Brannick, 2009).

It was therefore suggested to develop theoretical models and measurement approaches to capture the exposure to psychosocial risk factors and work stressors more 'objectively' and clearly differentiate them from the subjective reaction of 'stress' (Rugulies, 2012). One particular approach is observational job analysis.

Observational Job analysis to measure psychosocial risk factors at work

Job analysis, is a systematic method to determine the content of a specific job, including activities involved, tasks to be performed when and how, and equipment and tools needed to complete the job successfully. Job analysis is often used for applied human resources purposes. In the context of ergonomics, task analysis has been used to systematically analyse work tasks for designing human-machine or human-computer interfaces and to inform the implementation of automation (Kirwan and Ainsworth, 1992; Sheperd and Stammers, 2005). Work psychology built on this methodology and developed research tools, specifically observation job analysis instruments for the measurement of psychosocial working conditions and job stressors. The general purpose is to measure working conditions by trained expert observers independent of individual worker appraisal. These measures were deemed to be less confounded by the personal characteristics, interpretations and coping styles of the individual worker (Frese and Zapf, 1988; Greiner and Krause, 2000) .

An additional reason was to create risk assessment tools that are able to identify the sources of work-related stress reactions (e.g. in the task and systems of work set-up) to inform primary intervention measures to tackle job stress. Primary interventions manage the risk at source (e.g. by redesigning tasks, policy implementation, up-skilling), whereas commonly job stress inventions focus on secondary or tertiary interventions with the aim to minimise the impact of the risk to affected individuals (stress resilience or coping training, stress educational measures) or assist affected individuals with recovery and rehabilitation (e.g. counselling services, referral). In this paper the procedure of job analysis will be described and a selection of observations work analysis instruments will be presented that were developed in the tradition of work psychology, and specifically in the tradition of German Action Regulation theory (Hacker, 1994) and the Socio-Technical approach for the design of work systems .

Action Regulation Theory as a basis for the development of work analysis instruments

Job analysis may appear to be easily conducted when analysing simple manual tasks, where activities can be easily observed in real time during work. However highly skilled tasks and many modern work tasks include a range of cognitive elements necessary to perform the task that are difficult to observe. For example, complex tasks may require complicated information processing activities, decision and planning processes, interactions with others, reasoning and creative actions. In order to analyse those tasks by observation, a model of the 'cognitive architecture' of a job is required. One of the theories that has facilitated the development of such models is Action Regulation Theory developed in Germany (Hacker, 1994; Hacker, 2003; Oesterreich and Volpert, 1986; Volpert, 1992). The primary focus of ART applied to the study of work is the explanation of human behaviour at work and its determinants in the work environment. ART posits that human behaviour is goal-oriented; at work the goal is defined by the work tasks which will put demands on the worker for action. Actions do not just include the visible actions such as locomotion or movements but also cognitive processes which regulate the visible behaviour. Hacker (2003) differentiated between 3 hierarchical levels for the regulation of work activities: (a) an automated, unconscious mode that regulates simple and/or repetitive tasks, (b) a knowledge-based and possibly conscious mode for more complex, but mostly rule-based tasks and (c) a strictly conscious intellectual mode that is invoked in new situations or in executing highly complex tasks.

Within this process, stress will arise when the worker is confronted with working conditions that overburden human regulation ability or when no resources for effective coping and management of the exposure within the work organisation exist. Psychological processes measured in this way provide information about average or typical but not about individual psychological processes. Work analyses instruments based on ART commonly measure the 2 main dimensions: regulation requirements and regulation hindrances (stressors)

Regulation requirements: According to ART, regulation requirements are a resource and provide opportunities for learning and development, allow to have influence and control over the work procedures and permit to be creative. Regulation requirements are a measure of the structural possibilities provided by the specific task design and not an assessment of the individual ability. Low levels of regulation requirements reflect work tasks that require an automated mode of regulation because the work procedures are highly pre-determined and no decision or planning is required. High levels of regulation requirements reflect work tasks that are not entirely pre-determined and require active decision making and planning of the workers who may also be able to influence and control the work procedures and their own work environment. Higher levels of regulation requirements are considered a positive work characteristic with positive impact on health.

