KINEMATIC AND GAZE BEHAVIOUR DIFFERS BETWEEN HYPER AND HYPO-AFFORDANTS COMPLETING MANUAL MATERIALS HANDLING TASKS

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Dedication

This thesis is dedicated to my parents Wade and Charlene, and friends Taryn, Hailey, and Dale. Thank you for your unwavering support throughout this process and for believing in the beauty of the journey.

Abstract

Work-related musculoskeletal disorders are a significant global health challenge, representing a substantial portion of lost work hours, reduced productivity, disability, injury, and pain across industries worldwide. Low back discomfort and disease is the most prevalent work-related musculoskeletal disorder. Low back disorders often result from the cumulative loading from repetitive bending, grasping, lifting, and carrying present in manual materials handling tasks. while much research has focused on safe and injurious manual materials handling behaviour, it may be useful to identify the perceptual strategies and outcomes that both couple with and precede manual materials handling actions, enabling the development of targeted interventions to modify those behaviours and reduce the risk of injury.

This study investigates the differential impact of affordance perceptotype (hyper or hypo-affordant) and gaze behaviours on handling kinematics within ecologically relevant manual materials handling tasks. Specifically, this research aims to identify if differences exist in kinematic measures and visual attention strategies between affordance perceptotype sub-groups. The study used motion capture technology and vision tracking to quantify kinematics and gaze behaviour and examined two manual material handling tasks, with a static and dynamic target respectively. We predicted the hyper-affordant participants would identify with higher risk-taking behaviour plus demonstrate a limited visual attention strategy and injury-risk handling kinematics, with those behaviours connecting to an increased prevalence of musculoskeletal discomfort.

This research revealed that hyper-affordants did exhibit larger values for relevant handling kinematics plus different gaze behaviours, potentially increasing their risk of injury. The role of state and trait characteristics and gaze behaviour in occupational behaviour were not significantly associated to kinematic measures, task condition, or perceived affordance distance. This research contributes to the understanding that individual differences in perception then action may affect occupational behaviour and risk of work-related musculoskeletal disorders, thus emphasizing the value of considering perception when developing and delivering ergonomic interventions.

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List of Acronyms

Work Related Musculoskeletal Disorders	WR-MSDs
Low Back Disorders, Damage, and Discomfort	LBD
Manual Materials Handling	MMH
World Health Organization	WHO
Disability-Adjusted Life Years	DALY
Years of Life Lost due to Disability/ Years Lived with Disability	YLD
Canadian Centre for Occupational Health and Safety	CCOHS
Personal Protective Equipment	PPE
Lumbar Motion Monitor	LMM
Perception Action Coupling	PAC
Quiet Eye	QE
Physical Activity Readiness Questionnaire	PAR-Q
Physical Activity at Work Questionnaire	PAW-Q
Standardised Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms	SNQ – AMS
Eysenck Personality Questionnaire	EPQ
Overall EPQ Score	OALL
Risk Taking EPQ Score	RISK
Liveliness EPQ Score	LIVE
Impulsivity EPQ Score	IMPL
Non-Planning EPQ Score	NPLA
Affordance Threshold	AT
Infrared	IR
Initial Assignment dynamic. B	d.B
Initial Assignment dynamic. A	d.A
Static Handling Trial 0-5	s0-s5
Dynamic Handling Trial 0-5	d0-d5
User Interface	UI
Normalized Affordance Threshold	nAT
Standardised Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms Overall	SNQ-AMSO
Standardised Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms Low Back	SNQ-AMSLB
Analysis of variance	ANOVA

Chapter 1 : Review of Literature

1.1 Introduction

Work-related musculoskeletal disorders (WR-MSDs), particularly low back disorders caused by occupational demands, affect millions of people annually as the most frequently reported occupational physical health problem (Punnett & Wegman, 2004; Wu et al., 2020). This review of literature will examine foundational information regarding WR-MSDs, ergonomics, and occupational loading and identify strengths of the current conventional risk control model and various challenges in applying it to develop ergonomic interventions that aim to reduce rates of WR-MSDs. Implementation of a multidisciplinary approach will be discussed, namely incorporating perception action coupling and occupational affordance theories as means of expanding current ergonomic solutions and controlling for WR-MSDs risks. The theoretical foundation for the multidisciplinary approach outlined in this chapter combines multiple forms of technology to measure both perception and action. This chapter describes the literature relating to the technology and methodology of markered motion capture and vision tracking. This chapter also serves as an introduction to the experimental chapter of this thesis that aims to answer the following questions:

1. Does vision tracking expose a useful association in manual materials handling between gaze behaviour and affordance setting and occupational behaviour?
2. Do dynamic and static manual materials handling tasks differently influence workers' gaze behaviours and perception of safe horizontal handling affordances and occupational behaviour?

1.2 Work-Related Musculoskeletal Disorders

In the modern workplace, the prevalence of work-related musculoskeletal diseases and disorders has become a pressing concern. The term work-related musculoskeletal diseases and disorders was first discussed in publication by El Batawi (1978) who published again with the World Health Organization (WHO) as Chief of Occupational Health (El Batawi, 1984). In this work he began investigating the prevalence of the epidemic of work-related diseases, including multifactorial chronic non-communicable diseases that affect working populations (El Batawi, 1984). The occurrence of many occupational diseases are impacted by both occupational and non-occupational factors like task demands and nutrition, respectively.(Hales & Bernard, 1996). This perspective on occupational health has broadened the classification of occupational illness as a morbidity in which multiple work factors contribute in part to the causation of the illness (Hales & Bernard, 1996).

Work-related musculoskeletal disorders (WR-MSDs) is a broad term that describes any work-related disorder or disease of any anatomical structure of the musculoskeletal system (Lin et al., 1997; Wickström, 1982). WR-MSDs are often caused by physical factors (typically multiple and cumulative) relating to an occupational environment or behaviour (Hales & Bernard, 1996) and WR-MSDs impact hundreds of millions of people worldwide (Adegoke et al., 2008). Due to their complex multifactorial nature, Winkel and Mathiassen (1994) proposed that WR-MSDs are best understood through a cumulative loading model. This model considers the reduction of stress-bearing capacity of tissues following repeated load application that cumulatively results in reduced load tolerance of tissues (Kumar, 1990). In various occupations, the cumulative loading resulting from work tasks and occupational behaviours can risk the development of a WR-MSD (Jäger et al., 2000; Kumar, 1990; Norman et al., 1998). Many WR-MSDs are caused by an extreme and sustained exposure to a force, vibration, repetitive motion, and/or awkward posture, and in many cases, a combination of these listed risks are present (Center for Disease Control and Prevention, 2023). The most common WR-MSDs, including LBD and neck pain, are not solely caused by occupational factors, but a combination of occupational and non-occupational factors, and are therefore referred to by the WHO as 'work-related conditions'(National Research Council (US) and Institute of Medicine (US) Panel on Musculoskeletal Disorders and the Workplace, 2001). WR-MSDs commonly cause discomfort and disability. If left untreated, WR-MSD symptoms may intensify into severe and long-term pain and disability (Punnett et al., 2005). WR-MSDs can lead to loss of work hours, permanent disability, and in extreme cases can require invasive and long-term medical treatment (Motacki & Motacki, 2009). For the purposes of this thesis, WR-MSDs will encompass occupational diseases that can be caused by occupational exposure regardless of non-occupational factors or exposure.

1.2.1 Relevant Risks and Cumulative Effects

Acute musculoskeletal injuries involve one serious traumatic event to cause a sprain, strain, or fracture of a highly tolerant musculoskeletal tissue. The cumulative effect of exposure to various risks and their submaximal loads causes WR-MSDs (Chaffin & Baker, 1970). Most exposures leading to WR-MSDs are described by five characteristics of the task (Kuorinka et al., 1995):

1. Intensity of the applied force
2. Repetition of the movement
3. Position of the load and actor
4. Duration of the task
5. Presence of sustained awkward postures

Awkward postures including extreme trunk extension, trunk flexion, or trunk torsion place unnecessary loading onto spine and back tissues (Raffler et al., 2017). Employees completing manual materials handling (MMH) tasks involving these risk factors have the highest likelihood of developing WR-MSDs (Kuorinka et al., 1995). These risks are involved in many tasks that include bending, lifting, carrying, and transferring materials for work (Deros et al., 2010). The cumulative effect associated with repeating these movements can introduce micro-injury to soft tissue that over time can accumulate into severe pain, injury, or disability (Heneweer et al., 2011). These actions can put workers into high-risk positions, and are often performed repetitively and for long durations, which may contribute to the accumulation of loading (Keyserling et al., 1992; Wiker et al., 1989). The maximum load for an individual lift of sustained and vigorous nature have been identified (Waters et al., 1993), however many occupational tasks require workers to exceed this recommended safe load (Mital, 2017). Exposure to a heavy workload or large accumulated load and the awkward postures involved in MMH are among the highest risk factors for development WR-MSDs (Heneweer et al., 2011; Hoogendoorn et al., 1999).

Marras (2000) modelled the mechanical logic of a soft tissue load tolerance for a work task as adapted in Figure 1.1a. This model is simplified and representative of a non-biological system as the load has a consistent sinusoidal load-unload pattern. Subsequently there is a consistent safety margin between the load and the load tolerance. WR-MSDs can occur when forces on the body cause compressive, shear, or rotational counteracting forces within the tissue that exceed the soft tissue tolerance (Bernard & Putz-Anderson, 1997). As stated in Marras (2000), the initial model is over-simplified in practice – we *do* experience decreasing load tolerance of the soft tissues due to the cumulative effect of repeated loads with limited recovery phases (Bernard & Putz-Anderson, 1997). The initial ideal model is adjusted in Figures 1.1.b and 1.1.c introducing tissue tolerance reduction as time progresses and variability in loading respectively. This three-part model can be used to explain the reality of cumulative trauma caused by repeated variable loading (Marras, 2000).

1.2.2 Low Back Discomfort, Disorder, and Damage (LBD)

Low back discomfort, disorders, and damage (LBD; Marras et al., 1993) is one of the most costly and common causes of work-related disability (Dempsey, 1998). As of 2002, LBD affected an average of 80-85% people at some point during their lifetime (WHO Scientific Group, 2003). In 2017 approximately 577 million people globally were actively experiencing LBD (Wu et al., 2020). LBD is the most frequent activity-limiting complaint in young and middle-aged individuals (Lidgren, 2003), and is the most

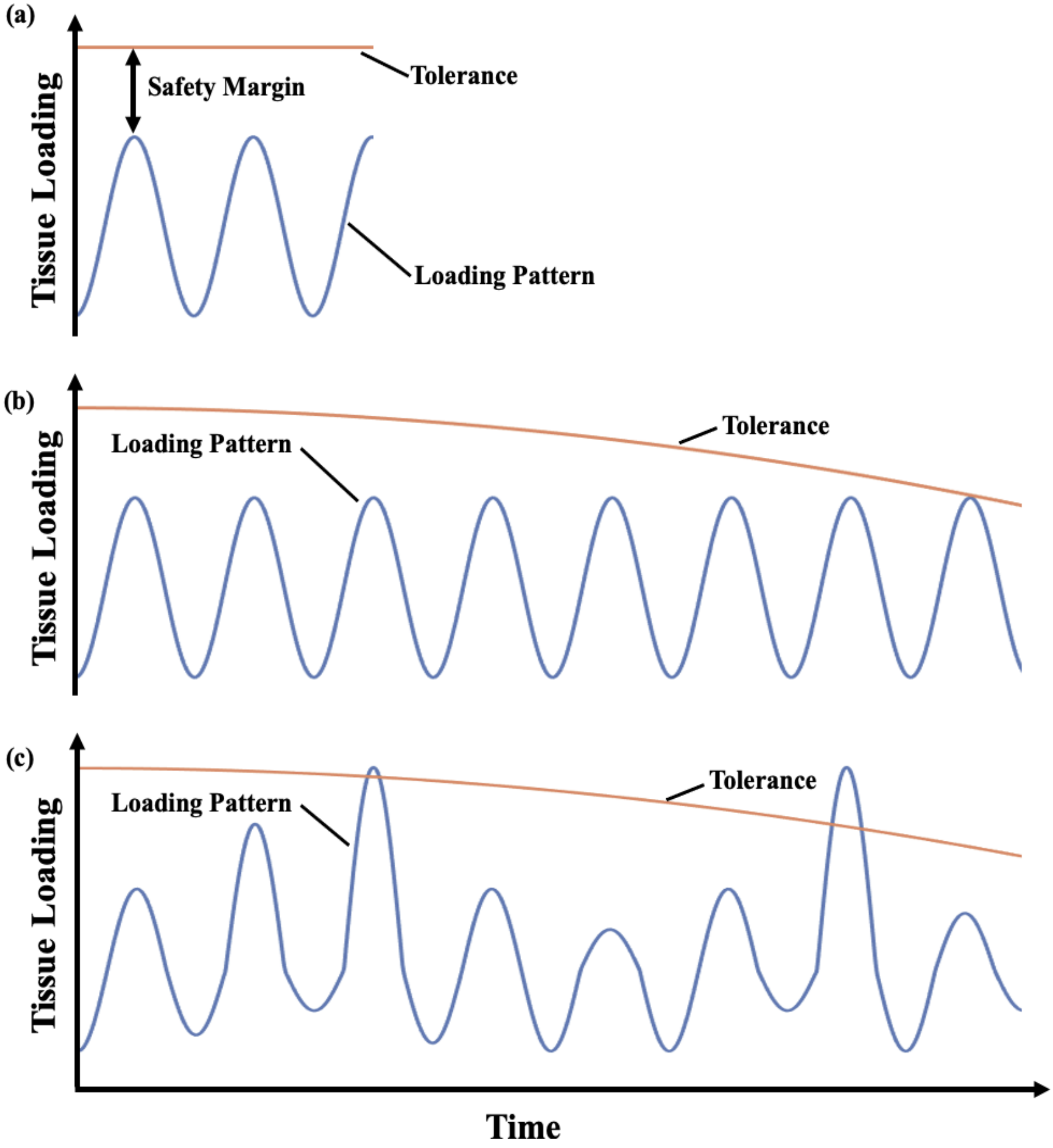

Figure 1.1: Mechanical Tolerance Failure Model. (a) The load and rest cycles are sinusoidal and equally spaced meanwhile the tolerance load is a set value which results in a consistent safety margin. (b) Modified Failure Model introduces a tolerance reduction due to tissue fatigue resultant from a cumulative applied load, while the load and rest cycle remains consistent, sinusoidal, and equidistant. (c) Modified Failure Model features tissue tolerance decrease and variable loading levels, reflective of the differing task demands relevant to behaviour at work. These images have been adapted from Marras (2000).

frequent occupational problem in high-income countries (Punnett et al., 2005; Punnett & Wegman, 2004). LBD due to work is commonly associated with the MMH tasks connected to 37% of the incidences and 40% of the cost of worker's compensation claims (Dempsey, 1998). In 2011, 36% of Canadians identified the lower back as their major site for chronic pain (Schopflocher et al., 2011).

The global impact of LBD can be modelled within a burden of disease method such as disability-adjusted life years (DALY; Hoy et al., 2010). The DALY model calculates years of life lost due to premature mortality and healthy years of life lost due to disability (YLD) to understand the total life years lost due to illness and injury. Using this model the global burden of LBD was estimated to be 2.5 million DALY in 2004 (Lopez et al., 2006). As of 2017, North Americans reported 4,930,000 years lived with disability (YLD) due to LBD, which is a 25% increase since 1990 (Wu et al., 2020). Canadian data is likely congruent with this increase, as are most highly developed areas of the world (Moulin et al., 2002). Provincially, data suggests LBD is the leading impetus for 31% of physiotherapy services rendered in Alberta (Cutforth et al., 2011). These data are cause for concern and action to effectively reduce the global burden of LBD among MMH workers (Buchbinder et al., 2013; Mathers, 2017). Models have been developed to understand, predict, and prevent injury of the low back based on many factors including tissue properties and kinematic measures of trunk bending and rotation (Marras et al., 1993).

1.2.3 Understanding and Modelling WR-MSDs of the Low Back

Repeated sub-maximal or sub-failure loading leads to tissue fatigue and decreased load tolerance of a tissue over time (Brinckmann et al., 1989). Tissue fatigue and injury are caused by the accumulation of low back micro-trauma produced by the application of either a repeated load or a sustained load for a long duration (McGill, 1997). The etiology and pathogenesis of many LBDs often involve repeated exposure to several types of loading involving compressive and shear loads (Brinckmann et al., 1989) of various duration and magnitude (Fathallah et al., 1998a), and combined motion with loading at high trunk velocity or displacement (Fathallah et al., 1998b).

Modelling this accumulated micro-injury and resulting LBD over days and months of employment is often inaccurate due to the convolutional nature of behaviour. Complex spine models have been developed to understand the loading biomechanics of single lifting techniques, however they are not unequivocally accepted for MMH applications due to the dynamic and employee-specific mechanics of completing each task (Adams, 1995). Spine models become impractically complex when considering additional factors of physical degradation and chemical restructuring of tissues as a response to loading (Adams et al., 1996). Simple models are useful to establish safe guidelines for industrial maximal allowable loads and to demonstrate safe body posture relative to low back loading. These models often fail to consider an individual’s anthropometry and subsequent movement patterns, however, they may lead to LBDs over time (McGill, 1997). Personal characteristics may also introduce additional risk factors based on age, strength, medical conditions, and level of physical conditioning (Waters &

Putz-Anderson, 1996). Environmental demands (i.e., temperature, lighting, noise, friction, etc.) and job-specific mental demands introduce additional complexities and risk factors that must be considered when designing models to adequately prevent LBDs (Waters & Putz-Anderson, 1996).

Prospective relationships need to be developed between factors involved with the development of LBD and factors that result due to LBD (Frymoyer et al., 1983). Individuals often experience pain before clinically observable tissue damage, but once the tissue becomes inflamed reactivation occurs more easily and pain is perceived at a lower stimulus level (Marras, 2012). This onset of tissue damage prior to pain makes it difficult to definitively study the onset and progression of LBDs in an ecological context, resulting in persistently high direct and indirect costs related to WR-MSDs of the low back (Punnett et al., 2005).

1.2.4 Ergonomic Risk Controls

Ergonomics is the study of interactions between workers and the working environment, which features physical, environmental, organizational, and cognitive demands (Hoe et al., 2018) involving human behaviour and human performance that interact with socio-technical systems in every workplace (Wilson, 2000). Socio-technical systems within occupational environments require effective blending of social and technical requirements of a system involving a wide range of considerations including those of the worker and the workplace (Carayon, 2006; Fox, 1995). Many ergonomics researchers have found that work demands are associated with musculoskeletal disorder symptoms, and that controlling these demands can reduce the development of WR-MSDs (Bernard et al., 1994; Bonfiglioli et al., 2006; Ortiz-Hernández et al., 2003; Szeto et al., 2009; Werner et al., 2005).

Ergonomic controls are primarily implemented by adjusting the workplace to better fit the work to the worker, specifically making it possible for a worker to remain in a more neutral posture to complete their work tasks (Abdul-Tharim et al., 2011). The Canadian Centre for Occupational Health and Safety (CCHOS) categorizes risk controls into five groups, including elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE; Canadian Centre for Occupational Health and Safety, 2022) . The model shown in Figure 1.2 (Canadian Centre for Occupational Health and Safety, 2022) provides a hierarchical approach to reducing or eliminating workplace hazards. The hierarchy reflects the effectiveness of each intervention. When applying this model, ergonomists search for possibilities to eliminate risk or substitute a lower risk before identifying possible controls or finally PPE to protect a worker from a hazard. Within this hierarchy of risk controls, multiple controls may be selected from within and between categories such that they combine to protect workers from the hazard (Canadian Centre for Occupational Health and Safety, 2022).

Engineering controls are commonly applied to existing MMH tasks that have a high incidence rate of WR-MSDs (Marras et al., 1999). Various engineering controls can be built into the work environment or process to minimize the hazards including physical or process controls (Canadian Centre for Occupational Health and Safety, 2022). Physical controls or physical ergonomic interventions are common and include implementing changes to the work environment or adding assistive equipment to reduce the risk factors present in certain occupations (Hoe et al., 2018). The physical strain on the musculoskeletal system required in bending, lifting, carrying, or transferring objects can be transferred to equipment via semi-automating a process, while installing an adjustable height working table can offset strain by reducing awkward MMH postures (Hoe et al., 2012; Hoe et al., 2018).

Ergonomic interventions are applied to work environments to reduce the risk of soft tissue injuries and WR-MSDs (Center for Disease Control and Prevention, 2023). Assistive devices have also been developed to lessen the load on individuals to reduce risk of injury (Abdoli-Eramaki et al., 2006; Lamers & Zelik, 2021). Wearable devices such as exoskeletons may aid in relieving the demands involved in MMH tasks. (Howard et al., 2020), and have shown positive results in reducing muscle activity and spinal fatigue (Bosch et al., 2016; Cho et al., 2018; de Looze et al., 2016). While the development of exoskeletons and other wearable devices is rapidly expanding and the research available has shown injury prevention, there are many limitations including financial and physical limitations (Kuber & Rashedi, 2021). Many ergonomists therefore intervene by altering factors of the workspace or the task rather than the human operator.

