Can High-Quality Jobs Help Workers Learn New Tricks?

A Multi-Disciplinary Review of Work Design For Cognition

Abstract

Understanding whether and how work design affects human cognition is important because: (1) cognition is necessary for job performance, (2) digital technologies increase the need for cognition, and (3) it is vital to maintain cognitive functioning in the mature workforce. We synthesize research from work design, human factors, learning, occupational health, and lifespan perspectives. Defining cognition in terms of both knowledge and cognitive processes/fluid abilities, we show that five types of work characteristics (job complexity, job autonomy, relational work design, job feedback, and psychosocial demands) affect employees' cognition via multiple pathways. In the short-to-medium term, we identify three cognitively-enriching pathways (opportunity for use of cognition, accelerated knowledge acquisition, motivated exploratory learning) and two cognitively-harmful pathways (strain-impaired cognition, depleted cognitive capacity). We also identify three longer-term pathways: cognitive preservation, accumulated knowledge, and ill-health impairment). Based on the emerging evidence for the role of work design in promoting cognition, we propose an integrative model suggesting that short-to-medium term processes between work design and cognition accumulate to affect longer-term cognitive outcomes, such as the prevention of cognitive decline as one ages. We also identify further directions for research and methodological improvements.

Bios

Sharon K. Parker (s.parker@curtin.edu.au) is a John Curtin Distinguished Professor at Curtin University, an Australian Research Council Laureate Fellow, Director of the Centre for Transformative Work Design, and a CI for the Centre of Excellence in Population Ageing Research. Her PhD is from the University of Sheffield. Research interests include job and work design, proactivity, mental health, job performance, and perspective taking.

M.K. Ward (mk.ward@curtin.edu.au) is a Research Fellow in the Centre for Transformative Work Design at Curtin University's Future of Work Institute. She received a PhD and MS in Industrial/Organizational Psychology from North Carolina State University. Her research interests include work design in entrepreneurship, and designing work to enhance cognition.

Gwenith G. Fisher (gwen.fisher@colostate.edu) is an Associate Professor in the Department of Psychology at Colorado State University, Adjunct Associate Professor in the Colorado School of Public Health, and Affiliate Investigator with the Centre of Excellence in Population Ageing Research. She received a PhD and MA in Psychology from Bowling Green State University and a BA from Penn State University. Her research examines individual and work factors related to worker health and well-being, including cognitive functioning.

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"You can teach an old dog new tricks, and this old dog wants to learn" (Thomas P. O'Neill).

Using ratings from experts, Miner (2003) identified work design theories as amongst the most scientifically valid and practically useful theories in the field of management. Drawing on the classic Job Characteristic Model (Hackman & Oldham, 1976), there is a strong theoretical underpinning as to what constitutes well-designed work. There is also clear evidence that psychologically well-designed work – such as work that offers job autonomy and variety – enhances employee motivation, performance, health and well-being (for a review of over 5000 articles, see Parker, Morgeson, & Johns, 2017). Yet we believe that there is untapped potential for work design to promote cognition: good work design might be a crucial part of an enriching work environment that helps 'old dogs to learn new tricks' and that preserves cognitive functioning as workers age.

Our aim in this review is investigate the link between work design and cognition. We bring together diverse perspectives from multiple disciplines, using work design theory as the integrating theory. We thus go beyond existing reviews on the effect of work and cognition that have been "within discipline" (e.g., Fisher, Chaffee, Tetrick, Davalos, & Potter, 2017; Nexø, Meng, & Borg, 2016; Parker, 2017; Wielenga-Meijer, Taris, Kompier, & Wigboldus, 2010). Combining perspectives allows the identification of missing aspects in each theoretical field, and hence develops a more comprehensive picture. Our guiding framework for the review is shown in Figure 1. As depicted, we are concerned with how work design can affect cognition via two distinct yet connected temporal processes: a short-to-medium term process, and a long-term process.