Work stressors are defined as hindrances in the work environment that interfere with and overtax the cognitive and psycho-motor regulation of work activity. The main dimensions of stressors include work barriers that impede or interrupt the cognitive or psychomotor regulation of action, such as frequent interruptions by others, poorly maintained work tools or withheld information. The worker cannot complete the work task as intended and needs to perform extra work or engage in risky behaviour to deal with the obstacle. The severity of the barrier is measured as minutes of extra work necessary to overcome the obstacle. Barriers are conceptualised as stressors with negative effect on health. Other dimensions of work stressors are monotonous working conditions, time-binding (a measure of the flexibility of timing of work activities) and capacity-overtaxing factors, such as noise with accumulating effects over time (Greiner and Leitner, 1989).

There are two main original work analysis instruments: *VERA* to measure regulation requirements (Oesterreich, Leitner, and Resch, 2000) and *RHIA* to measure work hindrances (Leitner et al., 1987). Both instruments can be applied in parallel. VERA provides a structured protocol and a 10-level categorisation with clearly defined regulation levels ranging from simple motor regulation (elementary assembly line tasks) to highly complex management tasks with responsibility for coordinating of different work areas (see Table 1). Two versions of the original instrument exist; one version for the analysis of industrial work (Oesterreich, Leitner, and Resch, 2000), one for the analysis of office work (Leitner *et al.*, 1993). RHIA provides a structured protocol and measures work barriers (interruptions and impediments), monotonous working conditions and time-binding for industrial work in manufacturing (Leitner *et al.,* 1987) and office work (Leitner et al., 1993). The interrater reliability of both instruments is good to very good (Leitner *et al.*, 1987; Oesterreich, Leitner, and Resch, 2000)

Procedure of work analysis in research studies:

The generic procedure of job analysis usually involves the observation of workers during regular work by a trained expert analyst. In a first step the analyst describes the 'cognitive and motor architecture' of the task as sequences and hierarchies of work steps including motor and cognitive actions necessary to complete the task. The analyst is instructed to stay in the background and not to interfere with the work activity. There are several approaches to scientific job analysis. It is commonly carried out during a typical day, the duration depends on the complexity of the task but may take an entire shift. The analyst usually follows a semi-structured observation protocol and documents the observations in a structured way and relate answers to defined categories provided. The analyst may ask specific questions about the task to clarify work procedures; questions do not address feelings or stress perceptions. If possible, administrative documents maybe used for further information such as shift schedules and job descriptions.

Job analysis in the context of occupational stress studies

These work analyses instruments have been applied to lager studies to ascertain the associations between work stressors, regulation requirements and health and have been further developed to apply to other work settings and types of work. Table 2 provides an overview of the recent applications and modifications used in research that are available in English.

Table 1: Ten-level categorisation of regulation requirements at work – VERA job analysis instrument (adapted from (Leitner et al., 1993)

Level 1	Rule application
1R	Work tasks are always done in the same way using the same procedures. The procedure is fully externally determined (e.g. assembly line work).
1	For completing the work task the *recognition* of the externally determined procedure is necessary (e.g. different cleaning tasks according to set rules).
Level 2	Decision
2R	Necessary to *visualize* the work procedure before starting or during completing the task (e.g. sequence of pre-set steps in handling standard online customer requests).
2	*One decision (*e.g. which tool to use*)* before or during the task, can then plan the task completion from start to end.
Level 3	Strategy decision
3R	More than *one decision within one task* and cannot plan from the start to the end of the task (strategy for repairing a car, one decision depends on another decision).
3	*One strategy decision*. From there it is clear what needs to be done next (e.g. whether to use SPSS or Stata to analyse data).
Level 4	Coordination of work areas
4 R	S*trategy decisions* and consideration that strategy decisions in work areas of others are not affected (e.g. introduction of a new software for a specific work unit that may be linked to other work units)
4	*Strategy decisions* in (at least) 2 areas of the task and has to *coordinate* them (introduction of a new software for 2 work units)
Level 5	Introduction of new work processes
5	Responsible for organising conditions for the *introduction of new work processes*. Existing work processes are not changed in a major way (e.g. implantation of new training programmes that affect salaries and costs)
5 R	Responsible for organising conditions for the introduction of new work processes. Existing work processes have to be combined in a new way (e.g. implementation of new production standards that affect several departments)