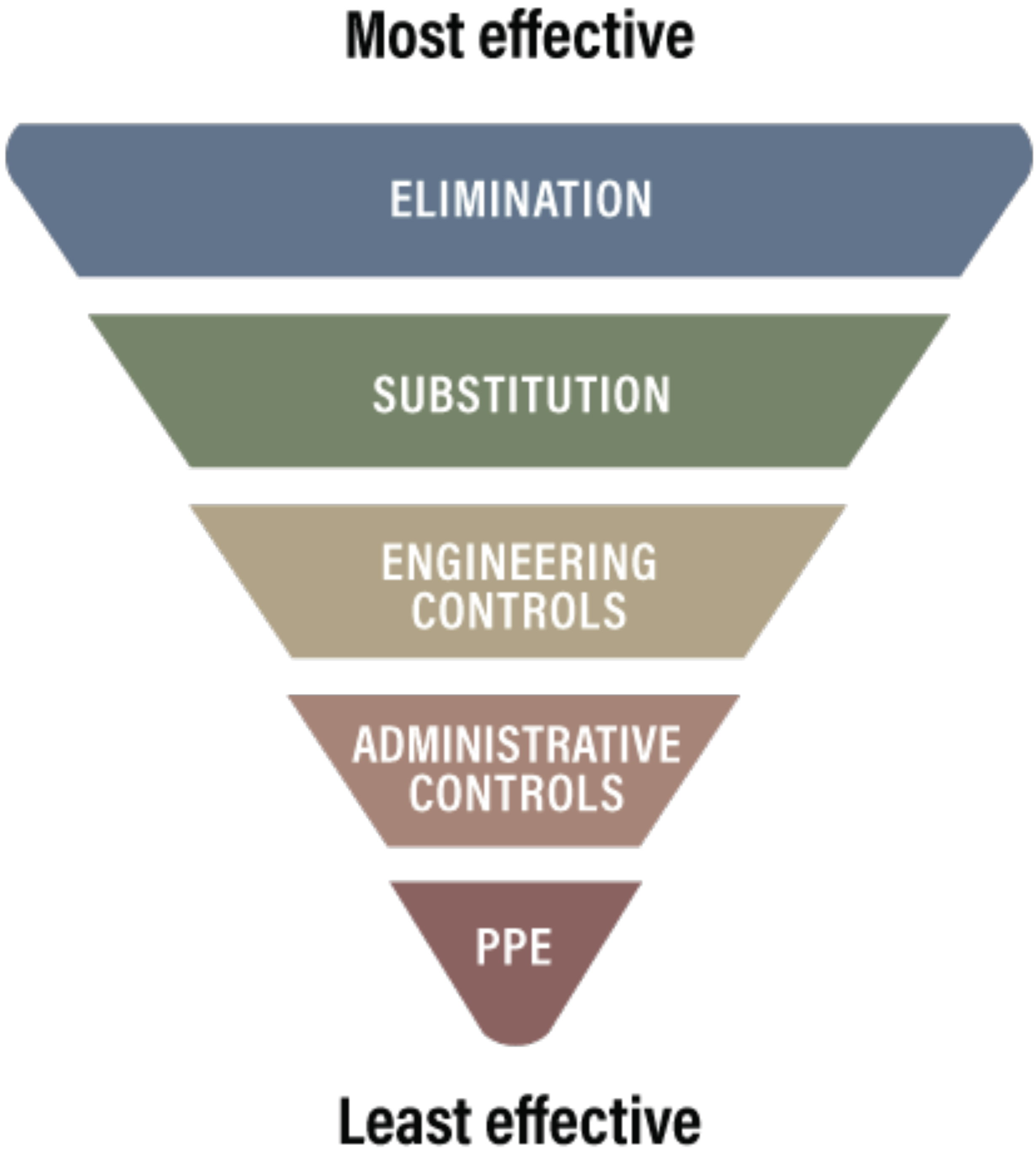

Figure 1.2: Hierarchy of Work-Related Musculoskeletal Disorder Risk Control. This hierarchy lists the five categories of musculoskeletal risk controls in the workplace from most effective to least effective category of intervention. Model from Canadian Centre for Occupational Health and Safety (2022).

1.2.5 Challenges to Ergonomic Risk Control

In a study by Marras et al. (2000) thirty-six different MMH jobs were monitored from sixteen different industries involving 142 experienced worker participants. All jobs were cyclical in nature, each with a one minute or less cycle time. Each participant was fitted with a lumbar motion monitor (LMM) and performed several iterations of job cycles, so the individual was accustomed to wearing the device prior to recording pre-intervention data including trunk motion. An ergonomic intervention determined by each company was applied to each job. The ergonomic interventions that were applied included the addition of lift tables (raising and lowering the products being handled), installation of lift aids (mechanically assist moving products), redesign of work area to increase work area safety and workflow, and installing production equipment (ease the jobs demands with new machinery or semi-automation of task; Marras et al., 2000). After it was believed the employees had been accustomed to the change, researchers then recorded the post-intervention data using the LMM. The post-intervention data were collected on average after 19 months, following the same pre-intervention protocol. This study also recorded incidence rates of LBD during both the pre-intervention and post-intervention phases. Following analysis of the post-intervention LMM recordings, jobs were grouped into High, Medium, and Low LBD-risk as defined by a risk assessment tool designed by Marras and colleagues (Marras et al., 1993). A Comparison group in which no intervention occurred was used as a control. The High LBD-risk category was not improved in either risk or incidence rate when compared to the pre-intervention data. The Low and Medium groups showed significant improvement, however, in both LBD risk and incidence rate, as shown in Figure 1.3. The ergonomic interventions' standardized effect on the High LBD-risk category decreased 1.47% between pre-intervention and post-intervention assessment of LBD risk (Marras et al., 2000). Marras et al. (2000) concluded classic physical ergonomic interventions did not reduce LBD risk or incidence rate in High LBD-risk tasks. The findings of this study indicate that ergonomic interventions designed to modify the actions of employees encounter significant challenges in their application and do not flawlessly reduce the risk and incidence rates of MSDs. The interventions for the Low and Medium LBD-risk groups were effective in this study. This well developed and highly regarded study by Marras et al. (2000) produced almost no effect on High risk-LBD group tasks, outlining the need for an enhanced approach to ergonomic interventions that will address the most LBD prone work tasks to have the largest impact in reducing the incidence of LBD.

Incidence rates of WR-MSDs are continuing to rise in many MMH occupations (Côté et al., 2009). Some ergonomic interventions are improving LBD incidence rates in some categories of study (Marras et al., 2000), but as the world-wide epidemic of WR-MSDs and LBDs continues (Driscoll et al., 2014; Hoy et al., 2014) it is clear that something is not working. Many researched interventions are impractical for MMH workplace and high risk work environment application (McGill, 2006). In many cases the interventions fail to address the underlying injury mechanisms of LBDs (McGill, 2006). Sorting through ineffective interventions to coalesce successful features and mechanisms is difficult, as much of published research highlights only effective strategies and very little research is published on the processes or theories that can explain negative effects, because of publication bias (Nielsen et al., 2006). An approach to identifying and

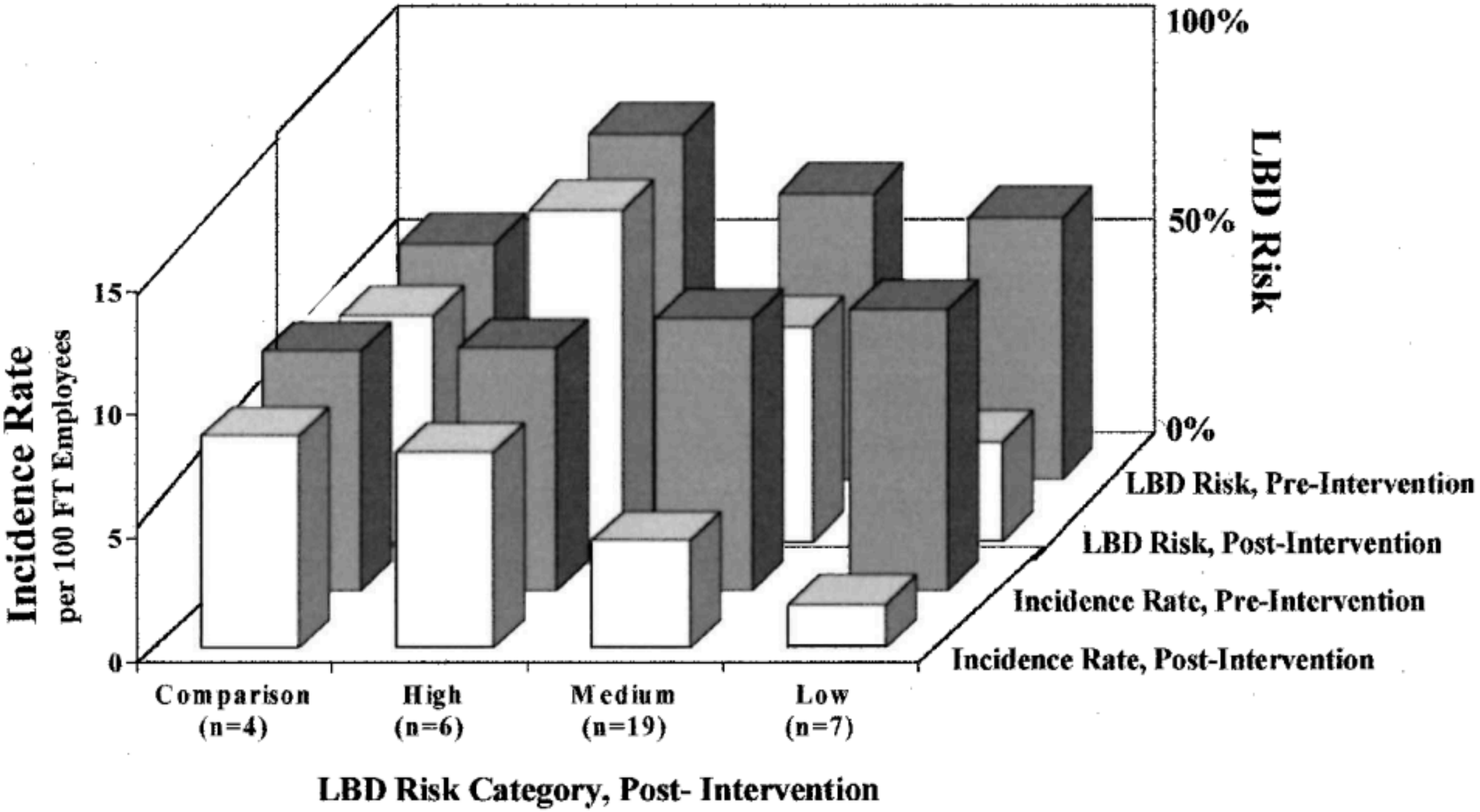

Figure 1.3: Injury incidence rate and LBD risk comparison. 142 participants from 36 different MMH jobs at 16 different companies were recorded completing several cycles of their job before and after an ergonomic intervention was employed at their workplace. Post intervention data were collected on average 19 months post intervention. The control group for the study (Comparison group) had no intervention. Categories of high, medium, and low were determined from the post intervention data, and compare the LBD risk and incidence rate of each job pre and post intervention. Results show a significant correlation in incidence rate and LBD risk factor, with a greatly decreased incidence and LBD risk in the low and medium categories, but post-intervention risk and incidence for the high LBD risk category and the Comparison group remained consistent with the pre-intervention measurements. (Marras et al., 2000)

addressing the causes of LBDs rather than the symptoms would involve adopting a more holistic view to ergonomics beyond reactively changing the working environment and instead involve proactively changing a workers' behaviour (McGill, 2006).

For a successful reduction of LBD incidence rates, ergonomists must consider changing an individual's behaviour to fit a task while also altering a task or work environment to fit better with an individual's behaviour (McGill, 2006). Faber et al. (2007) identified that individuals may change their behaviour in response to ergonomic interventions such as reducing load mass, decreasing reaching distance, and altering lifting height. They found these behavioural changes resulted in attenuation of the intended ameliorative effects such as individuals reaching from further away when load mass was decreased (Faber et al., 2007). The Theory of Risk Homeostasis by Wilde (1998) offers a possible explanation for these findings. Risk homeostasis posits that individuals accept a particular level of subjectively evaluated risk when partaking in any activity; therefore, as some risk factors are decreased, workers may increase their risky behaviour in other risk factors. These coupled challenges of behaviour changes and lack of effective control of the high-risk categories of MMH tasks further complicates reducing LBD risk and incidence rates because of increased complexity and individuality between different workers attenuation strategies to ergonomic intervention. Taking an ergonomic approach to design and redesign would require considering many of the interactions of a worker and the equipment, as well as worker to worker, and worker to other aspects of the environment (Wilson, 2014). This multifactorial approach requires a consideration of an individual's behaviour when interacting with their work environment.

Altering the physical workspace in attempt to reduce LBD risk and LBD incidence rates is difficult for high-risk jobs (Marras et al., 2000), especially when workers can develop emergent behaviours that attenuate the effectiveness of interventions (Faber et al., 2007). Developing interventions that take both issues into consideration requires a whole systems approach to studying the workplace, highlighting further areas for development of ergonomic intervention. Both issues may be occurring because workers were trained initially and then continued completing their cyclical tasks over many years before the intervention was introduced. This repeated consolidation of how a certain task should be completed may be the causal factor of why interventions can be unsuccessful. Additionally, experiences outside of the workplace (e.g., hobbies, physical activity) shape a person's understanding of physical literacy and health and affect a person's understanding of how things could be done safely in a work environment. This impact on work behaviours can affect the effectiveness of interventions by influencing how workers *could* complete their work behaviours with an integrated intervention because of how they think they *should* complete their work tasks (Hoogendoorn et al., 1999). This consideration of work behaviour and personal factors suggests an interdisciplinary approach to ergonomic intervention by considering worker's traits, cognitive aspects in ergonomics, and work behaviour. This approach to developing risk controls may be able to overcome the psychosocial and practical limits present in current ergonomics.

1.2.6 Interdisciplinary Ergonomic Approach to LBD

In a meta-analysis of epidemiological studies of risk factors for LBD, Skovron (1992) identified the need for an interdisciplinary ergonomic approach that could adequately test the relative importance of biomedical, mechanical, and psychosocial factors involved at both the onset and duration of LBD. To systematically review the etiology of LBD, Hoogendoorn et al. (1999) compared studies identifying LBD risk factors from physical loads from both work and leisure activities. The researchers found MMH, repetitive bending and twisting, body vibration, and heavy physical work were all strong risk factors for LBD, while no leisure activities had evidence as risk factors for LBD. More recent studies examined psychosocial factors and identified stressful or monotonous work to be linked to LBD onset 12 or 24 months into employment (Harkness et al., 2003), where low job satisfaction and low social support were identified as risk factors for days off work due to LBD (Hoogendoorn et al., 2002). It seems clear that cognitive demands, psychosocial loading, and personal traits are all important additions to the physical loads at work that influence the incidence of LBD. This cumulative causation also suggests the need for a deeper interdisciplinary approach to designing interventions to control risk factors and reduce incidence rates of LBD and other WR-MSDs in the workplace.

1.3 Ecology of Human Performance at Work

The relationship between humans and our environment is reciprocal as the environment impacts what people do and how they do it, just as humans both seek certain types of environments and modify select environments to suit specific tasks and deliver desired opportunities and outcomes. In a work context, each worker brings a certain knowledge and set of skills gained from experience to the job, along with certain motives and personal characteristics (Gilbert, 2013).

1.3.1 Dunn’s Model of the Ecology of Human Performance

The Ecology of Human Performance (Dunn et al., 1994) suggests action or performance results after an actor with a goal completes a series of tasks they perceive as available and appropriate for that intended performance, based on the actor’s interpretation of their current context. Table 1.1 provides definitions for many terms used in the model of The Ecology of Human Performance (Dunn et al., 1994). This model situates the person inside their context, where that context changes with respect to demands and possibilities depending on the persons’ specific perceptions and capabilities. This context then, specifically the person’s perception of it, dictates which tasks and actions are selected to generate a performance. Figure 1.4 illustrates Dunn’s basic model for the Ecology of Human Performance (Dunn et al., 1994). Context includes physical demands, psychosocial strains, environmental conditions, individual cognitive and physical factors, and state changes, among many others. Each of these factors contribute

Table 1.1: Terms Defined from the Model of the Ecology of Human Performance (Dunn et al., 1994).

Term	Model Specific Definition
Person	Individual considered in the model is embedded within their personal factors and environmental factors.
Context	Volume surrounding the person represents the biopsychosocial environment that the person is in. This environment, what it contains, and how the actor perceives it relative to their perceptions of their own capacities and needs all influence how the person selects performance relevant tasks.
Task	The encircled T's represent various alternative tasks. The interaction of the person's perception and context determine which tasks they select to generate a performance.
Performance	The outcome of individual tasks that deliver the intended outcome a person can complete depicted by different pathways is considered performance.
Performance Range	Tasks related to generating the desired performance and perceived as pertinent and completable by the person are spotlighted in this select area known as the performance range.

to the contextual lens of alternative tasks, and thus context in this model influences performance.

Applying The Ecology of Human Performance Model by Dunn et al. (1994) to the workplace highlights the combined context of interrelated personal, work, and environment factors that an individual must perceive on every work performance to complete their daily assigned performance(s). This model considers the affordance of ecological context due to the interaction of a person and their working environment, determined by personal factors, environmental factors, and occupational factors (Dunn et al., 1994). Within the model, a task consists of a group or set of behaviours that are objective and necessary to accomplish a performance. A person's skills and abilities that are used to perform a task must be supported by their environment's cues and features. A person will determine which tasks they can and should complete to deliver their required occupational performance based primarily on their perception of their skills, environment, and biopsychosocial potential and limits. Figure 1.4 is a basic model of the Ecology of Human Performance, while Figure 1.5 demonstrates the relationship for an individual person's context and focus on a specific performance (Dunn et al., 1994).

The Person's perception of context, including understanding of their skills and abilities, result in affordance differences between Persons as shown in Figure 1.5. Dunn et al. (1994) coined this resultant scope of relevant tasks or actions as the performance range. In environments where a person's skills and abilities are complimented by their perception of context, the performance range can be quite large, as shown for

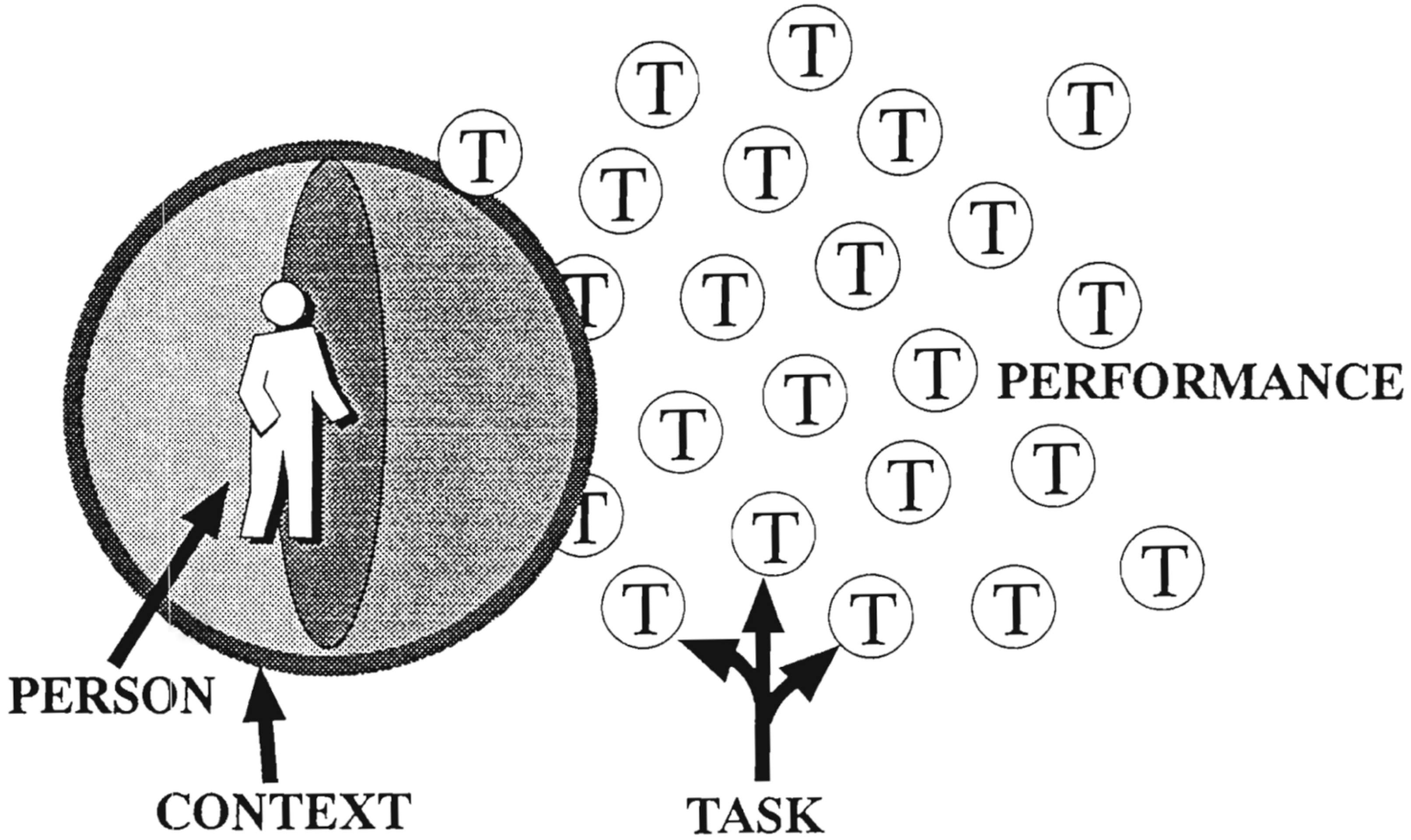

Figure 1.4: Model of Ecology of Human Performance. Model involves considering a Person within their personal Context. This contextual lens encompasses the environment plus the skills and knowledge possessed by the Person, and also includes their values, beliefs, and past experiences. This lens is therefore specific to a person and situation, and subsequently impacts what Tasks are perceived as relevant and completable (through the lens of the Person's context) when the person is attempting to reach a desired Performance or outcome. (Dunn et al., 1994)

Person A in Figure 1.5. Physical factors (ex. Musculoskeletal health, flexibility, strength, cardiovascular function) and cognitive factors (ex. confidence, decision making, and concentration) also modify or alter a perceived performance range. Each person that may participate in many of the same categories (example: father, low socioeconomic status, part time wood worker, and accountant) may still perceive a unique configuration of behaviours (identified here as tasks) to complete resulting from their physical and cognitive factors, and demands of their specific context (Dunn et al., 1994). Environmental features may negate tasks because they do not suit biopsychosocial factors or they are outside the individual's current abilities, thus restricting the performance range (Dunn et al., 1994). As shown in Figure 1.5 with Person B, an actor may be well equipped with skills and abilities preparing them for success. Perceptions of contextual limits like lack of resources, incomplete orientation within a new working environment, or excessive MMH distances and demands are examples of challenges that narrow performance range.

Similar to Dunn et al. (1994), other researchers have developed models to characterize the influence of personal and environmental factors on human behaviour in specific contexts (Kaplan, 1983; Moos, 1980). Like Dunn et al. (1994) these models characterise the intersection between the internal factors possessed by an individual and the perception of external factors stemming from their physical, psychosocial, and socioeconomic environment that generate specific and relevant opportunities, actions, and outcomes at work. These relationships between a person's internal and external factors result in specific perceptions and actions, a relationship well documented in Gibson's Theory of Affordances (Gibson, 1979).

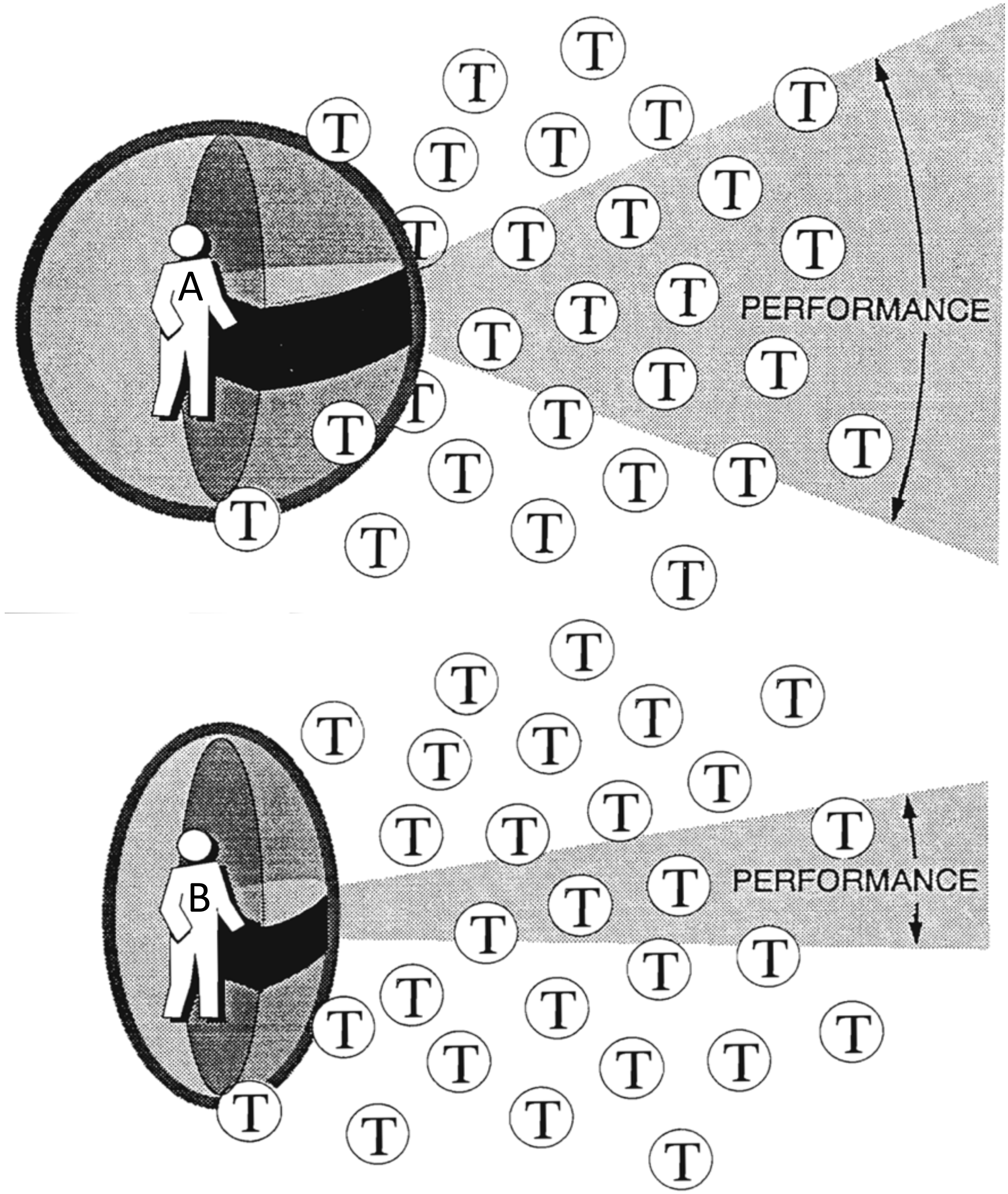

Figure 1.5. Model of the Ecology of Human Performance with Typical Performance Range vs Limited Performance Range. Person A has skills, knowledge, abilities, culture, and experience that are relevant in their current plentiful environment to allow for a large perceived performance range of many alternative behaviours (tasks) to complete their intended action (performance). Person B also has a large capacity of perceived skills, knowledge, abilities, culture, and experience that may be relevant to their intended goal, but they are within an environment with perceived constraints, therefore a limited performance range exists for alternative tasks they are able to select to generate performance.

1.3.2 Theory of Affordance and Perceiving our Environment

Gibson (1977) proposed a theory of affordances to describe the use of an object within an environment perceived by an observer (person within the environment) as an afforded property or an affordance of the current environment. This theory was foundational in the model of Ecology of Human Performance (Dunn et al. 1994). Any use or purpose of an object within an environment perceived by an observer is an affordance based on perceptions from the actor of the object, the environment, and the person (Gibson, 1979). The perceiving of affordances is neither strictly objective or subjective in nature as it relies on factors of both the environment and the person (Gibson, 1979). The theory of affordances identifies the relationship between perception and action and clearly outlines the necessity of prospectively adapting our movement plan based on what we perceive from our environment (Randerath & Frey, 2015). Motion can be actively adjusted as cues and factors of our environment alter perception and action (Gibson, 1979). Affordances can be considered as either action-scaled or body-scaled (Fajen et al., 2008), where body-scaled affordances relate measurable dimensions of an animal's body to a reciprocal property of its environment while action-scaled affordances associate motor capacities of an animal with (or within) their environment to define if an action is possible. Therefore, an individual’s perception and understanding of their environment determines their affordances that dictate how they will behave (Turvey & Shaw, 1999).

1.3.2 Perception and Affordance Derived Action and Behaviour

Personal perception is reliant on the interpretation of sensory sources coming from visual, tactile, vestibular, auditory, and proprioceptive systems (Ratcliffe & Newport, 2017). This personal perception pairs with knowledge and beliefs about oneself including personality traits, physical characteristics, abilities, and the understanding that we exist as an individual (Stangor, 2014). This pairing relies on integrating both physical and cognitive information to construct and maintain a sense of self and capabilities (Ratcliffe & Newport, 2017). Perceiving an environment into realistic affordances is a direct perception without requiring further cognitive processes; however, cognition can make perceptions more accurate (Fajen, 2007). Skilled individuals perceive environments and affordances that are relevant to their interests or needs, and make perceptions and decisions based on their skills when encountering new environments (Dreyfus, 2002). As individuals acquire skills, they adjust their perceptions of affordances relative to the specific demands of their environment (Dreyfus, 2002; Rietveld & Kiverstein, 2014). This skill acquisition can orient individuals to possible risks in their environment; however, many cumulative risks are invisible within a work environment and many unsafe handling behaviours do not provide instantaneous discomfort but instead manifest in the form of micro-trauma, which can build up over many years before an individual experiences any physical discomfort (McGill, 2015b). Training individuals to perceive risk of cumulative injury in the working environment is difficult because of the complex multifaceted nature of risk perception and decision making (Brown, 2014; Gibson, 1986).

1.3.3 Occupational Affordances

The Theory of Affordances (Gibson, 1977) has been referenced by industrial designers and ergonomics researchers including Norman et al. (1998) as having the potential to become the guiding principle for ergonomics and design fields. The analysis of affordances could produce insight into occupational behaviours that might be explained through the tight coupling between perception and action (Turvey, 1992). Gielo-Perczak and Karwowski (2003) have developed a framework to derive complex mutual relationships between the work environment and the worker, which utilizes the theory of affordances to relate a person's capabilities to their work environment's properties and features. This framework allows the modelling of affordances, and what perceptions or misperceptions of such affordances are derived and extrapolate this into various actions or behaviours that workers complete in their execution of a work task. Deriving a subsequent successful action from an affordance requires an accurate perception of both an individual's personal factors, environmental factors, and their interactions.

Employers are required to provide suitable work environments to reduce risks, inform employees of hazards, provide protocol and adequate training for the safe completion of tasks, and allow employees to refuse unsafe work (Employment and Social Development Canada, 2015). For an employee to understand their needs to complete a task safely or when task modification is required, an employee must know when, why, and how they are at risk. Knowledge of employees' perception of risk is critical for proper risk communication, risk management, and risk prevention (Portell et al., 2014).

Studies quantifying employees' safety training influence on their perceptions of risk have aided in developing safety protocols and training programs for employees (Sharma & Mishra, 2020). Additionally, increased attention to potential risks in an environment increases the emotional response to the risk including increased perceived severity, fright, and priority than other present risks (Mrkva et al., 2021). Workers are more likely to emotionally perceive risk rather than rationally consider calculated risk probability, severity, and utility (Xia et al., 2017), therefore understanding what visual factors influence emotional risk perception may highlight a difference between workers who perceive risk and those who do not under the same conditions or working within the same environment. Previously injured workers who have had a serious work place injury have a higher sensitivity to perceive risks and become dissatisfied with safety procedures that are more likely to lead to injury (Rundmo, 1995). Essentially, determining the many state and trait factors between workers who perceive risk and those who do not perceive risk in their working environment could improve intervention methods and training practices to reduce risk and incidences of injury (Namian et al., 2016; Xia et al., 2017).

1.3.4 Occupationally Relevant State and Trait Influences on Affordance and Injury Risk

State and trait factors are characteristic patterns of cognition, emotion, and behaviour (Steyer et al., 1999). Traits are those characteristics or patterns that exist among similar situations and remain relatively stable, whereas state refers to those characteristics or patterns that exist at a specific moment but can vary across time (Schmitt & Blum, 2020). Some work-relevant trait factors include experience, height, age, and gender, whereas work-relevant state factors include hydration, exhaustion, and mood. The state and trait factors associated with affordance involve both an individual's personal characteristics learned from experience, and how they relate to their current environment (Barim et al., 2019). Determining how these state and trait factors influence affordance setting is important for developing a holistic biopsychosocial model of risk and behaviour. Determining injury-risk or injury-avoidant trait factors could improve the applications of ergonomic interventions, specifically to specialize intervention techniques that will be more likely to modify the risky behaviours currently practiced.

Although work exposure is linked to musculoskeletal disorders, notably the strong association between manual materials handling and LBDs, many employees effectively avoid these injuries. In a sample of 149 MMH employees completing the same tasks within a nylon production plant, Stevenson et al. (2001) found that some developed soft tissue pain (55%), and some did not (45%). Certain task factors including lifting height, object mass, and frequency of movement have been related to determining the acceptable MMH parameters as perceived by the employee (Burgess-Limerick & Abernethy, 1998). Associations have been made between perceived risk and risk outcome such as MSD (Snook, 1999). Occupational risk perception and detection are additionally associated with existing musculoskeletal discomfort and perceived risk of lifting injury in MMH tasks (Yeung et al., 2002). Detecting risks is important to injury prevention in workers, however many slight discrepancies in both movements and postures have been identified between injury avoidant and injury prone workers. Wrigley et al. (2005) identified that the extension acceleration and extension moment of thoracic vertebrae 1, extension moment at sacral vertebrae 1, trunk compression, and box vertical velocity all differed between injury avoidant workers and workers who developed injury after this data collection. Identifying variability in lifting kinematics between injury avoidant and injury risk workers is a critical step forward, as determining the cause of this difference between lifting behaviours could lead to interventions that introduce changes of the perception stage of the task. If cumulative MMH behaviour leads to WR-MSDs, and environment and affordance perception lead to MMH behaviour strategy and repetitive task behaviour, injury-risk workers must perceive the same task environment differently than injury-safe workers, and subsequently couple these perceptions with their resulting behaviours. Quantifying what personal characteristics and biopsychosocial context lead to making certain perceptions and actions is critical to determine which different sub-groups of people make decisions to effectively avoid risks, and how they do it.

1.4 Visual Perception and Perception Action Coupling

Perception and action are coupled to generate and regulate ongoing behaviours (Thelen, 1990). This coupling effectively coordinates visual perception and musculoskeletal action within a continuous feedback system that links visual information to movement. Perception and action are functionally interdependent and changing a parameter relating to one typically influences the other (Gibson, 1979). Humans rely more heavily on visual cues with age (Bian & Andersen, 2013), specifically in luminance, motion, and symmetry (Faubert, 2002). An experience association is found when comparing expert to novice athletes, as experts have an increased control of their perception action coupling (PAC), and use a prospective control process (Mallek et al., 2017) that involves proactively anticipating movements associated with the demands or goals of an action (Hofsten, 1993) using PAC information and originating from visual attention and expertise.

1.4.1 PAC in Work and Work-like Environments

Perceptual cues are not merely passively received but are integral to guiding and shaping the motor actions that are executed in response to these cues within working environments and everyday spaces. Visual attention during movement necessitates changes in whole body coordination and orientation including trunk, head, and neck movement that can alter perceptual understanding of the environment (Peters et al., 2006). In the realm of ergonomics and human factors engineering, understanding the dynamics of perception action coupling is essential for designing work environments and tasks that enhance performance efficiency and minimize the risk of injury. The work environment may impede the efficiency of perception action coupling, reducing the workers ability to dissipate interactive forces during movement (Holt et al., 2005). This can potentially exacerbate risk factors associated with postures such as stooping, bending, or lifting (Holt et al., 2005). By examining how workers perceive and subsequently react to various stimuli in their environment including both task related items and non-task related items, researchers and practitioners can develop ergonomic interventions that are better aligned with natural human capacities, limitations, and perceptual behaviour. Addressing PAC within a work or work-like environment requires concurrent measurement of visual attention and action to assess the functional consequences of these postures and tasks (Palmer et al., 2013).

1.4.2 Measuring Visual Attention in Complex Environments

By studying the biopsychosocial and environmental factors that affect work behaviours, it is possible to identify what cues are attended to and what perceptions are coupled with a specific behaviour. Vision tracking goggles capture gaze location and gaze fixation position in an environment, and modern technologies allow for normal head movement (Grant & Spivey, 2003). This technology is worn as lens-less binocular glasses connected to a computer by a single cord over the shoulder of the individual, and three cameras are used to record the location of the two pupils and project them onto the third video, which is a capture of what is in front of the individual. The vision tracking program places a circle over the gaze location for each frame in the recording and reports the length of gaze, and error or confidence levels in that location by tracking the movement of both pupils over the task. Most gaze tracking technologies use a pupil-corneal reflex tracking method which identifies the corneal reflection and subsequently calculates the fixation point. The Pupil Core device developed by Pupil Labs uses a dark pupil detection algorithm that detects the darkest point in frame as the pupil over both a 2-D and 3-D simultaneous process. The algorithm uses a grey scale of the image, identifies edges in abrupt colour difference, defines the most dark region detected, filters edges of pupil to ensure inclusion of spectral reflections, extracts detected edges into contours and sub-contours based on continuity and curvature, determines multiple possible and often overlapping pupil candidates using ellipse fitting of curvature, and finally the augmented combinatorial search filters through candidate pupil locations to determine the best fit (Kassner et al., 2014). This technology has been used in hundreds of studies successfully finding links between visual attention and decision making (for example, Das et al., 2022; Faraji et al., 2022; Perrier et al., 2022).

Eye tracking and gaze capture technology has been applied to many areas of human performance including attentional focus during dart throwing (Asadi et al., 2022), cognitive function changes during plant viewing (Sugano et al., 2022), and visual control when aiming at a far target (Vickers, 1996b). This technology easily allows for gaze tracking to detect common focal points in complex environments such as during MMH tasks or activities of daily living (Land et al., 1999). While each application involves a specific use of the technology, many follow a similar structure. Kuhn and Kingstone (2009) specifically used eye tracking to determine if gaze direction is influenced by where another person is looking. It was determined that even when participants are instructed to not follow the eyes on the screen because they are incorrect 50% of the time, participants still selectively followed the direction of the other set of eyes instinctively (Kuhn & Kingstone, 2009). Gaze tracking technology is used to study the quiet eye (QE), defined as the final gaze fixation on a target during the preparation of a goal-directed movement (Wilson et al., 2015). Expertise is often considered as an independent variable in QE research (Panchuk et al., 2017).

1.4.3 Measuring Action in Experimental Occupational Tasks

Determining task demands involves studying body movement during experimental MMH. Using a biomechanical model of MMH behaviour researchers have been able to study the forces and impacts on the body throughout different lifting postures and techniques (Burgess-Limerick & Abernethy, 1997). Reflective infrared-marker motion capture are used in research to identify joint and bony landmark locations through a 3-D video of task completion (Cappelli & Duffy, 2006). These motion capture recordings can be used to identify acceleration, bending moment, and other behavioural values such as crunch factor, which is a validated measure of low back motion that combines axial rotation and axial velocity (Cole & Grimshaw, 2014). These methods have been applied to various fields involving models of complex environments including many sports applications (Ball et al., 2019). Measuring low back movement during industrial manual materials handling is critical to understanding the development of low back WR-MSDs (Andersson, 1981; Frymoyer et al., 1983). Understanding the factors of disease progression in the workplace is required to combat the worldwide epidemic of

LBDs and their link to industrial work (Garg & Moore, 1992; Pope, 1989). This comprehension of physical demands on a worker and contributing factors of the workplace have been studied by many researchers over an extended time period to determine how and why certain movements and tasks differentially lead to LBDs (Rowe, 1971).

Various devices and equipment have been used in literature to measure macro and micro body movements to understand risks associated with completion of specific tasks. The markered motion capture system typically uses a ring of infrared lights that surround an infrared camera. These lights reflect off markers on the body segments of an individual completing the experiment and are detected by the cameras. Cameras are oriented around a 3-D task space and calibrated to record accurate synchronous video between each camera to determine body posture at different parts of a task, and body mechanics of the movements in and out of extreme postures. This infrared reflective markered motion capture system has been used to collect biomechanical data for research in complex environments including athletics and in clinical applications (Mirek et al., 2007). The precision and accuracy exemplified in multi-camera systems make them reliable for professional athletics, clinicians, and ergonomists (Windolf, Götzen, & Morlock, 2008). Gooyers, Beach, Frost, Howarth, and Callaghan (2018) applied this technology to identify interactive effects of low back joint loads during MMH tasks.

1.4.4 Measuring Visual Attention and Action in Experimental Occupational Tasks

Researchers have combined the methods of motion and visual attention capture in many areas, notably in sport and activity, where precise motion is critical for successful performance (Panchuk & Vickers, 2006; Panchuk et al., 2017; Rodrigues et al., 2002; Vickers, 1992, 1995, 1996a; Vickers & Adolphe, 1997). These studies have identified success markers in both visual attention and motor behaviour while completing a specific task i.e., putting in golf, free throws in basketball, goal tending in ice hockey. The success in these experiments advocates for studying motion and vision behaviour simultaneously to gain insight into behaviour markers that neither technology can identify alone. Congruent capture from these behaviour measuring devices has been used in other areas as well including marking developmental coordination disorders in children, and in work environments including policing (Miles et al., 2015; Vickers & Lewinski, 2012). The latter policing study compared a group of rookie and elite officers on markers of accuracy of decision making and physical performance while under pressure and provided insight to perception action coupling, gaze control, and the importance of training for proper decision making in high stress situations.

1.4.5 Coupling it all Together

Affordances are produced from the interaction of occupational environments and workers, and perceptions of such affordances could be biased or distorted, which subsequently could be a consistent precursor to injury-risk actions/ behaviours that accumulate load, through various mechanisms, onto relevant musculoskeletal structures, leading to WR-MSDs in repetitive MMH tasks. The hypothesis is that individuals can be defined as **hyper**-affordant or **hypo**-affordant to an occupational task, context, or system, that this bias is not entirely explained by differences in physical characteristics and capabilities (the associations primarily established under Gibsonian psychology) but rather that occupational affordances are additionally and critically influenced by both transient state and permanent trait psychophysical capacities.

1.5 Project Outline

These theories and hypotheses have produced quantifiable research questions as follows:

1.5.1 Does vision tracking expose a useful association in manual materials handling between gaze behaviour and affordance setting and occupational behaviour?

1.5.2 Do dynamic and static reaching tasks differently influence workers' gaze behaviours and perceptions of safe horizontal handling affordances and occupational behaviour?

1.5.3 Outline of Thesis

The following chapters of this thesis will address the answers to these research questions.

Chapter two is an experimental chapter that will examine the association between perceived affordances, occupational psychophysics, and visual attention in an experimental MMH task.

Chapter three provides a global discussion to answer the research questions and will bring attention to the limitations of this experimental work.

Chapter 2 : Kinematic and Gaze Behaviour Differs by Perceptotype in MMH Task

2.1 Introduction

Work-related musculoskeletal disorders (WR-MSDs) is a broad term that describes any work-related disorder or disease caused by any factor (and typically multiple and cumulative factors) relating to an occupational environment or occupational behaviour (Hales & Bernard, 1996; Lin et al., 1997). In occupational environments, work tasks risk the development of WR-MSDs through cumulative loading of tissues leading to tissue fatigue (Brereton & McGill, 1999; Janssens et al., 2010) and accumulation of microinjury (Marras, 2012). WR-MSDs commonly cause discomfort that may intensify if left untreated into severe and long-term pain, injury, and disability, challenges that impact hundreds of millions of workers worldwide (Adegoke et al., 2008; Motacki & Motacki, 2009). Low back discomfort, disorder, and damage, collectively referred to as LBD (Marras et al., 1993), is one of the most costly and common forms of WR-MSD and all work-related disability (Dempsey, 1998), affecting 80-85% people at some point during their lifetime (WHO Scientific Group, 2003), and in 2017 approximately 577 million people globally were actively experiencing LBD (Wu et al., 2020). LBDs are often resultant from employment exposure, with between 11-80% of the occurrences linked to work factors (Marras, 2012). Lumbar loading from manual materials handling (MMH) tasks is significant and involves many injury risks including repeated sub-maximal loading that leads to tissue fatigue, resulting in decreased load tolerance of tissue over time (Brinckmann et al., 1989). The tissue fatigue and subsequent injury are primarily caused by the accumulation of micro-trauma to the intervertebral discs of the low back

(McGill, 1997). This trauma often involves several types of mechanical loading including compressive, shear, and torsion forces (Kumar, 1990) caused from behaviours including bending, lifting, carrying, and transferring materials (Brinckmann et al., 1989). These risk factors lead to LBDs based on their intensity, duration, repetition of loading, in combination with awkward reaching or lifting postures that compromise tissues and exacerbate loads (Hoogendoorn et al., 2000).

Ergonomic engineering interventions have been applied to MMH tasks and effectively alter selected kinematic measures including reaching distance, lifting height, and applied load. However, these interventions may introduce unintended, even counter-productive, changes to work behaviour. For example, Faber et al. (2007) identified counter-productive behaviour in response to ergonomic interventions, including increasing lumbar torsion angle when load mass was reduced and increasing lumbar lateral flexion angle when the working surface was lowered from shoulder to hip height. Biomechanical differences in kinetic lifting waveform patterns between injury-avoidant and injury-prone individuals before the onset of LBD have been identified (Wrigley et al., 2005), while personal, physical, and psychosocial risk factors that affect behaviour and lead to differential development of LBD have also been suggested (Marras et al., 1995). Taken together, these findings suggest that important intersections among personal characteristics may influence how individuals perform MMH tasks, and that cognitive and psychosocial factors are relevant contributors to the work behaviours that ultimately generate the cumulative mechanical loads causing LBD. Personal state and trait characteristics including expertise (Plamondon et al., 2012) and risk homeostasis (Wilde,

1998) may also affect behaviour at work, and possibly the likelihood of resulting WR-MSDs. These characteristics can effectively moderate the perception process characterized by selection, organization, and interpretation of visual stimuli to understand the environment (Duncan, 1984). Action follows perception in a coupled relationship (Warren, 1990), and identifying subtle differences in action (Burgess-Limerick & Abernethy, 1998; Wrigley et al., 2005), possibly as associated with state and trait characteristic differences between injury-avoidant and injury-prone workers, may lead to the development of robust interventions to alter work behaviour. Gibson (1977) proposed the Theory of Affordance identifying the dependency between person and environment and defining affordance as the actions a person perceives completable based on the person's perception of their environment and their abilities. Similarly, Dunn et al. (1994) proposed a model for the Ecology of Human Performance that defines an actor's perception of their capabilities and environment as personal context that ultimately directs what potential tasks they attempt to complete to produce performance. Applying this model to the workplace highlights the complex system of interrelated personal and environmental factors that provide a context workers will constantly experience and perceive while they determine how they complete work. Considering perception action coupling in the workplace through the theoretical works of Gibson (1977) and Dunn et al. (1994) could be a useful approach to understand injury-avoidant and injury-prone behaviours among workers engaged in MMH. Articulating this foundation as a theory, we can postulate that distorted or inaccurate perceptions of context exist that are generated by state and/or trait characteristics of injury-risk individuals. These distorted perceptions lead to selecting and completing actions that exceed a safe level of cumulative loading and can cause injury. In the occupational example, the difference between safe and unsafe action does not need to be large to lead to injury because the musculoskeletal demands load the system chronically and cumulatively.