Table 2: Selection of observational job analysis based on Action Regulation Theory (ART) used in stress and health studies

Studies	Measured work factors	Measured health outcomes	Sample
AIDA study (Leitner & Resch, 2005)	Work barriers measured in extra work (minutes)	Psychosomatic complaints, depression, irritation, satisfaction with life, psychosomatic complaints, eye trouble, allergic complaints	222 office workers in German manufacturing companies with 3 follow-ups
San Franscisco Busdriver Study	Work barriers: Impediments and interruptions measured in minutes of extra work, time binding, monotonous working conditions	Psychosomatic symptoms, smoking to cope, work accidents, absenteeism (Greiner and Krause, 2000; Greiner *et al.*, 1998), Hypertension *(Greiner et al.*, 2004), musculoskeletal symptoms (Greiner and Krause, 2006) Claims due to MSDs after 5 years	Based on N=81 worksite observations; Imputed values: n=308
Whitehall II Study Adapted RHIA office and VERA (Griffin et al., 2007)	Level of regulation requirements Work barriers	Depressive and anxiety symptoms (GHQ 30)	Based on 95 observations
Teacher Study (RHIA Unterricht) (Krause, Dorsemagen, and Meder, 2013; Meder, Dorsemagen, and Krause, 2008)	Work barriers, capacity overtaxing factors	-	48 observations of teachers
PIUS-Study: RHIA adapted to eldercare work (Jakobsen *et al.*, 2016; Jakobsen et al., 2015)	Work barriers (impediments and interruptions), level of regulation requirements , emotional demands	Depressive symptoms	95 observations of care workers in direct care
DOSES Study: (Meyland *et al.*,	Work barriers (impediments and	Musculoskeletal symptoms	441 observations with 12 moth

2016)	interruptions), emotional demands from residents		follow-up

For example, (Leitner and Resch, 2005) conducted job analyses with 222 German industrial office workers with 3 follow-ups and showed that a composite score of extra work due to work barriers was associated with heightened depressive symptoms, psychosomatic symptoms and a range of other health issues after 1 and 2 years in a prospective study with German office workers. Greiner adapted the RHIA instrument to the assessment of job stressors in urban transportation operators. 81 job analyses on 27 different transit lines formed the basis for several analyses, including analyses with imputed measures for drivers working on the respective analyses lines. Work barriers were found to be significantly associated with a composite score of psychosomatic symptoms, smoking to cope, work accidents and absenteeism (Greiner *et al.*, 1998; Greiner et al., 1997) , with hypertension (Greiner *et al.*, 2004), musculoskeletal symptoms (Greiner and Krause, 2006) and prospectively with MSD claims after 5 years. Further adaptation and application was of RHIA and VERA was done with a sub-sample of the British Whitehall II Study with British civil servants. In this study, level of regulation requirements but not the composite measure for barriers was associated with caseness of depression and anxiety (Griffin *et al.*, 2007).

A very interesting new adaptation and application of the job analysis approach within ART is to assess psychosocial work conditions within interaction work and dialogic work, such as teaching and eldercare work. Interaction work is a type of work that is accomplished by and in contact with others. The aim of this work is emotional or cognitive transformation by providing a service, e.g. care, counselling or teaching (Jakobsen *et al.,* 2016; Jakobsen *et al.*, 2015; Meder, Dorsemagen, and Krause, 2008) . For example, Jakobsen et al, (2015) reported that the higher the level of regulation requirements for eldercare workers the lower the depressive symptom score after adjustment for several confounders

Conclusions

Job analysis provides an alternative to the traditional way of self-reported psychosocial work exposures, especially in studies were researchers are concerned about the validity of their self-reported measures. They may also complement self-reported data and provide rich quantitative and qualitative information but also an opportunity for comparison of both ways of measurement and analysis of discrepancies between self-reported and externally assessed factors (Greiner *et al.*, 2004). Newer developments also use video analysis for validation Mederer *et al,* 2008) and input of results by hand-held devices (Meyland et al., 2016) also allow for integrating an ergonomic analysis with a psychosocial risk assessment within one common approach.

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The Impact of Court of Appeal Judgements on Damages in Personal Injury Cases, and sentencing in Health and Safety Prosecutions

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Abstract

This paper reviews judgments by the Court of Appeal and the High Court in personal injury, in health and safety prosecutions and in manual handling with the objective of informing readers of the Courts' approach to issues and in the hope of prompting discussion on how legal interpretation fits in with the philosophy underlying occupational health and safety.

Introduction

I would like to thank Leonard, Chiara and your committee for the invitation to talk here today. It is always an honour to be asked to address a conference and it is a particular honour to be asked to address the conference of your learned society.

I have over many years enjoyed attending the conferences of the Irish Ergonomics Society, so I am very aware of the high standards the Society sets and the academic tone of most papers. My paper is not academic but I hope it will be informative.

When I discussed the title of the paper with Leonard, I submitted the title above. However when I sat down to write this paper, I found the title did not reflect the topics I wanted to talk about

- One is the impact of the Court of Appeal on both awards of damages in personal injury claims and fines in health and safety prosecutions
- The other is the guidance High Court and Court of Appeal judges have given in manual handling personal injury claims in recent years.

For those here today who are pure ergonomists the latter is probably the more important, but if you are a health and safety professional with an interest in ergonomics and are advising employers on accident prevention and claims, both topics are important.

The Court of Appeal: impact on awards of damages

The Court of Appeal was established in October 2014, following a constitutional referendum. The role of the Court is to hear appeals against High Court judgments, which were previously heard by the Supreme Court.

By late 2015 the Court's judgments were beginning to have an impact, with the Court towards the end of 2015 reducing damages for pain and suffering awarded to Margaret Payne, who was injured in a motor accident from €65,000 to €35,000.

There followed in quick succession a number of cases.

Nolan v Wirenski
Again this case was a motor accident case. Mrs Nolan was awarded €120,000 damages for pain and suffering by a High Court judge. The Court of Appeal reduced the award to €65,000.

Shannon (Mrs) v O'Sullivan

This was another motor accident case. In this case the Court of Appeal reduced the damages awarded to Mrs Nolan from €130,000 to €65,000.

Shannon (Mr) v O'Sullivan

The case arose out of the same motor accident in which Mrs Shannon was injured. The Court described his injuries as "modest". The Court reduced Mr Shannon's award by €40,000, reducing the High Court award of €80,000 to €40,000.

Those three judgments sent a message to High Court and lower court judges. On average the awards were reduced by 49%. The message from Ms Justice Mary Irvine, who (on behalf of the three judge court) delivered the judgments in the three cases was that awards must be proportionate.

Offering some guidance on what is proportionate Ms Justice Irvine said that the purpose of damages is to provide compensation for pain and suffering. She noted that the maximum damages endorsed by the Supreme Court stands at about €450,000 for catastrophic injuries. In relation to catastrophic injury cases, it should be borne in mind that special damages for matters such as medical and social care, can vastly exceed general damages for pain and suffering.

In terms of what the Court of Appeal might think is proportionate the injuries suffered were:

- In the case of Margaret Payne back, neck and shoulder injuries resulting in on going pain.
- In the case of Mary Nolan shoulder, hand and thumb injuries resulting in 60 physiotherapy sessions, continuing taking of pain killing medication, some restriction in shoulder movements and ongoing discomfort. The Court of Appeal described the injuries as "modest".
- In the cases of both Mr and Mrs Shannon the injuries were described as "modest".

At around the same time the Court increased the award in the case of Blaine Murphy, a 19 year old man who was a spectator at a motor rally. He suffered a severe compound fracture of the lower tibia, with disruption of the tibiofibular joint, a dislocation of the left knee and his leg was amputated from above the knee. The High Court judge awarded Mr Murphy €100,000 for past pain and suffering and €100,000 for future pain and suffering. The Court of Appeal described the award for future pain and suffering to be wholly inadequate and increased it to €175,000, bringing the total award for pain and suffering to €275,000.