This study aimed to identify affordances amongst a sample of novice lifters completing a MMH task with relevant real-world parameters, namely handling task and load motion state. Vision tracking was used to characterize visual perceptual strategies and identify relationships with perceived affordance and work behaviours. Motion capture technology was used to quantify kinematics as a measure of action. We predicted that the convenience sample could be sub-divided into distinct groups of **hypo**-affordants and **hyper**-affordants based on their normalized perceived affordance threshold for the MMH task. This sub-division of **perceptotype** would establish two groups that we predicted would differ on both perception and action measured as visual attention and kinematics of lifting behaviour respectively and would also differ on many associated factors including risk taking (as a possible predictor of their distorted perception). Specifically, **hyper**-affordants would have increased normalized perceived affordance, higher scores for risk taking as a characteristic, would use less total visual attention and direct that attention to less relevant visual information, and would use larger displacements and velocities for axial rotation and lateral flexion during MMH. These perceptual and action differences would be exacerbated with DYNAMIC targets that require interceptive action, where the additional spatiotemporal constraints of contacting the object at a specific perceived affordance distance would require initiation of the movement at a specific time and with a planned velocity (Fajen et al., 2008).

2.2 Methods and Measures

2.2.1 Participants

Participants were recruited from the undergraduate population at the University of Lethbridge. Participants were compensated with class participation marks in the course from which they were recruited. The participants each signed their informed consent after receiving a verbal description of the requirements for participation. The height and weight of each participant was measured, and all participants reported normal vision or corrected to normal vision with corrective wearable lenses. Participants were seated at a computer where they completed a set of electronic questionnaires sequentially, including a COVID-19 screening questionnaire (Appendix 2.A) The COVID-19 screening questionnaire was used as exclusion criteria. The Physical Activity Readiness Questionnaire was completed as revised by Thomas et al. (1992; PAR-Q; Appendices 2.B) and all participants reported no injuries or pain that would prohibit participation in physical activity including transferring weight through manual materials handling during the experiment.

Subsequent to COVID-19 screening questionnaire, participants provided demographic information (Appendix 2.C) and completed work-related questionnaires (Appendix 2.D, Appendix 2.E). Participants were instructed to consider their average school day as their average workday if they did not work regularly for pay outside of school. Physical demands at work were self-reported using the Daily Physical Demands Questionnaire by Torgén et al. (1997; Physical Activity at Work Questionnaire; PAW-Q; Appendix 2.D). These responses were analysed and used to create comparative categorical scores between question type to compare **perceptotype** sub-groups. Musculoskeletal pain and discomfort in different anatomical areas was self-reported within the Standardized Nordic Questionnaire for Analysis of Musculoskeletal Symptoms initially validated by Kuorinka et al. (1987; SNQ-AMS; Appendix 2.E).

Following the MMH trials, participants completed the Eysenck Personality Questionnaire by Eysenck and Eysenck (1977; EPQ; Appendix 2.F). The EPQ was used to self-report risk taking behaviour as a trait, and results included an overall score (OALL) as well as risk-taking (RISK), liveliness (LIVE), non-planning (NPLA), and impulsiveness (IMPL) factor-scores that were all used in analysis. Questionnaires were completed by participants through a Qualtrics electronic form (Qualtrics, Provo, UT). Two participants were unable to access the electronic platform following their MMH trials and were instead instructed to complete a paper copy of the EPQ questionnaire, with those data transcribed to Qualtrics by investigator.

2.2.2 MMH Task and Perceived Affordance Threshold Setting

The experimental set-up included an anti-fatigue mat the participant stood on, facing a gravity roller system (Nestaflex, Cleveland OH, USA) that was secured on top of a hydraulic lift (Pentalift, Puslinch ON, Canada) as shown in Figure 2.1. The participant was instructed to stand with shoulder-width stance and asked to not move their feet once comfortable. The working surface on the rollers was 1.5m and 2m in length during the STATIC and DYNAMIC conditions respectively. The investigator adjusted the height of the hydraulic lift to position the working surface (or top of the roller system) at 51% of the participant's height to limit the subsequent impact of anthropometric differences between participants. During STATIC trials the roller system was horizontal and during DYNAMIC trials the left end was lowered, and the right end was raised while the center remained at 51% of participant's height, creating an angle of 30 degrees from parallel to the floor. The MMH task object was a black cube with face lengths of 30cm, and no handles or graspable features on faces. The box was latched closed and hollow, weighing 8kg.

The participants were randomly assigned into one of two groups that determined the order in which they completed the MMH task conditions, specifically starting with handling a STATIC or DYNAMIC object. The initial random assignment into two groups were named dynamic.B (d.B) and dynamic.A (d.A) groups. The d.B group completed STATIC trials and then DYNAMIC trials whereas the d.A group began with their DYNAMIC trials followed by their STATIC trials. The investigator ensured the readiness of both the vision tracking and motion capture systems before reading the STATIC or DYNAMIC task script explaining the task to the participant (Appendix 2.G). The task script directed the participant to imagine they were working as a package handler tasked with transferring boxes from their right side to their left, by sliding the object across the rollers. The script instructed participants to imagine they would be completing this task for 8 hours and they would not be able to change their distance once it was set, though they would be completing this task at their set distance repeatedly for the 8 hours. The participants were told the experimental MMH task would occur multiple times, and their maximum repeatable safe horizontal reaching distance should be set based on how they feel after observing the task and testing various postures. Following the script reading, either a blank trial (d0) for the DYNAMIC task or perceived affordance threshold trial (s0) for the STATIC task was completed. The perceived affordance threshold trial (s0) required participants to select their largest repeatable safe horizontal reaching distance to handle the object. The distance was later measured during handling trials using markered motion capture and recorded as perceived affordance threshold (AT). After the perceived affordance threshold trial, the participant completed five handling trials with the STATIC task condition (trials s1-s5) starting from a still, neutral, forward-facing position with their hands at their sides at rest until the investigator said “okay” when both the vision tracking, and motion capture systems were pre-recording. After reaching to their right and translating the MMH task object from their AT distance past their center line to the left the participant returned to their neutral posture and were ready to complete the next trial.

The blank DYNAMIC trial (d0) allowed the participant to observe the speed at which the object translates from their right to their left due to force of gravity acting on the mass on the inclined rollers. After completing the trial d0, the participant completed five DYNAMIC task condition handling trials (trial d1-d5) starting from a still, neutral, forward-facing position and ending when the investigator released the object. The box began sliding across the rollers approaching the right side of the individual where the participant intercepted and guided it to the end of the rollers on the participants’ left side before releasing it. They were instructed to intercept the object at their maximum perceived safe lateral reaching distance during DYNAMIC trials. Between each trial, the

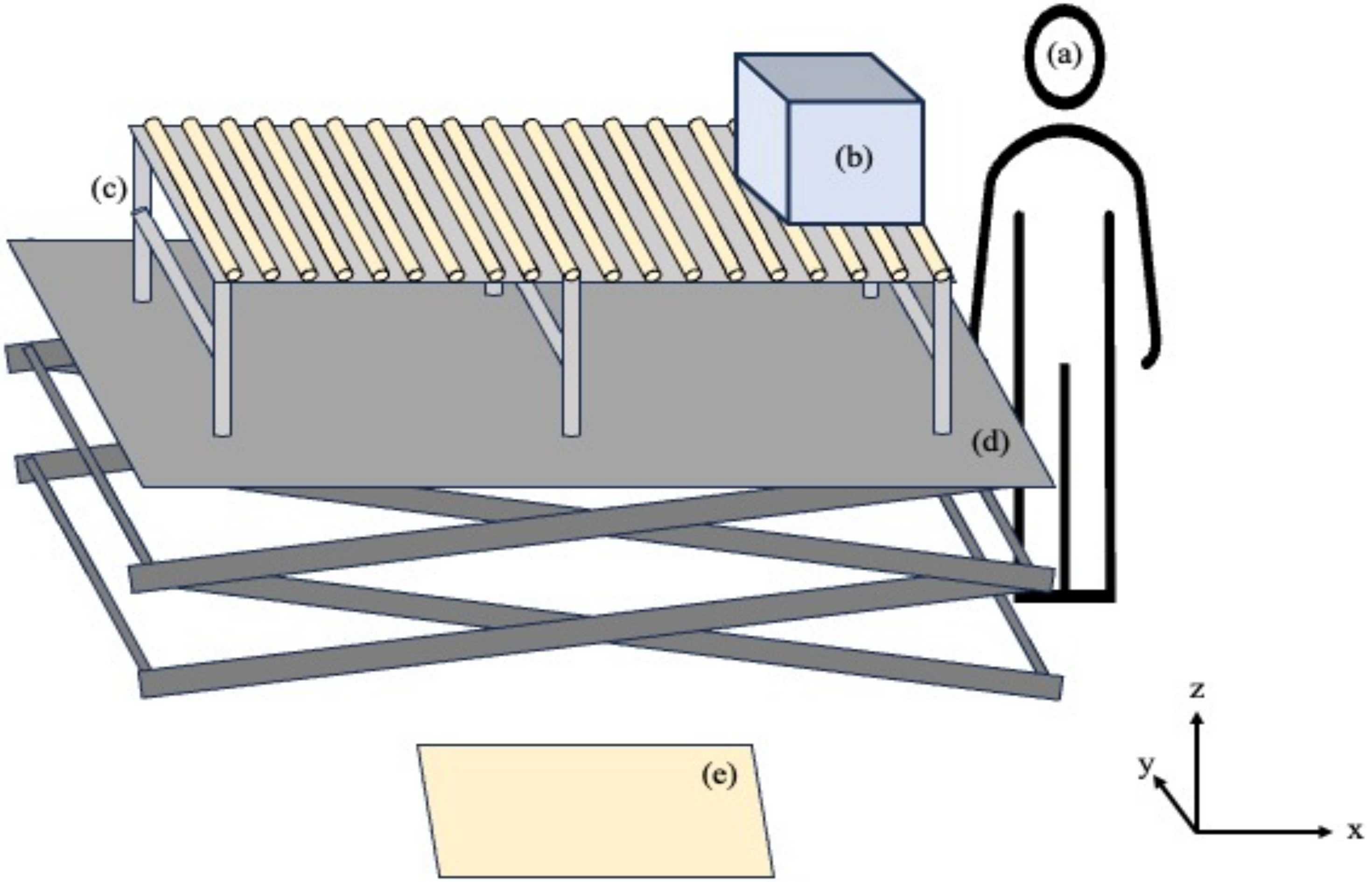

Figure 2.1: Experimental Set-Up of Perceived Affordance Threshold and Static MMH Trials. During Dynamic MMH Trials the roller system was positioned at a 30-degree angle sloping downward to the left of the participant and away from the investigator. Coordinate system used to spatially locate body segments of participants during MMH task shown. (a) Investigator (b) Task object (c) Roller system (d) Hydraulic press (e) Anti-fatigue mat the participant stood on.

participant stood in a relaxed neutral posture while the investigators moved the object back to its starting place on the right of the individual. In total, each participant completed five MMH trials with a STATIC object (s1-s5) and five MMH trials with a DYNAMIC object (d1-d5).

2.2.3 Motion Capture

Passive infrared reflective markers were fitted bilaterally to the participants' close-fitting clothing or exposed skin at (a) the posterior acromion process, (b) the lateral epicondyle of the humerus, (c) the ulna styloid process, (d) the lateral iliac crest, (e) the femoral lateral condyle, (f) the lateral malleolus, and the spinous processes of vertebrae (g) C7 and (h) L5. The distance between markers was measured and recorded. Three additional infrared-reflective markers were placed on the top of the task object at (i) the front center, (j) the midline centre, and (k) the back right corner, and one marker was placed on a post in front of the participant that signified the center point of the working space. The participant then donned the vision tracking goggles (PupilLabs, Pupil Core), and these featured two additional reflective motion capture markers (l) on vertical face of the goggle arms, at the most anterior aspect.

The Vicon Motus package was used to record biomechanical data with four infrared (IR) cameras positioned at different locations in the laboratory pointing toward the working space. The cameras were each surrounded by IR light-emitting diodes, and the IR light was reflected by the markers placed on the individual and detected by the IR cameras. The cameras were calibrated together around a 1m x 2m x 2m volume, synchronized to detect 4-dimensional marker movements, and record at a frame rate of 120Hz as the task was completed. Within this calibrated volume the cameras mapped cartesian coordinates of x, y, and z as shown in Figure 2.1 and recorded time elapsed as variable t. The body segment movement data were manually assigned to each corresponding bony marking label which linked the proper marker positions together. The measures extracted from this raw data involve displacement and rotation of bony landmarks and body segments during the MMH task. The measures of interest for this study include affordance threshold (AT; m) as a measure of the perceived maximum safe lateral reaching distance each participant selected in trial s0. The AT was measured from the centreline of the participant in a neutral posture to the mid-point of the object's selected location.

2.2.4 Vision Tracking

The vision tracking goggles worn by the participant recorded a world view in front of the participant and two cameras tracked the participants eyes recording their pupil activity. All three cameras were oriented into proper position for each individual. Calibration of the goggles required the participant to be seated in front of a laptop computer screen and maintain a still head and neck position while adjusting their gaze to focus for 3-5 seconds on 5 sequential points that appeared on the corners and center of the screen. The points appeared as targets with a coloured center inside of two grey rings. The colour changed from red to green as the participant fixated their gaze on the coloured center but remained a steady or flashing red if the eye cameras could not detect a pupil, or if the world view camera was not properly positioned. The calibration process aligned the world view camera and two pupil-detecting eye cameras, which established a synchronized orientation that not only ensured their focus convergence but also enabled seamless superimposition of real-time gaze position data onto the world view for live gaze position tracking by the researcher.

The PupilLabs Pupil Core package was used to record gaze tracking and visual attention behaviour during the affordance distance setting trial and MMH trials. A custom Python (Van Rossum & Drake, 2009) script was developed for a user interface (UI) to complete data processing of vision and gaze tracking data, and is included in Appendix 2.H. Measures extracted for analysis include duration of gaze, location of gaze, quantity of fixation, and frame count during each phase of the trial of the perceived affordance threshold setting trials. The gaze and fixation locations recorded include front side, front edge, leading side, leading edge, critical edge, object top, rollers, researcher, “off” working space, and error frames (no gaze detected) as labelled in Figure 2.2

2.2.5 Data Processing and Analysis

STATIC and DYNAMIC trials were both processed and analyzed for MMH kinematic and vision tracking results. In some cases, the same trial was used for motion capture and vision tracking analysis, however inconsistencies in data quality due to world view camera positioning and low confidence of gaze location made trial selection variable. Low data quality in both vision tracking and motion capture data sets also limited analysis of MMH trials to one example from s1-s5 and one example from d1-d5

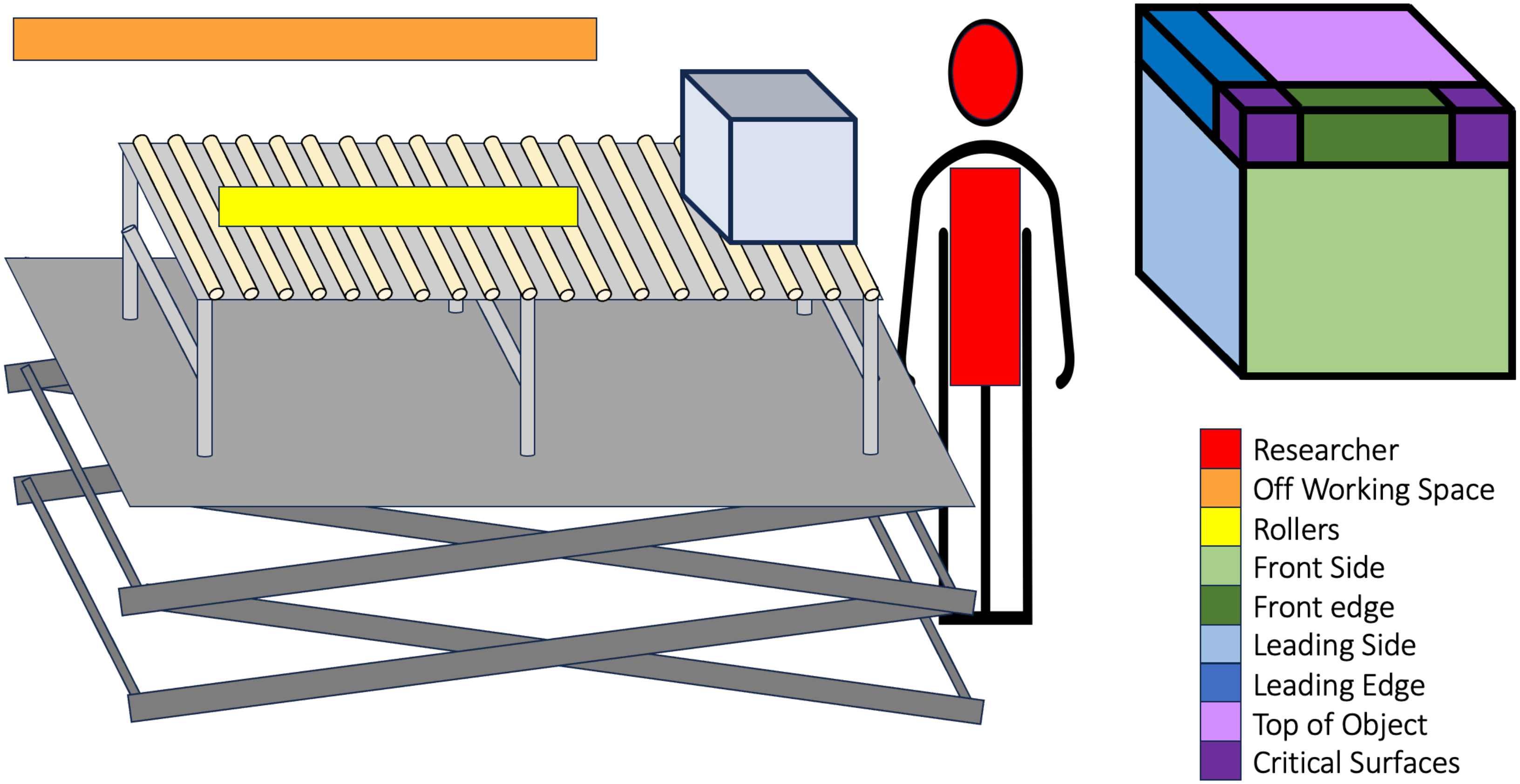

Figure 2.2: Experimental Set-up and Gaze Location. In our experimental setup, we categorized object sections as "side" or "edge." All other areas were classified as "off of the working space," "rollers," or "researcher." Participants focused on dark purple corners, labeled as "critical" and later as "usable" surfaces. Other surfaces and edges were color-coded (dark/light blue, dark/light green, and light purple) as "unusable." The researcher, off working space, and rollers were represented in red, orange, and yellow. The categorization of object and surrounding surfaces involves a high level of specificity, enabling the recognition of many gaze patterns before categorization into usable and non-usable. Anti-fatigue mat is not shown because it was not within the frame of recording of vision tracking.

for each participant. The s0 affordance and s1-s5 kinematic analyses were performed on forty-three participants. The d1-d5 MMH kinematic and s0, s1-s5, and d1-d5 vision tracking analyses were performed on forty-two participants and thirty-two participants respectively.

Affordance and Normalized Affordance

The maximum perceived safe lateral reaching distance (affordance threshold; AT) was selected by the participant during trial s0 of the STATIC trials. In DYNAMIC trials the maximum perceived safe lateral reaching distance selected for the task object was considered the DYNAMIC AT. This was calculated using x coordinate data from markers of bilateral acromion process and iliac crest, and the maximum displacement of the right ulna styloid process marker. The s1-s5 and d1-d5 AT were calculated differently because the object marker was placed in a still position in s1-s5 trials and the object marker was not consistently available in DYNAMIC trials as it was out of the initial frame and in motion throughout the trial. The mean x position of bilateral acromion process and iliac crest markers over the first 100 frames sampled at 120Hz provided a center line x value for the participant's resting posture. Some participants had missing or unassignable data points in some trials, including the left acromion process and left iliac crest markers. In these cases, markers placed on the C7 and L5 vertebrae were used to calculate the reference centreline for the body. The middle centre marker on the object or right ulnar styloid process x-coordinate value was used to calculate the AT from the initial centreline. The STATIC AT was used to calculate normalized affordance threshold (nAT) by dividing each AT (m) by the participants' height (m) to limit the influence of anthropometrics. The median split method described by DeCoster et al. (2011) was applied to the STATIC nAT to create **hyper** and **hypo**-Affordant sub-groups. This binary assignment was used to mirror the injury safe versus injury risk worker sub-groups that exist within workplaces.

Participant Information

Calculations were performed on each questionnaire to extract measures and compare **perceptotype** sub-groups on variables relating to risk taking, work experience, musculoskeletal discomfort, and demographic differences. Demographic measures extracted include height, mass, age, and gender. PAW-Q measures consisted of two sets of questions, each containing 7 questions. The first set (A) required binary responses to occupational behavioural questions such as “in an average workday, do you sit for 2 hours or more?” The second set (B) required a response on a Likert scale to indicate how often, ranging from daily to almost never, participants partook in a specific work-related behaviour. The complete method of calculating the categorical results was included in Appendix 2.I. Standardized Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms (SNQ-AMS) responses consisted of Y/N to experiencing pain in various anatomical locations and were analyzed from a total overall score SNQ-AMSO and low-back specific SNQ-AMSLB score from binary responses. The EPQ responses were binary and formed 4 logical factors as well as an overall score, identified as total score (OALL) and factor scores impulsivity (IMPL), risk-taking (RISK), liveliness (LIVE), and non-planning behaviour (NPLA). COVID-19 scores and PAR-Q results were exclusively applied as exclusion criteria and were not analyzed.

MMH Kinematics

Various calculations were performed to extract kinematic measures from markered motion capture data. Kinematic measures from motion capture analysis include shoulder flexion (degrees) calculated using the right lateral condyle of humerus, acromion process, and iliac crest markers in an x-z coordinate system. Trunk flexion measures were calculated as the maximum relative angular difference between neutral and reaching posture between the C7 and L5 spinal process markers in the y-z and x-z planes for forward trunk flexion (Hultman et al., 1984) and lateral flexion respectively (McNeill et al., 1980). Trunk rotation was quantified as the X-factor (degrees) measured as the relative maximum rotation of pelvic and pectoral girdles in the x-y plane (Brown et al., 2013). The maximum velocity of axial trunk rotation (degrees/second) was determined from the rate of change in trunk rotation angle per second in the x-y plane (Fan et al., 2014). Finally, crunch factor (degrees^2/second) describes the product of instantaneous velocity of axial trunk rotation and degree of lateral trunk flexion (Cole & Grimshaw, 2014). Crunch factor considered axial velocity in the x-y plane while at maximum lateral flexion angle in the y-z plane.