These judgments were delivered before the 2016 edition of the *Book of Quantum* was published. In none of the judgments did the Court of Appeal refer to the Book of Quantum. As best one can measure the awards relying on the courts summary of the injuries and in the absence of the medical reports the awards exceeded the Book of Quantum by

- In the Payne case €15,000. Under the UK Judicial College's Guidelines award would have been about €12,800, compared to the Court of Appeal's €35,000
- In the Nolan cases the award, at €65,000, exceeded the Book of Quantum by €13,500 and the UK Guidelines by about €31,000
- In Mrs Shannon's case, the award of €65,000 exceeded the Book of Quantum by €48,600 and the UK Guidelines by about €53,000
- In Mr Shannon's case the comparative figures are €46,400 and €50,000.

There may be perfectly justifiable reasons why the awards exceeded the Book of Quantum guidelines, but it is reasonable to ask: should the judges not have explained the reasons?

On the wider issue of Irish damages being in excess of UK awards and perhaps the awards in other jurisdictions, we await the report of the Personal Injuries Commission (which is part of the Government's Insurance Working Group) chaired by Mr Justice Nicholas Kearns.

The Court of Appeal: guidelines on fines in H&S prosecutions

In February 2016 the Court of Appeal sent out a clear message that a fine of €1m was not excessive. Rejecting an appeal by the defendant in the Roadteam Logistics (formerly Nolan Transport) case, the Court held that the fine of €1m was just and proportionate. The case arose following an accident in which two people were killed and others injured after an inadequately secured load slid off a trailer.

Just a couple of months ago the Court sent out an even more emphatic message. Following an accident in which a worker was killed while working inside a safety cage, his employer – Kilsaran Concrete – was fined €125,000 by the Circuit Court. The DPP, who brings prosecutions on indictment on behalf of the HSA, appealed the leniency of the fine.

Mr Justice Edwards, who delivered judgment on behalf of the three judge court, said there was, a deliberate breach of the law in order to maximise profits. Safety concerns raised by an experienced operator and a near miss were disregarded and ignored. This was "not a case of passive neglect or omission giving rise to a one off incident or a momentary lapse of attention by an operative". There was "wilful neglect".

He then went on to say court considered the case merited "a headline sentence towards the top end of the middle range or the bottom end of the high range" on the spectrum of sentences. The Court divided the spectrum into three ranges

- A low range with fines from zero to €1m
- A mid range with fines from €1m to €2m
- A high range with fines from €2m to €3m.

The Court then considered the pleas in mitigation. The Court rejected the plea that compensation payments should be considered in mitigation. **They are not and it is important to note this the Court said to be, in general, "treated as mitigation".** The Court did allow the employer's guilty plea, its co-operation with the HSA's investigation, its remorse, the remedial action taken and its "generally good safety record" as mitigating factors. He then said the offence merited a headline fine of €2m but the Court took into account the mitigating factors and reduced the fine by 50% to €1m.

Writing about the Kilsaran judgment in the June issue of *Health & Safety Review* Alison Fanagan, (who is a former chairperson of the Health & Safety Lawyers Association) and her colleague, Jason Milne of A&L Goodbody, solicitors, taking account also of the Roadteam case asked "whether €1m is now the default position for sentencing in fatal accident health and safety cases".

Since the Court of Appeal's decision in the Kilsaran case, there has been one Circuit Court judgment. Earlier this month, in Castlebar Circuit Court, Judge Rory McCabe imposed a fine of €300,000 on Wayss & Freytag Ingenieurbau AG, who were prosecuted following a fatal accident at the Corrib Tunnel site. As I write I don't know if Judge McCabe considered the Court of Appeal's judgment in the Kilsaran case.

There are three or four health and safety prosecutions due up for sentencing in July. When we know what the courts decide in those cases we will have an early indication of the impact of the Court of Appeal's guidelines in the Kilsaran judgment.

Courts' approach to ergonomics in manual handling cases

Speaking at this conference last year, the HSA ergonomist Frank Power spoke of the important part ergonomics has to play in ensuring healthy workplaces, which is one of the Authority's key policy objectives.

Very recently a High Court judge accepting an engineer's evidence that a supermarket checkout workstation had been ergonomically designed dismissed a personal injuries claim by a checkout operator. That ruling clearly establishes that courts recognise the link between ergonomics and safe and healthy workplaces. We will come back to the case in more detail later.