Vision Tracking

Gaze behaviour was coded into categorized gaze locations using a Python script created to assign a value to each frame while viewing the frame-by-frame vision tracking data video. This script was run for each available trial, and results are included from one trial of each target condition type per participant. This value was 0-9 representing ten locations as colour coded in Figure 2.2. The 10 locations were reduced into 4 including “off working space,” “on working space,” “usable surface,” and “non-usable surface” (Figure 2.3). This categorization was completed to avoid sparsity issues during statistical analysis because many of the 10 locations had expected values between 0 and 5, and to enhance the generalizability of the findings for comparison to other ecologically valid tasks involving different objects or components of a working space. The categorization of ten locations to four groups excluded the use of errored frames including those with no gaze detected, and those before and after task phases. These four categories were used in gaze location analysis.

The task was split into phases categorized as Initialization, Reaching, Handling, Release, and Recovery. The graphics depicting hand position during each phase as in Figure 2.4 were used in later figures to show hand position during each phase of vision tracking. The Initialization phase began when the object was in motion for DYNAMIC trials, and when the individual directed their attention to their right side toward the object once the researcher says “go” in STATIC trials. The Reaching phase began when the individuals’ hands enter the world video, and the Handling phase began and lasted the duration the individual had contact with the object. The Release phase began when the object was released and continued until the individual has returned to their neutral, forward-facing posture. Once in this neutral resting posture the Recovery phase began and continued until the next trial began. The definitive movements used to separate task

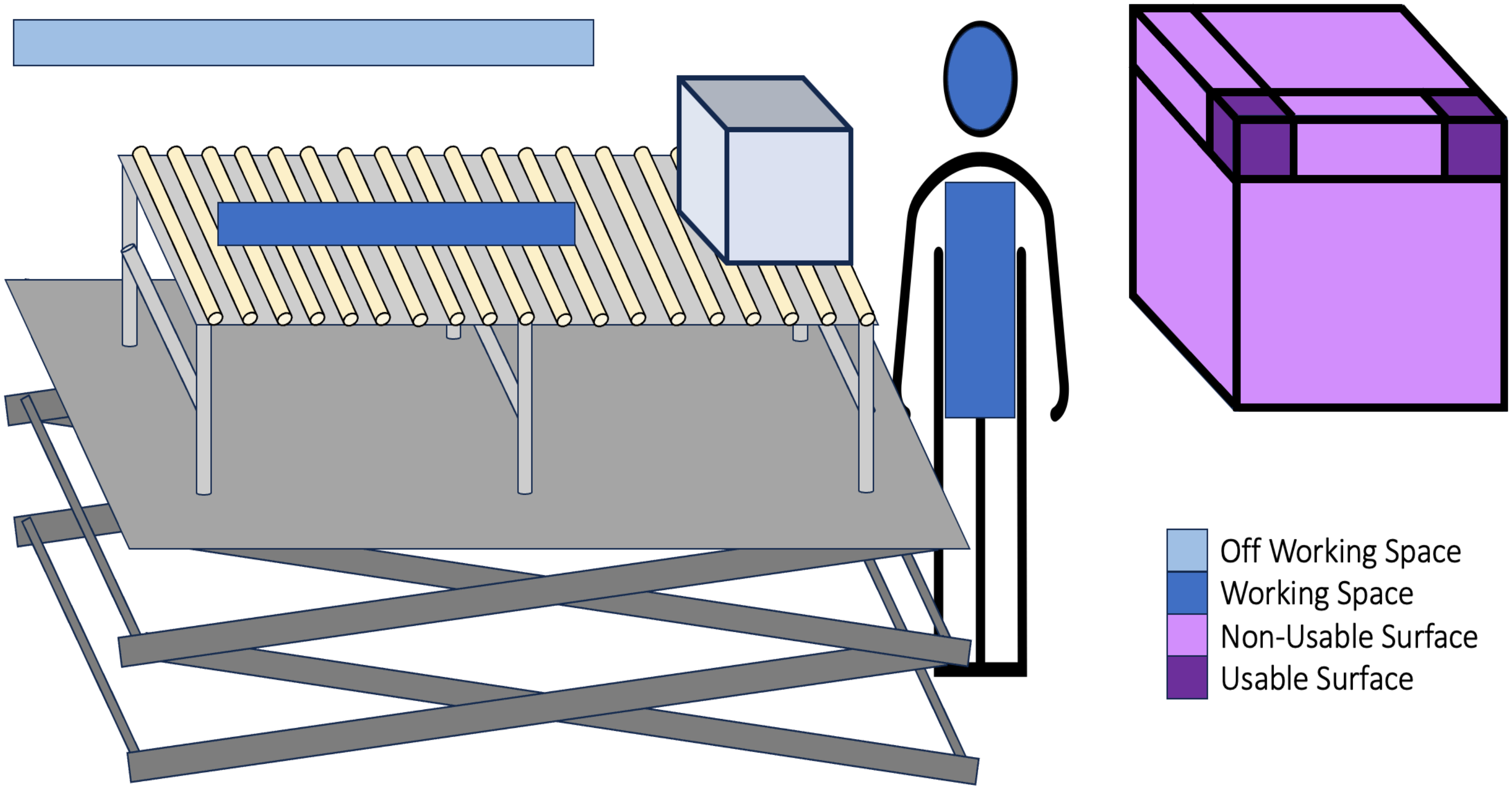

Figure 2.3. Experimental Set-up and Gaze Location Titles for Analysis. In our data processing set-up, we categorized object sections as "usable" or "unusable" surfaces. All other areas were classified as "off of the working space," or part of the "working space." The categorization of surfaces and sections that are used in data processing allows for higher clarify the resultant trends. Anti-fatigue mat is not shown because it was not within the frame of recording of vision tracking.

Figure 2.4. Graphic Depiction of Task Phases of Completion. The Initialization phase began when the object was in motion during dynamic trials or when the individual shifted their attention to the right side, prompted by the researcher's "go" command. The Reaching phase commenced as the individual's hands entered the field of view, while the Handling phase ensued and persisted throughout the individual's contact with the object. As the participant removed their hands from the object, the Release phase began and extended until the individual returned to their neutral, forward-facing posture. Finally, the Recovery phase was the neutral posture each participant rests in as researchers reset between trials. Initiation and Reaching phases were analysed in perceived affordance threshold setting and both task conditions.

phases included when hands entered the frame, made contact, released the object, and exited the frame as shown in Figure 2.4. These definitive moments were identified within the vision tracking data allowing for phase separation of the gaze location data. The gaze locations were identified over the entire trial then summed for each task phase and the predominant task phase gaze locations and gaze duration were used to compare task condition and **perceptotype** sub-groups. All of the kinematic measures from MMH trials were maximum values of distance and rotation that often occurred just prior to contacting the object but still within the Reaching phase.

2.2.6 Statistical Analysis

Independent t-tests (2-tailed) were used to confirm no unintentional differences between randomized d.A and d.B assignment with respect to demographics and EPQ scores. Further independent t-tests were conducted to identify significant differences between **perceptotype** sub-groups of **hyper** and **hypo** groups in variables including demographics and EPQ scores, reported as 2-tailed significance. Pearson's Chi-square and Fischer's Exact tests were used to identify 2-tailed differences between overall musculoskeletal discomfort and low-back discomfort scores on the SNQ-AMS, compared between **perceptotype** sub-groups of **hyper** and **hypo**. Mann-Whitney U Tests were used to identify asymptotic 2-tailed significant differences between **perceptotype** sub-groups of **hyper** and **hypo** on PAW-Q scores.

A 2-way mixed design MANOVA test was completed to determine the significant differences for main effects and interaction effects within all kinematic measures for the between-subjects factor of **perceptotype** sub-group (GROUP; **hypo** and **hyper**), the within-subjects factor of task condition type (TARGET; STATIC and DYNAMIC), and the interaction of GROUP and TARGET. Multiple follow-up 2-way mixed design ANOVA tests were then completed to identify the effects and interaction effects of GROUP and TARGET on each kinematic measure.

Fisher's Exact tests were conducted to determine if **perceptotype** significantly influenced gaze location during affordance distance setting, STATIC trials, and DYNAMIC trials. McNemar tests were used to determine if **perceptotype**, task condition, or phase had significant influence on gaze location during Initialization and Reaching phases of STATIC and DYNAMIC task conditions. Fisher's Exact tests were designed for small samples, specifically to be more accurate than Chi-square on small samples by providing an exact p value rather than an approximation as calculated in Chi-square, however their outcome can be interpreted in the same way (Fisher, 1935). Specifically, when 20% or more of the outcome cells have expected frequencies less than 5, a Fisher's Exact test is more accurate than Chi-square tests (Fisher, 1925; Fisher, 1956; Upton, 1992). This is relevant because there are a minimum of 13 participants that visually focus on 4 gaze locations therefore at least one of the four gaze locations (25%) will have a frequency of less than five, therefore Fisher's Exact test will be more accurate than Chi-square tests in this application. McNemar tests are preferred for categorical paired and matched data over Chi-square tests because of their specificity with low sample sizes and expected frequencies less than 5 (McNemar, 1947; Pembury Smith & Ruxton, 2020). Statistical significance was set at $p < 0.05$ for all tests.

2.3 Results

2.3.1 Participants

Forty-three participants were enrolled into the study, and data from all subjects was available for demographic measures and STATIC task condition kinematic analysis. Good data from forty-two participants were available for the DYNAMIC task condition, and thirty-two participants were included in vision tracking analysis. Data losses were due to incomplete 3-D coordinate motion capture reconstruction and vision tracking losses were due to improper world-view camera positioning and camera calibration inconsistencies. Confirming the absence of difference between groups d.A and d.B was crucial to ensure no unintended biased resulted from random ordering. Subject demographics, self-reported questionnaire scores, and normalized affordance threshold were analyzed using an independent t-test based on randomised groups of dynamic.A (d.A) and dynamic.b (d.B), reported as 2-tailed significance (Table 2.1). The nAT was not significantly different between d.A and d.B groups, confirming that target condition block randomisation did not significantly influence nAT.

2.3.2 Normalized Affordance Threshold Sub-Grouping

Applying the median split method (DeCoster et al., 2011) to nAT resulted in twenty-two **hyper**-affordant and twenty-one **hypo**-affordant participants from the forty-three total. Subsequent demographics and sub-group mean self-reported questionnaire scores were re-calculated for **perceptotype** sub-groups of **hyper**-Affordant and **hypo**-Affordant. Normalized affordance threshold was significantly different between **perceptotype** sub-groups as identified from an independent t-test, as shown in Table 2.2. The 22 participants in the **hyper** sub-group (*M* = 0.414, *SD* = 0.039) demonstrated significantly greater nAT than the 21 in **hypo** sub-group (*M* = 0.281, *SD* = 0.089; *t*(41) = 6.453, *p* = <.001).

To identify underlying trait or state characteristic differences between sub-groups that may have driven **perceptotype** states the EPQ and PAW-Q were analyzed at the sub-group level. Table 2.2 includes sub-group **hyper** and **hypo**-affordant EPQ-OALL score and factor scores for IMPL, RISK, LIVE, and NPLA. Scores from SNQ-AMQ categorized into overall (SNQ-AMSO) and low-back-specific (SNQ-AMSLB) values compared through Chi-square tests were also included in Table 2.2. A Mann-Whitney *U* test was conducted to determine if the average reported work activities of the **hyper** sub-group differed from the average reported work activities of the **hypo** sub-group from PAW-Q. Average daily work activities of **hyper** were A: 2.50 (*SD* = 0.80); B: 9.05 (*SD* = 6.31) and **hypo** were A: 3.10 (*SD* = 1.04); B: 9.43 (*SD* = 5.63), as shown in Figure 2.5. Many sub-measures of the PAW-Q were analyzed including individual questions (A: Figure 4(a) and B: Figure 4(c)), sub-groupings of similar questions (Figure 4(d)), and the total scores from sections A (Figure 4(b)) and B (Figure 4(d)). No significant differences were identified between **hyper** and **hypo** sub-groups for any state or trait measure including the sub-measures and sub-groupings of PAW-Q.

Table 2.1. Randomized d.A/d.B Grouping of Subject Demographics and Questionnaire Scores

Measure	**d.A**	**d.B**	***p***
No. of Subjects	21	22	
Gender (M/F/NB)	5/16/0	7/14/1	
nAT (m/m)	0.343(0.125)	0.356(.056)	.667
Height (cm)	168.14(10.11)	172.73(10.12)	.145
Mass (kg)	71.10(16.35)	78.00(18.02)	.196
Age (yrs)	22.62(5.91)	22.14(7.45)	.816
EPQ OALL	8.62(7.07)	7.22(7.30)	.529
EPQ IMPL	3.19(3.40)	3.09(3.34)	.923
EPQ RISK	5.90(2.64)	5.27(2.86)	.457
EPQ LIVE	2.48(0.75)	2.55(1.26)	.829
EPQ NPLA	-4.67(1.77)	-5.27(1.93)	.290
SNQ-AMSO (Y/N)	14/7	20/2	.069
SNQ-AMSLB (Y/N)	9/12	16/6	**.047**

Values are mean (standard deviation) for continuous scale variables and number for nominal variables.

NB: Non-Binary; EPQ: Eysenck Personality Questionnaire; SNQ-AMS: Standardized Nordic Questionnaire for Analysis of Musculoskeletal Symptoms; Y/N: Yes symptoms were reported/ No symptoms were not reported; nAT: Normalized Affordance Threshold.

Table 2.2. **Perceptotype** Sub-Group Subject Demographics, and Questionnaire Scores using an independent t-test. 2-tailed significance is reported.

Measure	hyper-Affordant	hypo-Affordant	*p*
Group (d.A/d.B)	12/10	9/12	
No. of Subjects	22	21	
Gender (M/F/NB)	7/15/0	5/15/1	
nAT (m/m)	0.416(0.039)	0.282(0.091)	**<.001**
Height (cm)	169.7(11.3)	171.3(9.3)	.624
Mass (kg)	73.68(16.51)	75.62(18.58)	.719
Age (yrs)	23.3(8.5)	21.4(4.0)	.347
EPQ OALL	7.1(7.6)	8.7(6.7)	.476
EPQ IMPL	2.6(3.4)	3.7(3.2)	.316
EPQ RISK	5.2(2.8)	6.0(2.7)	.393
EPQ LIVE	2.5(1.1)	2.5(1.0)	.941
EPQ NPLA	-4.8(1.9)	-5.1(1.8)	.573
SNQ-AMSO (Y/N)	16/6	18/3	.457
SNQ-AMSLB (Y/N)	12/10	13/8	.625

Values are mean (standard deviation) for continuous scale variables and number for nominal variables.

NB: Non-Binary; EPQ: Eysenck Personality Questionnaire; SNQ-AMS: Standardized Nordic Questionnaire for Analysis of Musculoskeletal Symptoms; Y/N: Yes symptoms were reported/ No symptoms were not reported; nAT: Normalized Affordance Threshold.

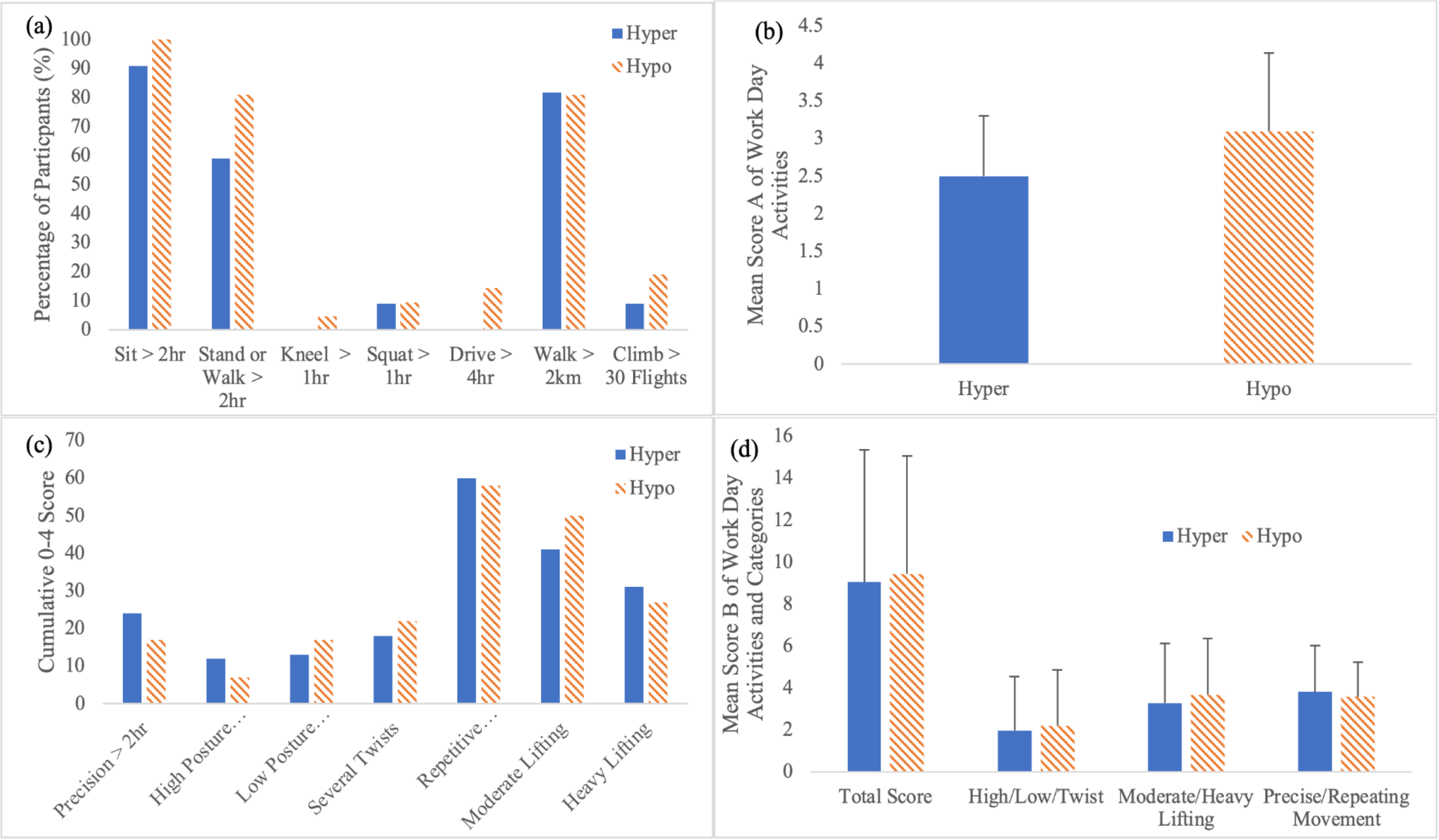

Figure 2.5. Physical Activity at Work Questionnaire Results. (a) Participants that answered "yes" to questions 1-7 from both **perceptotype** sub-groups of **hyper** and **hypo**-Affordant. (b) Mean score of participants from questions 1-7 from **hyper**- and **hypo**-Affordant scores per participant were between 0-7 summed from the first 7 questions. (c) Cumulative score from questions 8-14 that were answered using a nominal Likert scale: 0= Almost never; 1=1-3 days per month; 2=1 day per week; 3=2-4 days per week; 4= every workday. These scores were summed over 7 questions and the cumulative score of the **perceptotype** (maximum of 28 per participant) was included. (d) Mean score of totals of 7 questions, and categorized groups.

2.3.3 MMH Kinematics, Perceptotype, and Task Condition

The **hyper** sub-group had increased kinematic measures compared to the **hypo** sub-group and this difference persisted throughout all measures in the STATIC task condition, and all except crunch factor in the DYNAMIC task condition. These **perceptotype** (**hyper** and **hypo**-affordant) and task condition (STATIC and DYNAMIC) marginal means and standard deviations are included in Table 2.3. These observations in kinematic measures were further supported by the 2-way mixed design MANOVA interaction effects between **perceptotype** (GROUP: **hyper**-affordant or **hypo**-affordant), and task condition (TARGET: STATIC or DYNAMIC; $F(7,35) = 2.833$, $p=.019$, partial $\eta^2 = .362$). Main effects of GROUP ($F(7,35) = 4.527$, $p=.001$, partial $\eta^2 = .475$) and TARGET ($F(7,35) = 39.308$, $p<.001$, partial $\eta^2 = .887$) were also found.

Post-hoc comparisons were completed for **perceptotype** (GROUP), task condition (TARGET), and the **perceptotype** x task condition (GROUP x TARGET; Figure 2.3). Univariate comparisons including 2-way mixed design ANOVA tests were conducted to determine the effect of GROUP (**hyper** and **hypo**) and TARGET (STATIC and DYNAMIC) on kinematic measures (Figure 2.3). The **hyper perceptotype** sub-group had significantly higher measures of normalized affordance threshold ($p <.001$), shoulder flexion ($p=.001$), axial trunk velocity ($p = .008$), and crunch

Table 2.3. **Perceptotype** Sub-Group and Task Condition plus Interaction Effects 2-Way Mixed Design Univariate ANOVA Test Results and Mean and Standard Deviation Kinematic Measures. Group Mean of Participants’ Maximum Values are Reported.

Measure	**HYPER**		**HYPO**		**GROUP**	**TARGET**	**GROUP x TARGET**
	STATIC	**DYNAMIC**	**STATIC**	**DYNAMIC**	***p***	***p***	***p***
Normalized Affordance Threshold (m/m)	.415(.039)	.204(.054)	.281(.089)	.149(.062)	**<.001**	**<.001**	**<.001**
Shoulder Flexion (°)	42.0(8.6)	31.5(12.3)	28.0(10.7)	25.0(12.3)	**.001**	**<.001**	**.038**
Lateral Trunk Flexion (°)	15.8(10.4)	8.8(10.2)	10.7(8.7)	6.6(5.3)	.072	**.005**	.454
X Factor (°)	21.8(11.9)	15.3(10.7)	19.7(14.0)	12.8(8.5)	.363	**.008**	.954
Forward Trunk Flexion (°)	26.5(13.8)	13.5(11.1)	20.6(16.1)	11.7(11.0)	.201	**<.001**	.454
Axial Trunk Velocity (°/s)	56.1(17.4)	31.1(25.8)	33.4(18.6)	28.5(26.9)	**.008**	**.006**	.059
Crunch Factor (°^{2}/s)	722.9(476.4)	169.4(165.5)	338.3(360.1)	179.3(335.3)	**.016**	**<.001**	**.015**

Values are mean (standard deviation) continuous scale variables.

factor (p = .016) compared to the **hypo** sub-group. All kinematic measures analyzed were significantly higher in the STATIC task condition including normalized affordance threshold (p < .001), shoulder flexion (p < .001), lateral trunk flexion (p = .005), x-factor (p = .008), forward trunk flexion (p < .001), axial trunk velocity (p =.006), and crunch factor (p <.001) when compared to the DYNAMIC task condition. Interaction effects of **perceptotype** x task condition were significant in kinematic measures of normalized affordance threshold (p < .001), shoulder flexion (p = .038), and crunch factor (p = .015). In summary, **perceptotype** sub-groups **hyper**- and **hypo**-affordant differ on normalized affordance threshold within both task conditions and in measures of kinematics and vision tracking direction and duration.

2.3.4 Vision Tracking during Perceived Affordance Threshold (s0)

The **hypo**-affordant sub-group had a significantly higher frame count (measured at frequency of 30Hz) during the Initialization phase (M= 53.4; SD= 33.0; p = .012) in s0 (static affordance setting) trial than the **hyper**-affordant sub-group (M= 26.1; SD= 14.8) as presented in Table 2.4. The frame count of the Reaching phase did not differ significantly between sub-groups.

The gaze location during Initialization and Reaching phases of the perceived affordance threshold trial are included in Figure 2.6. A Fisher's Exact Test was conducted to evaluate whether the gaze location during perceived affordance threshold setting was significantly different between the **hyper** and **hypo** **perceptotype** sub-groups for the

Initialization and Reaching phases. Gaze location distribution was not significantly different between the **hyper** and **hypo** sub-groups during Initialization, *p* = .828 (2-tailed) or Reaching, *p* = .673 (2-tailed). During Initialization and Reaching phases the **perceptotype** sub-groups focused their visual attention onto different surfaces and the **hypo** sub-group had one additional participant with a detected gaze location in the Reaching phase than in the Initialization phase. In the Initialization phase of perceived affordance threshold setting, the **hypo** sub-group visually fixated primarily on the non-usable surfaces (n= 5 of 13) and the **hyper** group fixated primarily off of the working space (n= 7 of 16). In the Reaching phase both **hyper** (n= 8 of 16) and **hypo** (n= 7 of 14) primarily focused off of the working space and had a similar distribution between each gaze location, as shown in

Figure 2.6.

2.3.5 Static Handling (s1-s5) Vision Tracking

The distribution of gaze location during STATIC task condition handling compared between sub-groups of **perceptotype** are displayed in Figure 2.7, showing each groups's primary gaze location during one trial. A Fisher's Exact Test was conducted to evaluate whether the gaze location during STATIC task completion was significantly different between the **hyper** and **hypo perceptotype** sub-groups during trial phases of Initialization and Reaching. Gaze location distribution was not significantly different between the **hyper** and **hypo** sub-groups during Initialization, *p* = .918 (2-tailed) or Reaching, *p* = .762 (2-tailed). Both the **hypo** and **hyper** groups primarily focused off of the working space during Initialization. During the Reaching phase **hypo** attended to usable and non-usable surfaces equally while the **hyper** sub-group attended to usable surfaces more than non-usable.

2.3.6 Dynamic Handling (d1-d5) Vision Tracking

The distribution of gaze location during DYNAMIC task condition handling was compared between sub-groups of **perceptotype** in Figure 2.8, showing all participants' primary visual focal location during one trial. A Fisher's Exact Test was conducted to evaluate whether the gaze location during task completion was significantly different between the **hyper** and **hypo perceptotype** sub-groups during DYNAMIC trial completion phases of Initialization and Reaching. Gaze location distribution was not significantly different between the **hyper** and **hypo** sub-groups during Initialization, $p = 1.00$ (2-tailed) or Reaching, $p = .260$ (2-tailed). In Figure 2.8 the **hyper** sub-group shifts their primary gaze from off of the working space in the Initialization phase to the usable surface in the Reaching phase and the **hypo** sub-group shifts from the working space during the Initialization phase to off the working space and non-usable surfaces during Reaching.

Table 2.4. Duration of Perceived Affordance Threshold Setting Trial (s0) in Different Task Phases Compared Between **hyper** and **hypo**-Affordant Sub-Groups.

Phase	**hyper-Affordant**	**hypo-Affordant**	***p***
Initialization (Frames)	26.1 (14.8)	53.4 (33.0)	**0.012**
Reaching (Frames)	75.6 (59.0)	88.8 (51.2)	0.541

Values are mean (standard deviation) for continuous scale variables.
Unit of measure is Frames: frame count sampled at frame rate of 30Hz.

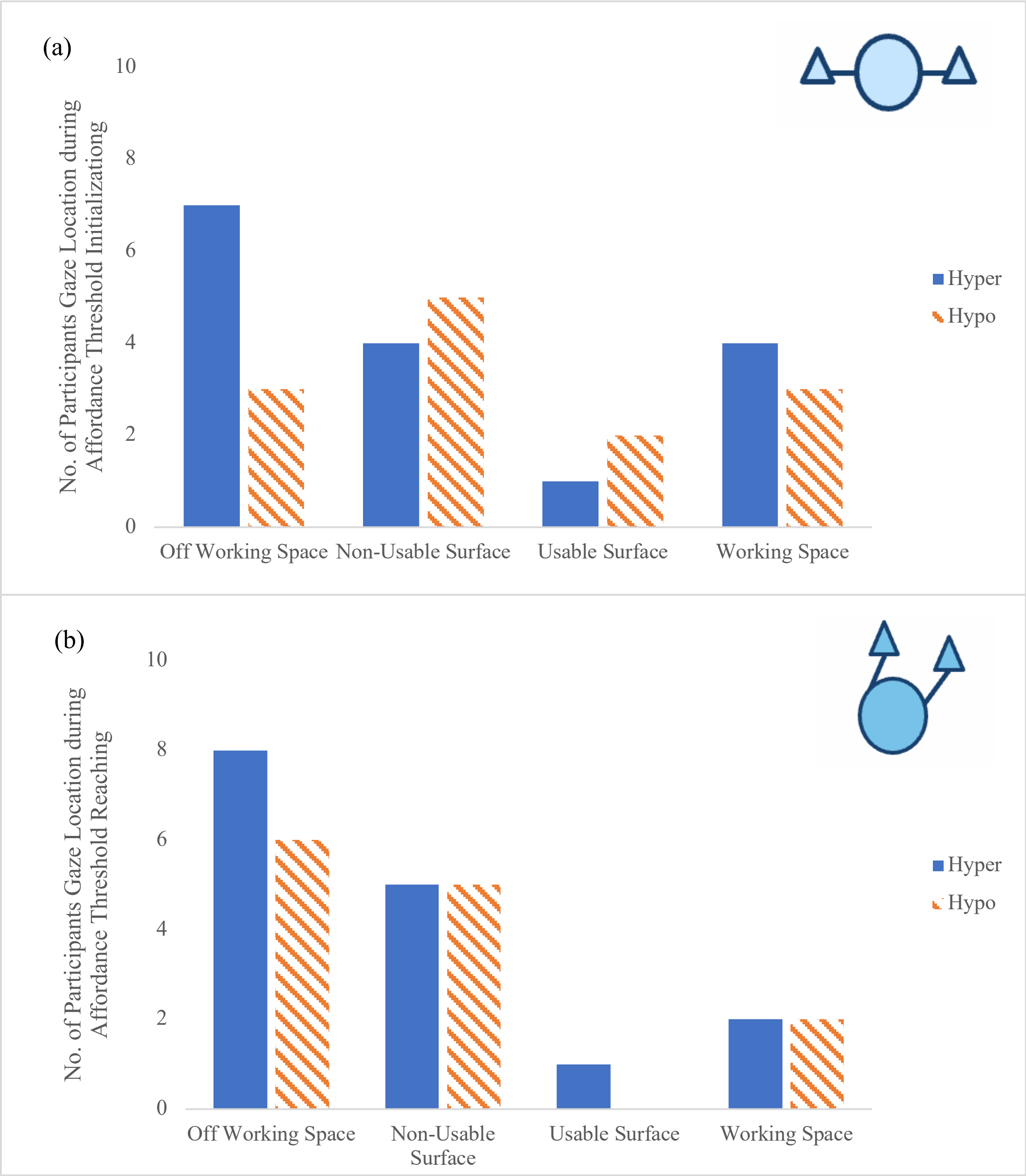

Figure 2.6. Participant Primary Gaze Locations During Perceived Affordance Threshold Setting (s0) Separated into Task Phase, with vertical axis showing the number of participants for each primary gaze location. (a) Initializing Phase. **Hyper**-affordant sub-group focuses attention off of the working space and away from the object whereas **hypo**-affordant focuses attention primarily onto the non-usable surfaces of the object. (b) Reaching Phase. **Hyper** and **hypo**-affordants focus attention off of the object while reaching toward it and focus on non-usable surfaces.

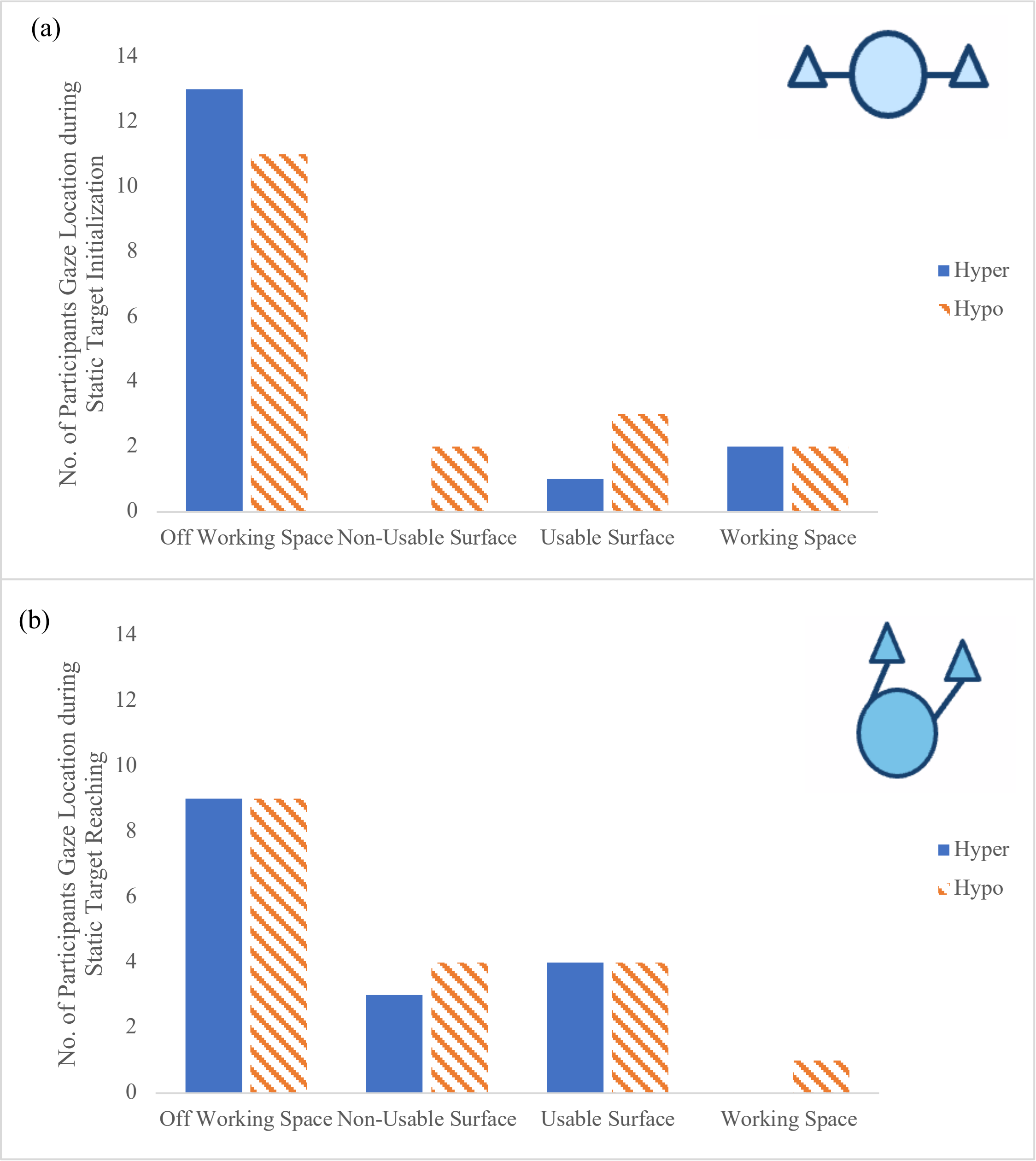

Figure 2.7. Participant Primary Gaze Locations During Static Trial Condition Separated into Task Phase , with vertical axis showing the number of participants for each primary gaze location. (a) Initialization Phase. Both **hyper** and **hypo**-Affordant group's primary gaze location was off of the working space while the next majority of **hyper**-Affordant group focused on the working space, and the **hypo**-Affordant group focused to un-usable surfaces of the object. (b) Reaching Phase. Both Sub-Groups primarily focused off of the working space while reaching to the object however a much larger fraction of both **hyper** and **hypo**-Affordants focused on non-usable and usable surfaces of the object. During the reaching phase none of the **hyper**-Affordant group remained focused on the working space.

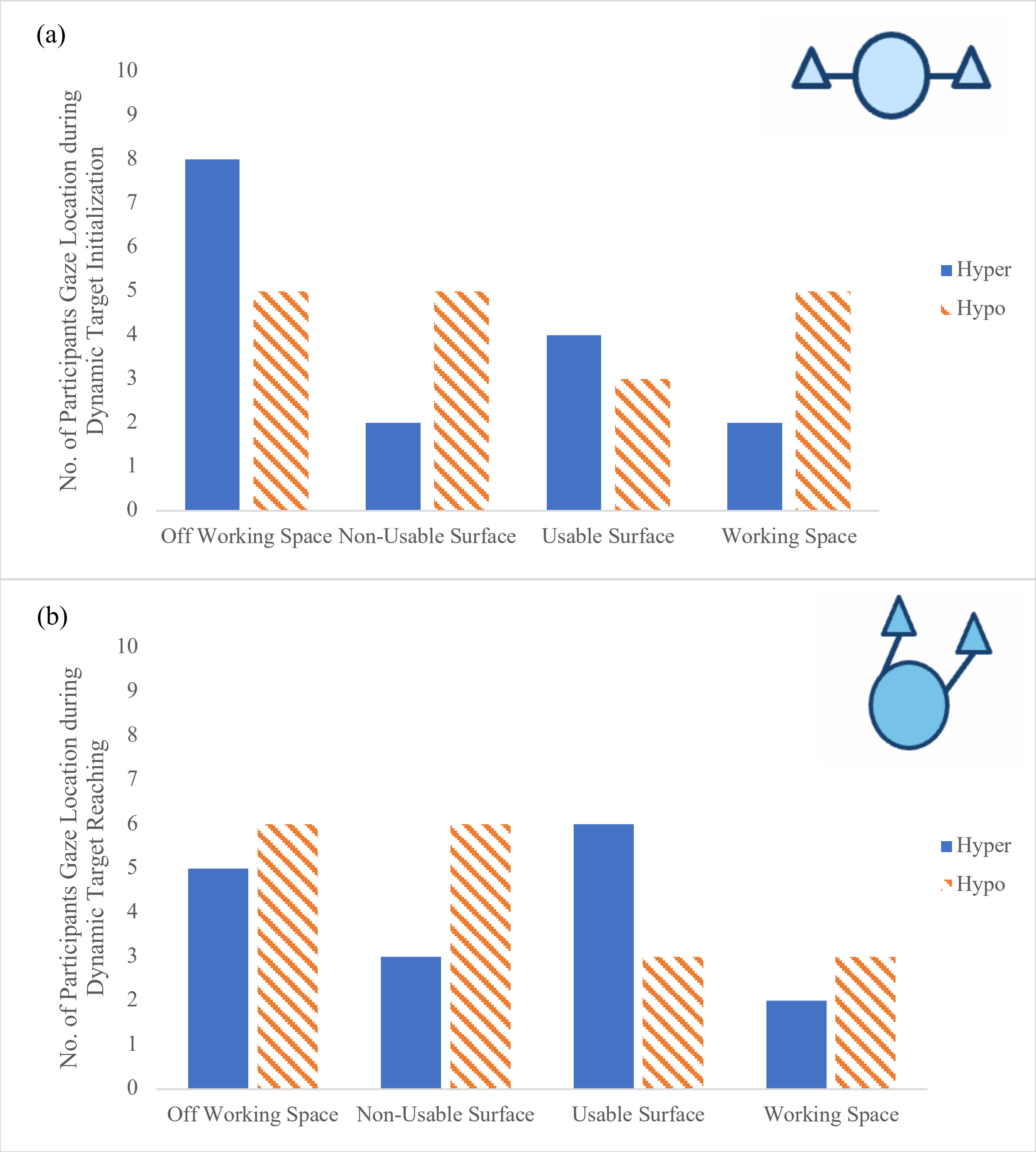

Figure 2.8. Participant Primary Gaze Locations During Dynamic Trial Condition Separated into Task Phase, with vertical axis showing the number of participants for each primary gaze location. (a) Initialization Phase. The **hyper**-affordant group's primary gaze location was off of the working space and the primary gaze location of the **hypo**-affordant group was equal between non-usable surfaces, off of the working space, and on the working space. (b) Reaching Phase. The **hypo**-affordant sub-group primary focus was off of the working space and on the un-usable surfaces of the object, whereas the primary gaze location of the **hyper**-affordant group was on the usable surfaces of the object.

2.4 Discussion

In this study, we investigated the relationship between normalized affordance threshold, visual attention, kinematic measures, task condition, and self-reported state and trait characteristics during a MMH task. Based on theories including Gibson (1977) and Dunn et al. (1994), we hypothesized that our participant sample could be sub-divided into **perceptotype** groups of **hyper** and **hypo**-affordants, and those groups would differ on relevant perceived affordance, visual attention, and action behaviour during our experimental MMH task. This **perceptotype** division of a homogenous group by applying the median split method was used to mirror the injury risk and injury safe binary of workers that exists within workplaces. The results confirmed **hyper**-affordants selected larger affordance distances that involved larger kinematic measures of shoulder flexion, axial trunk rotation velocity, and crunch factor. Additionally gaze location during affordance setting differed between **perceptotype** sub-groups but no differences were found during the MMH task. Additionally in this study, the measurement of state and trait characteristics did not exhibit any significant correlation or association with perception and behavior. The interpretation, application, and relevance of these findings are discussed in this section.

2.4.1 Normalized Affordance Difference

To investigate the relationship between kinematic measures, visual attention, and task condition, a group of student participants were recruited. The participants were highly homogenous with no significant differences in demographics or work-related-experience questionnaire scores and were divided post-hoc, using the median-split method (DeCoster et al., 2011), into two sub-groups that significantly differed on their perceived affordance for an experimental manual materials handling (MMH) task. When setting their normalized affordance distance, participants were read a fixed script instructing them to adopt the role of a package handler preparing for an 8-hour shift, and to select their safe maximum normalized affordance distance that they could complete repeatedly over the course of 8 hours. This difference in normalized affordance also existed when the load condition changed in an ecologically valid way (dynamic target object that translated across rollers towards the participant instead of reaching to stationary target object). The normalized affordance value was calculated using the affordance threshold reaching distance (m) divided by the participants height (m) relating this normalized affordance to anthropometrics of the participant. Additionally, the working height was adjusted to 51% of the participants height to limit the influence on anthropometrics impact on normalized affordance distance. Considering not only physical anthropometric data but also the perception of one's anthropometry is important in work environments as long-term tool use results in perceptual changes to body segment lengths and can impact normalized affordances (Coelho et al., 2019; Sposito et al., 2012).

The National Institute for Occupational Safety and Health (NIOSH) developed equations to calculate safe load and loading parameters (Waters et al., 1993). These equations state the most safe axial rotation to complete a lifting or handling task is zero, with a relative decrease in lifting potential of 30 percent at 90 degrees of asymmetry (Nussbaum et al., 1995). Every participant in this study completed both STATIC and DYNAMIC handling tasks with non-zero axial rotation. This shows each participant, independent of **perceptotype**, selected a maximum safe reaching distance that increases loading and injury risk, and this risk was significantly increased in the **hyper perceptotype** sub-group.

2.4.2 Perceptotype Kinematic Differences

We observed significantly increased handling kinematics in the **hyper** sub-group, including the measures of shoulder flexion, axial trunk rotation velocity, and crunch factor. The interaction between **perceptotype** sub-group and task condition was also significant in kinematic measures of shoulder flexion, and crunch factor. The findings of increased axial trunk rotation velocity and crunch factor amongst **hyper**-affordants connect greater rotational velocity to greater affordance and larger maximum safe reaching distance. This relationship could be due to many factors including increased reaction time, postural control, or coordination, within the **hyper**-affordant sub-group that facilitated their further and faster trunk rotation toward the object in both the STATIC and DYNAMIC task conditions. Reaction time, postural control, and coordination are trainable through different experience and exposure to visual stimuli reaction. It was predicted and confirmed that a greater perceived safe affordance and greater perceived kinematic measures would be related to **perceptotype**.

To avoid risk of injury and decrease incidence of injury workers will need to avoid unsafe movement kinematics. Many ergonomics researchers have expected differences between injury avoidant and injury prone MMH behaviour to be major visible differences that are correctable with structured training regimes and on-going learning (Plamondon et al., 2010). Instead, the difference between safe and unsafe MMH behaviour may be minor, and thus not easily correctable because the difference may originate with the perceptual stage. In this study, the **hyper** sub-group are using MMH kinematics that have been established as potentially injurious for motion segments of the lumbar region under chronic load conditions (Marras, 2008; Marras et al., 1995; McGill, 2015a). The kinematic measure magnitudes are largely dictated by the normalized affordance threshold (nAT) as larger relative distances require increased shoulder angle and greater relative trunk rotation. Therefore, behaviour training should be considered parallel or secondary to training perception that could moderate affordance perceptions. Additionally, increasing understanding of musculoskeletal health and physical literacy might assist proper joint and movement kinematics and additionally decrease injury risk and rates of injury that may arise due to unsafe and uninformed action (Miller et al., 2018; Rauscher & Myers, 2014).

2.4.3 MMH Task Gaze Behaviour

The frequency distribution for visual fixation locations did not differ between groups or targets for any phases of the MMH trials. This result was counter to the prediction – based on Vickers' numerous works identifying 'the quiet eye', specifically increased fixations on task-relevant features immediately prior to critical phase of the skill amongst individuals with skill-specific proficiencies (for example, surgeons tying knots or varsity basketball players attempting free throws; Vickers, 2016), it was expected the **hypo-affordant** group would direct more visual attention to graspable aspects of the MMH target and to the workspace between actor and target based on higher compatibility between perception and action for this sub-group (Tucker & Ellis, 1998) and in concordance with previous experiment in this lab (de Bruin et al., 2008). This difference was also expected to be exacerbated by the dynamic target condition, where coincidence anticipation then accurate interception of the accelerating target was required and both being psychomotor tasks that have previously been associated with increased need for visual information for accurate completion (Tresilian, 1995; Whiting & Sharp, 1974). Again, this difference between targets for the measure of frequency of visual fixation at specific MMH relevant locations did not exist in this experiment in any predictable way. This difference does not specifically disagree with the Dunn model for the Ecology of Human Performance (Dunn et al., 1994), as it may be possible to visually attend to similar information but perceive different magnitude and organization of action to deliver performance. However, it does challenge the concept that consistently attending to less useful or even distracting task context information is a primary contributor to the differences in perceived affordance and related group-specific MMH kinematics identified here, and that could lead to WR-MSDs.