During his talk last year Frank Power spoke about the Authority's publication, *Ergonomics Good Practice in the Irish Workplace* and drew the link between the development of good ergonomic polices and the reduction or elimination of manual handling. We also know from last year's conference, from the excellent paper presented by solicitor Frank Laffan, from the Limerick based firm Harrison O'Dowd, that that manual handling accidents are a fruitful source of litigation.

Those cases are also a fruitful source of learning for employers. In this paper I am covering some of the cases mentioned by Mr Laffan and some others (see Schedule). So what lessons can we learn from the cases? From the eight cases in the Schedule below one word jumps out – training. Three of the cases are particularly important: Barry, Meus and Martin.

The two High Court judgments – the judgments in the Barry and Meus cases – highlight the importance of risk assessment, relevant task specific training, the limitations of video training, the need to train workers in a language they understand and the importance of post-training supervision. For employees the judgment in the Barry case, in which the injured worker was held to be one-third responsible for the injuries she suffered highlights the importance of saying no when asked to perform unsafe tasks. The lesson from the Martin case for employers is that if training provided is ignored by an employee, the employer has a good defence to a claim. The lesson for employees is not to ignore systems of work which they have been trained to operate.

For employers there are a number of messages from the judiciary in the Barry and Meus judgments:

- Risk assessments must be task specific
- Training must be adequate to enable an employee to perform his/her duties safely, with the training comparable to the task to be performed
- DVDs and slideshows, while a useful training tool, must be relevant to the task to be performed
- Training must be delivered in a form, language and manner that the employee (person being trained) understands
- Training must be followed up by supervision to ensure the employee is using the correct manual handling techniques
- There is no point in managers offering help if that puts them at risk, as that is not a solution to the problem
- Expecting employees to ask colleagues for help if the colleagues are busy is not a defence
- Workers should not be expected to lift from above shoulder level
- Judges are not impressed when plaintiffs (injured workers) engineers go out to inspect store rooms and find them cluttered. This confirms injured workers' claims that the workspace was cluttered.

Martin judgment raises a serious policy issue

I want to conclude this talk by drawing attention to one particular sentence in the Court of Appeal's judgment in the Martin case.

The High Court judge found that Ms Martin's employer was negligent because it did not have in place a manual handling training system which included practical training for employees concerning the lifting of products (potatoes). Rejecting this finding, Ms Justice Irvine said **"I believe" such a system would be neither reasonable nor practicable for any employer, particularly one such as the defendant, who presumably has an ever changing range of products from groceries to furniture to household goods which employees have to handle on a regular basis".**

Continuing, Ms Justice Irvine said she was quite satisfied that an employer, such as the defendant (a supermarket) in the Martin case, reasonably discharged its obligations to the plaintiff (Ms Martin) by training her on a regular basis as to the principles of safe manual handling which it was then up to Ms Martin to deploy when faced with any given task. The fact that the training in respect of safe lifting techniques may have been done using empty cardboard boxes or boxes with handles, cannot on the evidence be considered to be a failure on the part of the employer to meet its common law and statutory obligations.

While we must remember that Ms Justice Irvine's words were uttered in the context of a particular case, the Court of Appeal sets precedent and it would seem to me, that whatever about the finding that the employer in this case was not liable (because no causative link was shown and because the employee did not follow instructions) Ms Justice Irvine's comment offer employers who have not provided task specific training with a defence against claims or at least some claims.

These comments merit discussion.

Schedule: Manual handling case law

Procedures not implemented

In a court case taken by an airline worker, who alleged that he suffered a back injury, a High Court judge said that while the airline had training procedures in place, they were not followed in practice. The court heard that stairs are brought to the door of the plane so that passengers can disembark. They are brought by a mechanical float but have to be positioned manually. On the day the accident occurred, the worker told the court he had to manoeuvre the stairs on his own. While he was doing this he felt something slide in his back. He was taken to hospital but it was two months before he was able to return to work.