It might be the case that the simple demands of this MMH task were adequately perceived by mostly similar visual attention fixation strategy, regardless of **perceptotype** group or target state. Land et al. (1999) used gaze detection to identify sequential target to target eye movements at the highest functional level (operation control hierarchy, in their terminology) for a complex task (tea making in an ecological setting), but a regular, often circular, fixation pattern on many individuals targets and spaces inside that larger task. This cyclical visual fixation has also been observed for well-learned tasks like general locomotion (Hollands et al., 2002), locomotion with obstacle crossing (Patla & Vickers, 1997), locomotion with terrain changes (Marigold & Patla, 2007), stair climbing (Zietz & Hollands, 2009), reach to grasp (Voudouris et al., 2018), and attentive automobile driving (Land & Lee, 1994). For the current study, more information about both pattern of visual fixation locations, cyclical or otherwise, and the duration of those sequential visual fixations could provide similar useful insights about the behaviour, and possible differences between groups or targets. More refinement in experimental protocol and data analysis would be required to deliver these measures – the three-dimensional nature of the ecologically valid MMH task imposes some limits on the two-dimensional measure of video-based gaze direction assessment. Many researchers remove this limitation by using screen-based tasks and desktop or fixed gear visual attention measurement (Kar & Corcoran, 2017), and thus introduce the limitation of experimental task validity. Synchronized gaze and motion capture is a recently developing experimental technique (Stone et al., 2024), but has both equipment needs and analysis demands beyond the scope of this thesis.

2.4.4 Affordance Setting Gaze Behaviour

Significant differences in gaze behaviour were found between the **perceptotype** sub-groups during affordance setting for STATIC trials. The **hypo**-affordant sub-group had a significantly higher frame count during the Initialization phase. The Initialization phase began when the researcher started transferring the box toward them, and ended as the participant began reaching their hands into the field of view of the world view recording. The frame count is a metric of time as the frame rate of the system recorded at 30 frames per second. Specifically, the sub-group with a significantly shorter selected maximum perceived reaching distance spent significantly more time, on average, visualizing the task before reaching out to the object and testing various postures. This difference may be attributed to various potential factors. As **hyper**-affordants perceive greater distances as safe in their environment they may have higher confidence in their abilities or a lower perception of risk of the specific task, and this confidence could lead to the quicker decision making and affordance distance setting of the **hyper** sub-group. Conversely, the **hypo** sub-group may be slower at selecting their maximum perceived affordance distance as they are more cautious or risk-averse and thus more deliberate with their decision making resulting in slower action. Other factors influencing these results could be experience or comfort with physical activities. People used to physical activity or MMH may make quicker decisions when reaching away from their body. In contrast, those unfamiliar with such tasks might find reaching tasks awkward or uncomfortable. Therefore, they might spend more time thinking about the task and visualizing the object in translation and ultimately choose a shorter reach distance. Cognitive processing styles, perceptual ability, perceptual-motor efficiency, stress level, or other individual personal factors contribute to human performance (Staal, 2004) and may also contribute to time spent before selecting reaching distance and the magnitude of perceived safe reaching distance. Ultimately, we did not question the participants regarding these possible compounding factors including confidence, physical or athletic history, cognitive processing, perceptual-motor efficiency, or stress as they were outside of the scope of this study. Because of this, we are unable to attribute these findings within this context to a specific factor as the state and trait characteristics we did analyze were not different between sub-groups of **perceptotype**, and further studies will be required to determine if state and trait characteristic differences exist between **perceptotypes**.

2.4.5 State and Trait Characteristics

State and trait characteristics can be divided on one key concept of permanence: state characteristics are temporary as environments, experiences, and circumstances change around us whereas traits are stable core consistencies of an individual (Matthews et al., 2003). Within our measures of state and trait characteristics no differences were found between **perceptotype** sub-groups. These measures included measures of personality from the EPQ (Eysenck & Eysenck, 1977). Previous findings suggest that behavioural traits differentially contribute to risk factors associated with the development of LBD (Marras et al., 2000). Many studies have been completed linking risk taking behaviour to personality traits. Furnham (2022) applied the motives, values, and preferences inventory scale to a group of more than 26,000 individuals, concluding that individuals with compliant, vigilant, and cautious traits were more likely to be safety conscious and observant, leading them to understand the role of safety in the workplace and thus follow guidelines. Additionally, previous literature states occupational risk-taking behaviour can be associated to detectable personal factors and personality traits (Ayoub & Mital, 1989; Plamondon et al., 2012). This may not have been detected because the EPQ used in this study as a measure of personality may not have been relevant to the nature of risk taking in this experiment.

In prompting participants to select their maximum safe reaching distance, we were not requesting they partake in an intentional risk-taking behaviour. As for the EPQ, we were requesting information regarding intentional risk-taking behaviour. There were no significant differences between the **perceptotype** sub-groups on the overall or factor scores of the EPQ. We suggest the EPQ is sensitive largely to intentional or conscious risk, whereas the difference in normalized affordance threshold that separates the participants on **perceptotype** could be based on an unintentional or unconscious risk tolerance. Further investigation should be completed to identify if unintentional risk differences exist between **perceptotype** sub-groups.

The other characteristics measured including experience and exposure to work-related tasks did not have any significant associations between the characteristics and **perceptotype** sub-groups. Specifically in relation to the PAW-Q (Torgén et al., 1997) and SNQ-AMS (Kuorinka et al., 1987) questionnaire results pertaining to work-related exposure, the participants may not have had meaningful experience regarding physically demanding work which would limit the validity of their responses. In occupational environments, experienced workers fail to recognize, report, or avoid risk and risky behaviour (Faber et al., 2007). Perception of risk level or riskiness associated with an activity or behaviour may be dependent on four utility factors including potential expected benefits and costs of both risky and safe behaviour alternatives (Wilde, 1998). Perceiving expected costs or benefits of risky or risk aversive behaviour can be learned through taking similar risks in other environments. If much of the sampled population had limited relevant work exposure as the baseline for their risk-taking decision making, finding meaningful connections between **perceptotype** sub-group and state and trait characteristics is challenging.

2.5 Conclusion

This is the first study to compare differences in gaze behaviour, kinematic measures, and task conditions between **perceptotype** sub-groups of participants in an experimental manual materials handling (MMH) task to identify characteristic differences that lead to behaviour differences. A primary finding of this study is that increased affordance distance also increased potentially injurious MMH kinematics, including shoulder flexion, axial trunk rotation displacement and velocity, and crunch factor. Specifically, the **hyper**-affordant sub-group used increased axial rotation velocity and crunch factor that could markedly increase their risk of WR-MSD under the cumulative demands common in MMH. Task conditions additionally impacted perceived affordance of MMH reaching tasks and task conditions differentially affected the perceived affordances between **perceptotype** sub-groups. Gaze duration during affordance threshold setting was also significantly different between **perceptotype** sub-groups, suggesting perceived affordances may be related to the amount of sensory information informing the cognitive process. Differences in fixation frequency at gaze locations were not statistically significant. Future studies could examine other measures to identify state and trait characteristics that may lead to increased perceived affordances and investigate if these perceptions and actions are modified by expertise, age, and gender.

Chapter 3 : Global Discussion

3.1 Introduction

An experimental procedure was developed and implemented to examine perceived affordances, occupational behaviour, MMH kinematics, with examination of gaze behaviour and state and trait characteristics that influence perceptions and performance. This research is largely based on foundational theories including the cumulative nature of WR-MSDs, the Theory of Affordances (Gibson, 1977), and the Ecology of Human Performance (Dunn et al., 1994). Specifically, Gibson (1977) posits that the environment offers opportunities for action that are perceived differently between individuals, and Dunn et al. (1994) highlights human performance is intricately linked to the interaction between individuals and their environments, thus different individuals perceive context that leads to different performance or outcomes. We predicted that some individuals may possess distorted MMH affordance perceptions that stem from state and trait characteristics and lead to injurious mechanics and specific gaze behaviour strategies during action. These misperceptions can prompt actions surpassing safe cumulative loading levels that can result in injury. Specifically, vision tracking and motion capture analysis were applied to a MMH task to quantify relationships between visual perceptual behaviour and subsequent action kinematics within two ecologically valid task conditions.

This study aimed to answer the following research questions:

1. Does vision tracking expose a useful association in manual materials handling between gaze behaviour and affordance setting and occupational behaviour?
2. Do dynamic and static manual materials handling tasks differently influence workers' gaze behaviours and perception of safe horizontal handling affordances and occupational behaviour?

We predicted distorted affordances exist amongst a sample exposed to an occupationally relevant MMH task, such that the sample could be sub-divided by **perceptotype** creating two sub-groups of **hyper** and **hypo**-affordant participants. It was hypothesized these groups would differ on traits of risk taking, perceptual behaviour measured using vision tracking technology, and action behaviour measured as lifting kinematics. Specifically, we predicted **hyper**-affordants would have higher measures of risk taking as a characteristic and use less total visual attention to determine their perceived safe affordance distance. Additionally, we predicted **hypo**-affordants would direct their attention to more relevant visual information and spend more time visualizing the task context rather than just the MMH target which would orient them more wholistically to their environment and decrease perceived affordance distance. We predicted **hyper**-affordants would direct their attention predominantly to the surfaces of the task target they intended to grasp, and lack contextual cues from the task, and their greater affordance distances would result in increased risk of injury of the trunk and axial girdles. Finally, we predicted that dynamic task conditions would exacerbate these differences between **perceptotypes** because of the increased psychomotor demands required for interception of a moving target.

3.2 Integrated Discussion

A participant group, homogenous in demographics, was divided into two sub-groups that differed significantly on their perceived maximum safe lateral reaching distance for an experimental MMH task. The MMH task consisted of reaching to handle a stationary object (static task condition) and reaching to intercept and handle the same object in motion from the right side of the participant as it moved towards them (dynamic task condition). In both conditions the participant handled the object at their maximum safe perceived affordance threshold distance as they defined it based on a fixed instruction set and their contextual information. The sub-groups were predicted to also differ for measures of vision tracking, lifting kinematics, and personality characteristics.

3.2.1 Affordance Perception

Applying the median split method (DeCoster et al., 2011) to normalized affordance threshold measures separated a convenience sample into two distinct sub-groups with **hyper**-affordant and **hypo**-affordant **perceptotype**. This divergence in normalized affordance (nAT) persisted even as the load condition changed in an ecologically relevant manner, specifically involving a dynamic target object that translated across rollers towards the participants. The link between **perceptotype** sub-group affordance threshold in both static and dynamic agrees with foundational theories including the Ecology of Human Performance (Dunn et al., 1994) that state a person determines their actions within their environment based on a person-specific lens evaluating information from their context. The finding that the **hyper** sub-group, also had a significantly higher nAT in the dynamic condition, suggests that the personal lens that resolves context was similarly present in both task conditions, leading to these significantly larger maximum perceived safe reaching distances in both task conditions in agreeance with Dunn et al. (1994). This could also mean the task condition may be a less relevant aspect of context in this task, as both targets were perceived similarly with respect to nAT between the two **perceptotype** sub-groups.

This additionally agrees with Gibson (1977) referencing the environment is perceived differently by each participant and although part of the context was altered, it was equally changed across participants. Many researchers identify MMH differences that are injury-risk within one sub-group which agrees with our finding in relation to increased risk of LBD if completing high levels of trunk motion (Marras et al., 1995; Plamondon et al., 2014). This literature is somewhat equivocal regarding why or how these sub-groups form between individuals, and how to train or motivate injury-risk individuals to make safer reaching behaviours. Perception may provide the connection between how affordance distance is conceptualized and what affordance distances are ultimately selected. The noted significant difference in normalized affordance also translated into distinctly different handling kinematics between the task conditions and **perceptotype** sub-groups including a significantly increased risk of WR-MSD in the **hyper** sub-group compared to the **hypo** sub-group.

3.2.3 Manual Materials Handling Kinematics

The **perceptotype** sub-group comparison of handling kinematics found significant differences between the **hyper** and **hypo**-affordant sub-groups. Further analysis through kinematic measure by univariate comparisons between the **hyper** and **hypo** sub-groups identified significant differences among measures of maximum shoulder flexion, maximum axial trunk velocity, and crunch factor. Shoulder flexion may be attributed to the affordance distance itself, as individuals needed to reach further away from their body. Axial trunk velocity and crunch factor were largely independent of total distance or angle and are representative of behaviour, specifically an intentional and personal balance between intensity of movement and loading and duration of movement while longer duration movements may be more physiologically demanding (Marras, 2008). More intense movements, though it is movements with greater amplitude and greater velocity, have been associated with increased risk of cumulative overload leading to WR-MSDs (Chaffin et al., 2006). Thus, the significantly increased displacements and velocities observed amongst the **hyper**-affordant participants during static and dynamic MMH trials here suggests their significantly increased perceived affordances could be a good prediction of (and strong association with) the significantly increased MMH kinematics commonly attributed to WR-MSDs. These findings agree with Dunn et al. (1994) as **hyper**-affordants perceived their context differently, and that would bring more tasks, including these higher intensity movements into the perceived acceptable (and safe) performance range. Examination of kinematics during other relevant tasks may provide a broader understanding of the relationship between **perceptotype** sub-group, occupational kinematics, and risk of WR-MSDs.

3.2.4 Target Conditions

The kinematic measures between task conditions of static and dynamic were all significantly different. In both tasks participants were directed to handle the object at their maximum perceived safe reaching distance. An ecological approach to interceptive action could imply perceptual attunement (Gibson, 1969). In this process, individuals adjust their perceptions to align with and become more sensitive and receptive to the physical demands based on their experiences within a specific environment or relevant context (Gibson, 1966; Gibson, 1986). This adaptation is, in part, responsible for differences in informational variables used by individuals with different expertise levels in a particular skill or task (Fajen et al., 2008). When comparing **perceptotype** sub-groups of **hyper**- and **hypo**-affordant across task condition, the effect of both independent variables significantly impacted the normalized affordance threshold and some kinematic measures.

Many aspects of a dynamic target could impact perception and action of an individual. Some aspects include velocity and acceleration of moving target, distance between object's starting place and interception point, the consistency of motion, cognitive considerations, and experience of the participant (Fleury et al., 1998; Le Runigo et al., 2005). Cognitive considerations relevant in this MMH task include tracking the object, determining the participant's intended interception point, and timing the initiation and velocity of movement to meet the object at their intended interception point (Tresilian et al., 2003). These findings agree with the foundational works of Dunn et al. (1994) as context has changed between static and dynamic task conditions and therefore perceptions of context should and did change, thus the task completed changed as a result. This could still be person dependent and seems to be when comparing **perceptotype** sub-group and task condition effects.

Every participant completed their maximum perceived lateral affordance threshold handling task at a shorter normalized distance in the dynamic condition compared to the static. This may be important behaviour to consider when designing a workspace that completes a similar task to promote shorter reaching distances and less injury-risk kinematics associated with reaching to handle and axial trunk rotation.

3.2.5 Visual Attention

We predicted an association between **perceptotype** sub-group and gaze locations and durations during affordance setting and active MMH for both static and dynamic conditions. Affordance setting for static trials and active MMH trials were segmented into phases of movement for visual attention analysis. The **hyper** sub-group performed the Initialization phase of affordance setting for static trials significantly faster than the **hypo** sub-group. This difference may have contributed a lot of additional visual information to the **hypo** sub-group than what is observed by the **hyper** sub-group. We predicted the

Initialization phase would be the primary phase in which affordance setting observation is occurring, however participants may have continued observation into the Handling phase while in contact with the object at different postures. This suggests that individuals selecting a shorter reaching distance, safer affordance threshold, and more injury-avoidant behaviour are also likely to both gather more visual information and spend more time determining that safe threshold.

Perceptotype sub-groups also varied on gaze behaviour during MMH handling in static and dynamic task conditions though these variations did not differ significantly. Overall, our results suggest increased visual attention of **hyper perceptotype** off of the working space compared to **hypo** during Initialization phase of both task conditions. Additionally, during the Reaching phase, **hyper** sub-group then increased visual attention to the usable features of the object they were reaching toward and grasping, whereas the **hypo** sub-group focused on the non-usable features of the object during this Reaching phase. Some researchers argue that certain cue or object features affect task goal conceptualization and therefore influence subsequent action (Marteniuk et al., 1990; Wenderoth & Weigelt, 2009). This could explain the visual attention during Initialization and different movement kinematics during the Reaching phase of the MMH task. Additionally, prolonged focus on usable features of the target object may increase movement velocity as the participant focuses on and plans their hand placement in a specific location (Prablanc & Martin, 1992). Determining, predicting, or altering how workers will complete tasks is difficult (Faber et al., 2007); however, intervention with either the work task or the worker by altering the tools used or the work behaviours respectively can decrease incidence and impact of LBD (Wickström et al., 1993). Altering a work task by introducing visual cues can alter the workers' behaviour, including affordance distance and subsequent activity (Bandaralage et al., 2020). This perception-level approach to ergonomic intervention may offer valuable opportunities for designing more effective and user-friendly tools, equipment, or environments.

In the current study the variation found for gaze locations in different tasks and phases between **perceptotype** sub-group were not significant. It is possible that visual attention was not adequately characterised within this study. Future work to identify and quantify this relationship should be completed using widely accepted data collection and analysis methods for gaze behaviour data.

3.2.6 Personality and Expertise

According to Dunn et al. (1994), the perception of context and determination of performance range is personal, and given that we hypothesized that people who perceived a significantly different performance range and/or performed significantly differently would have some meaningful difference in relevant state and trait characteristics. Contrary to this prediction, though, no significant difference was found between **hyper** and **hypo perceptotype** sub-groups on any measure of state or trait characteristic analyzed, including the trait of risk-taking. The overall EPQ score and EPQ factor scores were predicted to be greater for the **hyper perceptotype** sub-group as we hypothesized higher self-reported risk taking and greater self-selected maximum affordance distance threshold would be positively correlated. There was no relationship between these measures. WR-MSDs occur amongst many workers who believe they are working within safe limits of their body, and it may be the case that participants selecting **hyper-**affordant reaching distances believe the distance is within their safe range are not specifically intentional risk takers. Additional non-occupational tests of perceived affordance and specific situational measures of risk-taking behaviour could help identify this association more effectively.

Additionally, the PAW-Q was utilized to identify work-related history and commonly occurring occupational behaviours in each participant's "normal workday." The results of this questionnaire were not as expected, as we did not predict any responses would have included tasks such as frequent daily heavy lifting, bent and twisted working postures, and over four hours of driving. These questionnaire results are further discussed in the limitations section.

3.2 Limitations

Several limitations exist regarding this study that are separated into three categories for discussion including Participants and Questionnaires, Methods and Measures, and Data and Analysis.

Participants and Questionnaires

Collecting MMH handling data from a convenience sample of university undergraduate students is not representative of the population in question that typically completes this type of work. Within this sample 68% of participants identified as female, 28% as male, 2% as non-binary, and 2% as both non-binary and female. The skewness of demographics could impact the findings of this study because 86% of MMH workers are typically men (NOC Classifications 7, 8, and 9; Statistics Canada, 2021). Participants aged 15-24 accounted for 86% of the sample participants versus only 11% of the Canadian population (Statistics Canada, 2021), narrows the applicability of the findings. A larger study that can examine associations between **perceptotype** and demographics such as gender and age is recommended to expand these findings.

Work related questionnaires including the PAW-Q were completed by participants with the suggestion to consider an average school day as an average workday. This poses a limitation because of the uniformity of the employment experience between participants as they were all students, plus it introduces recollection bias from participants. Some participants reported their average workday from previous or current part time employment positions as evident from the responses to the heavy lifting and driving task related questions for example's, which generates some discrepancy in the interpretation of the results. Some participants would have past work or current work to report on while others would not, and it is unknown what led participants to answer about work or school. Additionally, the PAW-Q was completed improperly by many participants and made it necessary to omit the results of a question regarding perceived exertion during work tasks limiting the validity of the questionnaire.

Self-reporting bias is present in research, affected by social desirability and recall bias amongst other limitations (Althubaiti, 2016). Many questions within the EPQ and other questionnaires used can introduce self-reporting bias that has proven to be a consistent limitation within self-reporting (Gunthert & Wenze, 2012). Some of these questions intend to identify the present state of the participant can be interpreted as referencing the past and therefore can introduce recall bias or inaccurate recall (Coughlin, 1990). Additionally, if individuals have not reflected on their on-going behaviours, traits, and tendencies they must consider factors of past behaviour to determine their answer. Individuals are additionally more likely to recall exposure to risk than exposure to a healthy alternative (Althubaiti, 2016) therefore questions directly relating to risk exposure and behaviour have limited validity.

Methods and Measures

Initially it was our intention to use the mean kinematic measures over all five data sets in analysis minus any errored trials, however, this was not feasible due to occasional marker occlusion in data collection. Both the dynamic and static task condition trials were affected by the consistent loss of left side markers that introduced subsequent difficulties in data processing and extraction of measures. The earliest quality trial was selected for each participant for analysis, to minimize learning and fatigue effects. This modification of the original method introduces a limitation because the trial used in analysis was not consistent between participants, therefore, some differential learning may have occurred. Additionally, considering only one trial of each task condition per participant introduces a limit that we cannot average across all trials.

The measures extracted from vision tracking data have not been identified or used in previous research in literature making it difficult to test findings against a standard for validity. Vision tracking is well established within research (Vickers, 2009), however this application is novel, and as such our developed method to test and compare for gaze location and gaze duration have not been validated. Continued work in vision tracking with ecologically valid work tasks is required to develop a standard for vision tracking.

Data and Analysis

Limitations to data and subsequent processing and analysis included poor quality vision tracking data that lead to exclusion of some participants and limited sample size of comparison data. The first set of data collection contained errors of world view orientation and were unusable to extract vision tracking data. Additionally, after the first set of data were collected and reviewed, the research team determined affordance distance setting trials (s0) provided additional insight to perception action coupling.

Because the decision to include these data was delayed fewer participants were included in affordance distance setting trial vision tracking analysis than in the handling trial vision analysis. It may be the case that the simple demands involved in this manual material handling (MMH) task were perceived by similar visual attention fixation strategies regardless of **perceptotype** group or task condition. Land et al. (1999) and subsequent studies have documented this fixation behaviour in various contexts found eye movements during complex tasks may develop fixation patterns on targets or spaces within the larger task. This agrees with findings in other well-learned tasks including locomotion with varying difficulty (Hollands et al., 2002; Marigold & Patla, 2007; Patla & Vickers, 1997). Understanding the specifics of visual fixation patterns and durations in this MMH task could offer insights into behavior and group differences, but refining experimental protocols to accurately capture these patterns in three-dimensional tasks remains challenging and limits the findings of this study.

Markered motion capture has specific limitations, notably occlusion, occurring when some markers are blocked from view of multiple cameras and thus are not accurate in one or more axes in output. Additionally, registration issues limit markered motion capture, as some marker trajectories overlap in space and the label of one marker erroneously registers to the incorrect marker exiting the overlap. Other types of motion capture include electromagnetic, inertial, active marker, and exoskeleton, each of which experience their own unique advantages, challenges, and limitations (Gu et al., 2016; Guo et al., 2011; Kim et al., 2020). Markerless motion capture has increasing prevalence and reliability in research settings, showing promise for improved validity of data and might provide easier integration with other objective behavioural measures including vision tracking in both occupational and experimental settings.