The airline argued that the worker had been trained and he had not been left on his own to manoeuvre the steps. Help was at hand and he should have requested it. The airline argued that it insisted that two people should carry out the task of manoeuvring the steps. While the judge accepted that the airline had provided training and required two people to carry out the manoeuvre, he said that on this occasion the standard set was not followed in practice. He awarded the worker €40,000 damages. (*Warcaba v Ryanair and others*)

No training

A worker in a recycling plant suffered serious back injuries while he was lifting a pallet. He was off work for some months. When he attempted to return to work he was issued with P45. The worker brought a claim alleging that he had not been trained or instructed in manual handling. His employer denied liability, saying that the worker had been injured in a previous road traffic accident. The worker accepted that he had been injured in such an accident but suffered facial, not back injuries. The case was settled during the hearing. The settlement figure was not disclosed. (*Dubinski v Conroy Recycling Co*)

No training to carry files

A worker in a hospital's records department, who suffered a back injury when placing bundles of files on a trolley, was awarded damages of €30,000 by the High Court. The woman claimed she had not been given any manual handling training before the accident, though she was subsequently. While an engineer for the hospital gave evidence that the weights been carried were not excessive, he agreed "the manual handling training regulations were mandatory". Awarding damages, a High Court judge said the failure to provide training was the principal cause of the accident.
In a connected case, heard at the same time, the woman was also awarded €60,000 for bullying and harassment. (*Kelly v Bons Secours*)

Training not implemented

A supermarket worker suffered a back injury when lifting boxes which were stacked on a trolley well above her head height. As she was pulling down a box (she did not know what it contained), she realized when it came into her arms that it was too heavy. She had to take the weight and put it down as quickly as she could. This required her to perform a twisting movement. A few minutes later she felt pain in her back.
While the judge hearing the case accepted that workers had been trained not to stack trolleys above eye level and to put heavier goods on lower levels, she said that on this occasion the practice had not been followed. Awarding the injured worker €88,000 in damages, the judge apportioned liability holding the employer to be 70% responsible for the accident and the worker 30%. Reducing the

award to €59,677, she said the worker should not have tried to lift the box down. (*Barry v Dunnes Stores*)

Training inadequate and no proper follow up

Awarding a supermarket worker, who injured her back while loading a trolley, a High Court judge found that the training she received was inadequate in relation to her duties. The judge said that on the day of the accident the injured worker had to take boxes from a store room. They were stored above her head height and she had to knock them off the top of the pile and let them fall to the ground. While doing this she suffered a back injury.
The judge said that a demonstration with a box of A4 paper was not remotely comparable to the lifting task the worker was required to carry out and there was no proper follow up training. (*Meus v Dunnes Stores*)

Not reasonable to expect practical training

The Court of Appeal overturned a High Court award of damages to a supermarket checkout operator who left her till and went to the fruit and vegetable cabinet to get a bag of potatoes for a customer. As she lifted a bag, which was wedged between two other bags, she tore muscles in her right arm. The High Court awarded her damages of €67,000.
However the Court of Appeal held the employer had a system of work in place by which the checkout operator could have summoned assistance for the customer. She ignored this system. The Court also held that the woman had been trained and knew how the load was to be lifted, though as discussed above there are aspects of the Court's judgement that merit discussion. (*Martin v Dunnes Stores*)

No evidence from trainers fatal for defence

Awarding a picker in a distribution centre, who suffered a serious back injury damages of €153,159, High Court judge commented that the people who were alleged to have given training were not called to give evidence. The court heard that the worker was injured when lifting trays of yogurt from a pallet. He squatted down on his hunkers, pulled the trays towards him. When he was turning to put the trays in a cage he experienced a sharp pain in his back.
The injured worker told the court he had been given elementary training in manual handling. A trainer used an empty box to demonstrate a safe method of lifting. He had not received any training on lifting or turning. None of those who gave training were called to give evidence. The judge held that the employer was negligent in failing to provide adequate training. He also held that the pick rate was excessive. (*Spes V Wincanton Ireland*)

Checkout workstation ergonomically designed

A supermarket checkout operator claimed that she suffered a finger injury while lowering the chair she was going to sit on at the checkout. An engineer for the supermarket gave evidence that the checkout was ergonomically designed and build around the sales assistant who was centrally located in the workstation. It was he said the movement of the chair by the operator when settling into the checkout that result in the lever on the chair which caused to be over a cash box, with her finger being caught by the lever and the cashbox.

Accepting the engineer's evidence, the High Court hearing the case said the accident was not reasonably foreseeable and dismissed the claim. (*Wilcynska v Dunnes Stores*).