3.3 Conclusions

This study contributes knowledge to ergonomics and biomechanics fields connecting perception to action through kinematics and vision tracking. The kinematic measures and vision tracking data were compared to the static and dynamic manual materials handling task conditions. The task condition comparison identified that both **hyper**-affordant and **hypo**-affordant **perceptotype** sub-groups selected larger affordant distances and used increased handling kinematics. Many significant differences were identified in MMH behaviour between the affordant sub-groups that can be used to develop informed ergonomic interventions. No significant differences were identified amongst several self-reported measures of state and trait characteristics.

Our results align closely with established theories such as Gibson's Theory of Affordances (1977), the Ecology of Human Performance by Dunn et al. (1994), and the concept of the cumulative development of WR-MSDs. Specifically these findings highlight that changes to context lead to different task and action opportunities afforded by participants, and these actions have a personal aspect to them as proposed by Gibson (1977). Specifically, our findings support Dunn et al. (1994) that individuals can recognize opportunities for action in work tasks, linking these perceptions to their actions in meaningful ways. Notably, some participants engage in manual material handling (MMH) with movements linked to a higher risk of WR-MSDs, possibly stemming from the initial perceptual stage. Here, identifying and adjusting these actions could help reduce both the incidence and overall costs associated with WR-MSDs.

In conclusion, affordance distance **perceptotype** has a reliable relationship with WR-MSD injury relevant kinematic measures including shoulder flexion and crunch factor. Affordance **perceptotype** also affects visual behaviour during initialization and reaching to grasp a target in affordance setting trials, where the **hypo perceptotype** sub-group gathered visual information during initialization, and then directed more attention to the unusable surfaces during reaching. The **hypo**-affordant sub-group additionally spent significantly more time gathering visual context prior to setting their affordance distance threshold. These findings suggest that ergonomic interventions could be developed considering the perceptual behaviours used by individuals completing the work tasks, namely visual cues directed to specific usable surfaces and context locations.

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Appendix A: COVID-19 Screening Questionnaire

Have you travelled outside Canada in the last 14 days?

- ○ Yes (1)
- ○ No (2)

Have you had a close contact with a confirmed case of COVID-19 in the last 14 days?

- ○ Yes (1)
- ○ No (2)

Do you have any new onset (or worsening) of the following symptoms:

	Yes (1)	No (2)
Fever (1)	○	○
Cough (2)	○	○
Shortness of breath (3)	○	○
Runny nose (4)	○	○
Sore throat (5)	○	○
Chills (6)	○	○
Painful swallowing (7)	○	○
Nasal congestion (8)	○	○
Feeling unwell / fatigued (9)	○	○
Nausea / vomiting / diarrhea (10)	○	○
Unexplained loss of appetite (11)	○	○
Loss of sense of taste or smell (12)	○	○
Muscle / joint aches (13)	○	○
Headache (14)	○	○
Conjunctivitis (pink eye) (15)	○	○

Have you shown your proof of vaccination? (QR Code)

- ○ Yes (1)
- ○ No (2)

Appendix B: Physical Activity Readiness Questionnaire

NAME ____ DoB _______________

EMAIL ____ TEL ________________

If you’re aged 15-69, the PAR-Q will tell you if you should check with your doctor before significantly changing your physical activity patterns. If you’re over 69 years and aren’t used to being very active, check with your doctor. Please read each question carefully and answer honestly by ticking YES/NO.

	YES	**NO**
Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?		
Do you feel pain in your chest when you do physical activity?		
In the past month, have you had a chest pain when you were not doing physical activity?		
Do you lose balance because of dizziness or do you ever lose consciousness?		
Do you have a bone or joint problem (for example back, knee or hip) that could be made worse by a change in your physical activity?		
Is your doctor currently prescribing medication for your blood pressure or heart condition?		
Do you know of any other reason why you should not take part in physical activity?		

If YES, please comment:

If you answered YES to one or more questions: You should consult with your doctor to clarify that it’s safe for you to become physically active at the current time.

If you answered NO to ALL of the questions: It is reasonably safe for you to participate in physical activity, gradually building up from your current ability level.
I have read, understood, and accurately completed this questionnaire. I confirm that I am voluntarily engaging in an acceptable level of exercise, and my participation involves a risk of injury.

SIGNATURE __________________________ PRINT NAME __________________
DATE __________

Appendix C: Demographics Questionnaire

Q154 **In this section we will ask you some questions about you. Please feel free to be completely honest. This survey is completely anonymous and confidential; your answers will not have a name or email address associated with them.**

Q155 Please enter your age in numbers (**e.g.**, 49):

____

Q37 **How would you classify your gender identity (select all that apply)**

☐ Man (1)

☐ Woman (2)

☐ Transgender (3)

☐ Non-binary/non-conforming (5)

☐ Prefer Not to Answer (4)

Q157 **Which of the following do you identify as? (select all that apply)**

☐ Asian (1)

☐ Black (12)

☐ Caucasian (3)

☐ Hispanic (2)

☐ Indigenous (4)

☐ Other option not listed here (14)

Q158 **If you selected other in the question above please specify**

____

Q159 **Are you currently a student?**

○ Yes (1)
○ No (2)

Q160 **What is the highest level of education that you have completed?**

○ Less than grade 8 (1)
○ Grade 8 (2)
○ High school (3)
○ College degree/diploma (4)
○ University undergraduate degree/diploma (5)
○ University graduate degree (6)
○ I prefer not to disclose (7)

Q162 **How much do you weigh? (Please enter weight in pounds, e.g., 180 lbs)**

____

Q163 **What is your height? (Please enter height in feet and inches, e.g., 5'1")**

____

Appendix D: Physical Activity at Work Questionnaire

In the average work day you do: - Sit for more than 2 hours in total
Yes
No

In the average work day you do: - Stand or walk for more than 2 hours in total
Yes
No

In the average work day you do: - Kneel for more than 1 hour in total
Yes
No

In the average work day you do: - Squat for more than 1 hour in total
Yes
No

In the average work day you do: - Drive for more than 4 hours in total
Yes
No

In the average work day you do: - Walk more than 2 kilometers in total
Yes
No

In the average work day you do: - Climb more than 30 flights of stairs in total
Yes
No

How often are you involved in - Precision work for more than 2 hours in a day
Every work day
2-4 days per week
1-3 days per month
Almost never

How often are you involved in - Working postures that had your hands above your shoulders for more than 30 minutes in total

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

How often are you involved in - Working postures that had your hands below your knees for more than 30 minutes in total

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

How often are you involved in - Bent or twisted working postures of the trunk several times per hour

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

How often are you involved in - Repetitive finger movements several times per minutes, for more than 2 hours per day

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

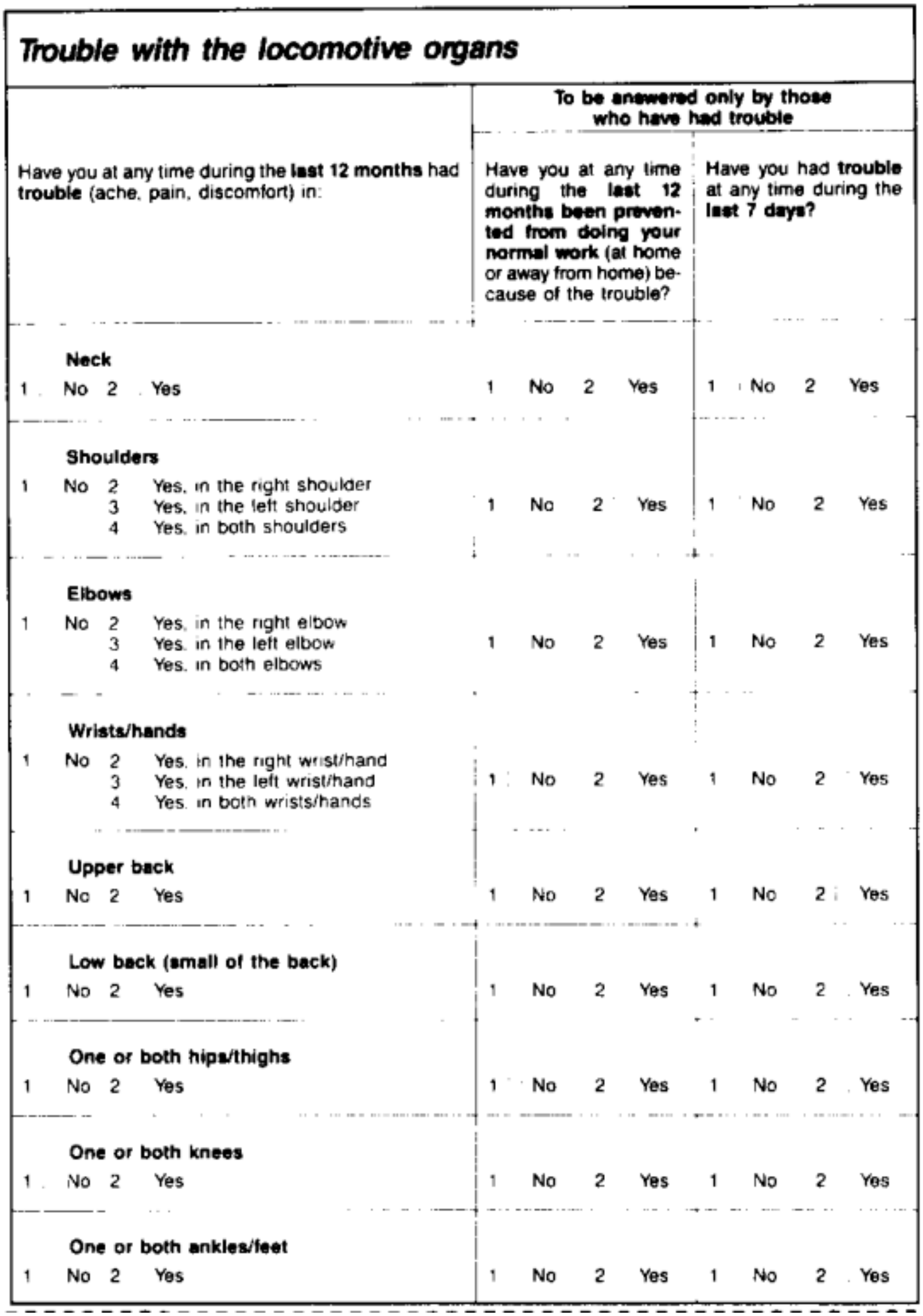
How often are you involved in - Lifting and / or carrying loads between 5 and 15 kilos (11 and 33 pounds)

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

How often are you involved in - Lifting and / or carrying loads greater than 15 kilograms 33 pounds)

- Every work day
- 2-4 days per week
- 1-3 days per month
- Almost never

Appendix E: Standardized Nordic Questionnaire for Analysis of Musculoskeletal Symptoms



Trouble with the locomotive organs

	To be answered only by those who have had trouble	
Have you at any time during the **last 12 months** had **trouble** (ache, pain, discomfort) in:	Have you at any time during the **last 12 months been prevented from doing your normal work** (at home or away from home) because of the trouble?	Have you had **trouble** at any time during the **last 7 days?**
Neck 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
Shoulders 1 No 2 Yes, in the right shoulder 3 Yes, in the left shoulder 4 Yes, in both shoulders	1 No 2 Yes	1 No 2 Yes
Elbows 1 No 2 Yes, in the right elbow 3 Yes, in the left elbow 4 Yes, in both elbows	1 No 2 Yes	1 No 2 Yes
Wrists/hands 1 No 2 Yes, in the right wrist/hand 3 Yes, in the left wrist/hand 4 Yes, in both wrists/hands	1 No 2 Yes	1 No 2 Yes
Upper back 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
Low back (small of the back) 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both hips/thighs 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both knees 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes
One or both ankles/feet 1 No 2 Yes	1 No 2 Yes	1 No 2 Yes

Appendix F: Eysenck Personality Questionnaire

Q1 Do you often buy things on impulse?

○ No (1)

○ Yes (2)

Q2 Would you prefer a job involving change. travel and variety, even though it might be insecure?

○ No (1)

○ Yes (2)

Q3 Do you usually make up your mind quickly?

○ No (1)

○ Yes (2)

Q4 Do you like planning things carefully, well ahead of time?

○ No (1)

○ Yes (2)

Q5 Do you often get into a jam because you do things without thinking?

○ No (1)

○ Yes (2)

Q6 Can you make decisions quickly?

○ No (1)

○ Yes (2)

Q7 Do you save regularly?

○ No (1)

○ Yes (2)

Q8 Are you slowed and unhurried in the way you move?

- ○ No (1)
- ○ Yes (2)

Q9 Would you rather plan things than do things?

- ○ No (1)
- ○ Yes (2)

Q10 Do you generally do and say things without stopping to think?

- ○ No (1)
- ○ Yes (2)

Q11 Do you quite enjoy taking risks?

- ○ No (1)
- ○ Yes (2)

Q12 Do you usually think carefully before doing anything?

- ○ No (1)
- ○ Yes (2)

Q13 When the odds are against you, do you usually think it worth taking a chance?

- ○ No (1)
- ○ Yes (2)

Q14 Would you enjoy parachute jumping / sky diving?

- ○ No (1)
- ○ Yes (2)

Q15 Are you an impulsive person?

- ○ No (1)
- ○ Yes (2)

Q16 Would you make quite sure you had another job before giving up your old one?

- ○ No (1)
- ○ Yes (2)

Q17 Can you put your thoughts into words quickly?

- ○ No (1)
- ○ Yes (2)

Q18 Would regular health checks make you feel better?

- ○ No (1)
- ○ Yes (2)

Q19 When you go on a trip, do you plan routes and times carefully?

- ○ No (1)
- ○ Yes (2)

Q20 Do you prefer to 'sleep on it' before making decisions?

- ○ No (1)
- ○ Yes (2)

Q21 Are you usually carefree?

- ○ No (1)
- ○ Yes (2)

Q22 Do you often do things on the spur of the moment?

- ○ No (1)
- ○ Yes (2)

Q23 Would life with no danger in it be too dull for you?

- ○ No (1)
- ○ Yes (2)

Q24 Would you enjoy fast driving?

- ○ No (1)
- ○ Yes (2)

Q25 Do you often get involved in things you later wish you could get out of?

- ○ No (1)
- ○ Yes (2)

Q26 Would you do almost anything for a dare?

- ○ No (1)
- ○ Yes (2)

Q27 Do you often change your interests?

- ○ No (1)
- ○ Yes (2)

Q28 Are you rather cautious in unusual situations?

- ○ No (1)
- ○ Yes (2)

Q29 When buying things, do you usually bother about the guarantee / warranty?

○ No (1)
○ Yes (2)

Q30 Do you prefer activities that 'just happen' rather than those planned in advance?

○ No (1)
○ Yes (2)

Q31 When on holiday, do you look for relaxation rather than excitement?

○ No (1)
○ Yes (2)

Q32 Do you mostly speak before thinking things out?

○ No (1)
○ Yes (2)

Q33 Do you get so 'carried away' by new and exciting ideas that you never think of possible snags?

○ No (1)
○ Yes (2)

Q34 Do you need to use a lot of self-control to keep out of trouble?

○ No (1)
○ Yes (2)

Q35 Do you get bored more easily than most people doing the same old things?

○ No (1)
○ Yes (2)

Q36 Do you hate standing in a long line for anything?

- ○ No (1)
- ○ Yes (2)

Q37 Do you get extremely impatient if you are kept waiting by someone who is late?

- ○ No (1)
- ○ Yes (2)

Q38 Do you often long for excitement?

- ○ No (1)
- ○ Yes (2)

Q39 Before making up your mind, do you carefully consider all of the advantages and disadvantages?

- ○ No (1)
- ○ Yes (2)

Appendix G: Task Scripts

Task Script for STATIC Task Condition:

"You are a package handler at an amazon facility. Your job is transferring boxes from the conveyor coming out of a chute into a truck for delivery. You like to hurry the process by reaching along the conveyor to handle the boxes, the question of "what do you think the largest distance you could safely and repeatedly reach up the conveyor to grasp and pull the boxes?

You will select your safest horizontal reaching distance by instructing the investigator to move the box closer or further. Adjusting the distance is not a simple task – only you know how you feel, and where the box should be positioned for safest handling. If you feel the box is too far, have it moved closer. If you feel it is too close, have it moved further. You are only going to set this distance once. Do not be afraid to make multiple adjustments before we start the handling – you have to make enough adjustments, so the box is set at your safest horizontal position. You can never make too many adjustments, but you can make too few.

After your safe reaching distance is set, you will complete this task multiple times reaching out to the box and translating it to your left side before releasing the box. Do you have any questions?"

Task Script for DYNAMIC Task Condition:

"You are a package handler at an amazon facility, your job to transferring the boxes from the conveyor coming out of a chute into a truck for delivery. You like to hurry the process by reaching alone the conveyor to handle the boxes, the question of "what do you think the largest distance you could safely and repeatedly reach up the conveyor to grasp and pull the boxes?

You will perform this action multiple times, intercepting the box on the conveyor at your safest horizontal reaching distance. Selecting the distance is not a simple task – only you know how you feel, and at what point the box should be intercepted for safest handling. If you feel the box is too far, wait before you intercept it. If you feel it is too close, intercept it sooner. You are going to complete this task multiple times after the initial translation.

The box will slide to you the first time, and please don't intercept it. This is to show you the speed that the box slides on the conveyor due to gravity. The second time and all subsequent times please intercept the box on your right and translate it to your left side before releasing the box. Do you have any questions?"

Appendix H: Main Python (main.py) UI Script

```
import numpy as np

import argparse

import glob

import cv2

import os


BLOCK_WORDS = ['.DS_Store']


# How many frames to skip, 2 = every other, 3 = every third etc.

PROCESS_EVERY_N_FRAME = 2


def play_video(file):

    print("Playing:", file)


    # Setup our data

    videoData = np.zeros((0,), dtype=str)


    # Temp hack, set file name for first row

    videoData = np.append(videoData, [file])
```

```
# load video capture from file

video = cv2.VideoCapture(file)


# get metadata

width  = int(video.get(cv2.CAP_PROP_FRAME_WIDTH))

height = int(video.get(cv2.CAP_PROP_FRAME_HEIGHT))


# window name and size

cv2.namedWindow("video", cv2.WINDOW_AUTOSIZE)


# Get number of frames

frameCount = int(video.get(cv2.CAP_PROP_FRAME_COUNT))


while video.isOpened():

    frameNumber = video.get(cv2.CAP_PROP_POS_FRAMES)


    # Read video capture

    ret, frame = video.read()


    # Ensure we have video left to play

    if not ret:

        break
```

```
        # Only Process every n frames
        if frameNumber % PROCESS_EVERY_N_FRAME == 0:
            # Draw UI
            cv2.putText(frame, "Frame " + str(int(frameNumber)) + " (" +
str(int((frameNumber / frameCount) * 100)) + "%)", (0, height - 5),
cv2.FONT_HERSHEY_SIMPLEX, height / 400, (255, 255, 255))

            # Display each frame
            cv2.imshow("video", frame)

            # show one frame at a time
            key = cv2.waitKey(0)
            while key not in [ord('q'), ord('a'), ord('s'), ord('d'), ord('f'), ord('g'), ord('h'),
ord('j'), ord('k'), ord('l'), ord(':')]:
                key = cv2.waitKey(0)

            # Quit when 'q' is pressed
            if key == ord('q'):
                break
```

```
# ? Frame
if key == ord('a'):
    videoData = np.append(videoData, [0])

# ? Frame
if key == ord('s'):
    videoData = np.append(videoData, [1])

# ? Frame
if key == ord('d'):
    videoData = np.append(videoData, [2])

# ? Frame
if key == ord('f'):
    videoData = np.append(videoData, [3])

# ? Frame
if key == ord('g'):
    videoData = np.append(videoData, [4])

# ? Frame
if key == ord('h'):
    videoData = np.append(videoData, [5])
```

```
        # ? Frame
        if key == ord('j'):
            videoData = np.append(videoData, [6])


        # ? Frame
        if key == ord('k'):
            videoData = np.append(videoData, [7])


        # ? Frame
        if key == ord('l'):
            videoData = np.append(videoData, [8])


        # ? Frame
        if key == ord(':'):
            videoData = np.append(videoData, [9])


# Release capture object
video.release()


# Exit and destroy all windows
cv2.destroyAllWindows()
```

```
    # Show and return the beautiful data
    print(videoData)
    return videoData


def start():
    # Get options from user
    parser = argparse.ArgumentParser(description='Kaylas Magic Video Truthy Pie')
    parser.add_argument('assets', type=str, help='Glob pattern for assets location')
    parser.add_argument('--output', dest='output', default="./output.csv", help='where to save data (default: ./output.csv)')
    args = parser.parse_args()
```

```
# Find all files in glob path

filenames = glob.glob(args.assets)


# Remove garbage

safeFilenames = [word for word in filenames if word not in BLOCK_WORDS]


# Setup our data

data = []


# Loop over each and play the video

for path in safeFilenames:

    videoData = play_video(path)

    data.append(videoData.tolist())


# We determine the max length of frames in any of the videos

rowLengths = []

for row in data:

    rowLengths.append(len(row))

maxLength = max(rowLengths)


# Then "pad" the remaining data so that we have a "balanced" matrix

for row in data:

    while len(row) < maxLength:
```

```
        row.append('')
balancedArray = np.array(data)

# Transpose so that each column is a video
finalData = balancedArray.transpose()

# Save the beautiful data
np.savetxt(args.output, finalData, fmt="%s", delimiter=",")
```

Appendix I: Physical Activity at Work Questionnaire Scoring Methodology

Question Set A:

1. In the average work day you do: - Sit for more than 2 hours in total
2. In the average work day you do: - Stand or walk for more than 2 hours in total
3. In the average work day you do: - Kneel for more than 1 hour in total
4. In the average work day you do: - Squat for more than 1 hour in total
5. In the average work day you do: - Drive for more than 4 hours in total
6. In the average work day you do: - Walk more than 2 kilometers in total
7. In the average work day you do: - Climb more than 30 flights of stairs in total

Questions A1-A7 were reported on a binary scale, 1= yes, 0=no. To calculate the total score of participants' responses of section A, a total ranging from 0/7 – 7/7 was tabulated for each participant, and averaged over the **hypo** or **hyper perceptotype** sub-group.

Question Set B:

1. How often are you involved in - Precision work for more than 2 hours in a day
2. How often are you involved in - Working postures that had your hands above your shoulders for more than 30 minutes in total
3. How often are you involved in - Working postures that had your hands below your knees for more than 30 minutes in total
4. How often are you involved in - Bent or twisted working postures of the trunk several times per hour

5. How often are you involved in - Repetitive finger movements several times per minutes, for more than 2 hours per day
6. How often are you involved in - Lifting and / or carrying loads between 5 and 15 kilos (11 and 33 pounds)
7. How often are you involved in - Lifting and / or carrying loads greater than 15 kilograms 33 pounds)

Questions B1-B7 were reported on a ordinal scale, 0= almost never, 1= 1-3 times per month, 2=1 day per week, 3=2-4 times per week, 4=every work day. Each question was scored based on a mean and standard deviation for both **perceptotype** groups. To calculate the total score of participants' responses of section B, a total ranging from 0/28 – 28/28 was tabulated for each participant and averaged over the **hypo** or **hyper perceptotype** sub-group.