Insert Figure 1 about here

In a ***short-to-medium term process*** (yellow shade, Figure 1), well-designed tasks, jobs, or roles give workers the opportunity to use one's knowledge and cognitive processes/ fluid abilities, and also facilitate change in knowledge (e.g., learning, the development of expertise). As

summarised in the figure, such short-to-medium term cognitive processes are crucial in organisations for two main reasons. First, cognition is a key input to individual-level performance, which in aggregate affects organisational performance. Thus, cognition is one of the most important 'capacity' drivers of effective individual work performance (Carpini, Parker, & Griffin, 2017). Across many different types of jobs, core task performance is predicted by job knowledge (Schmitt, Cortina, Ingerick, & Wiechmann, 2003) as well as cognitive processes (Hunter, 1986; Schmidt & Hunter, 2004). These cognitive variables also predict adaptive performance, or coping with and responding well to change (Jundt, Shoss, & Huang, 2015), and proactive performance, such as initiating new work methods (Frese & Fay, 2001). The link between cognition and work performance is shown in a meta-analytic finding that those who engage in informal learning at work have on average 32% higher performance than those who do not (Cerasoli et al., 2018). At the organisational level, performance is derived from members collectively learning how to respond to dynamic changes to the environment, which requires "continuously enhancing and upgrading the capabilities of individuals so as to enable them to create new value" (Bartlett & Ghoshal, 1998, p. 33).

Second, when work design promotes short-to-medium term cognitive outcomes, a further benefit is that this helps build a workforce able to deal with increasingly complex work as a result of technological change. The past two decades have seen a rapid increase in the proportion of knowledge work occupations and this trend is expected to continue (Holford, 2019; Jacobs, 2017). The rapid pace of digitalization, such as the increasing use of AI, means that individuals will need to be able to quickly adapt by learning new skills and new roles (Dellot & Wallace-Stephens, 2017). Many new roles will be more cognitively demanding as manual and routine tasks are automated (Frey & Osborne, 2017). Thus, the changing world of work means that questions about how to foster cognition and accelerate learning will increase in relevance into the future (Parker & Grote,

2020), as indeed shown by large-scale government programs focused on this aim, such as the UK's Foresight project on 'mental capital' (Government Office for Science, 2008).

There is also emerging evidence for a ***longer-term cognitive process*** (grey shade, Figure 1). As we shall see, over longer time periods, occupational work characteristics can help to prevent a decline in cognitive processes and fluid abilities, with some evidence of underpinning changes in brain neurology. This process is important given the global trend toward people working until older ages due to increased longevity and changes in economic policies about later pensions to sustain economic growth (Fisher, Chaffee, & Sonnega, 2016). Having workers stay in the workforce longer means attending to the question of how to maintain the cognitive performance of mature workers (Fisher et al., 2016), especially given that some cognitive functions decline with age. Enhancing cognitive health amongst mature workers has benefits for not only for the retention, employability, and performance of mature workers, but also for these individuals' successful ageing more broadly.

Our guiding framework (Figure 1) indicates that work design and these processes sit within an organizational context, and are shaped by elements within that context (such as leadership styles, organisational structure, culture, and strategy). Likewise, organisations, and in turn work design, are embedded within a wider public policy and legislative environment that affect employment law and retirement timing. Importantly, one implication of this nesting of work design within wider contexts is that work design can be changed - not only through processes like job crafting and local work redesign - but also through altering the organisational and/or public policy/legislative context. We return to this point later, when we discuss practical implications of this research.

In this article we describe the key concepts in this review (cognition and work design), as well as our deliberately broad approach for capturing the diverse literature on this topic. We then review the findings, synthesized across the diverse perspectives in the literature. Finally, we propose an integrating model, identify key insights, and propose future research directions.

KEY CONCEPTS AND REVIEW APPROACH

We sought to identify all papers that consider or investigate the link between work design and cognition, with both of these elements considered broadly, as we elaborate next.

Cognition

In cognitive psychology (Gazzaniga, Ivry, & Mangun, 2002; Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010), there are two key categories of cognitive variables: *knowledge* (mental representations) and *cognitive processes and fluid abilities* (mental operations that transform and manipulate representations). This distinction between knowledge and cognitive processes/fluid abilities underpins the distinction between crystallised and fluid intelligence (Horn & Cattell, 1967), and between cognitive pragmatics and cognitive mechanics (Baltes, 1987). Figure 2 shows our focus on these elements of cognition, as well as on change in these aspects of cognition.

Insert Figure 2 about here

More specifically, *knowledge* includes aspects such as declarative or factual knowledge (knowing 'that'), procedural knowledge (knowing 'how'), and tacit knowledge (non-codified, informally-obtained knowledge). These forms of knowledge can change in short-time frames as people learn new concepts and develop new skills. Knowledge typically also increase over the life span based on experience and accumulated expertise, with some people developing wisdom (e.g., the capacity to make sound judgements). As an example of knowledge in the workplace, a salesperson can apply her knowledge of a products' features to sell products to clients. With repeated opportunity, she will learn more about the product and the clients, developing expertise and more nuanced mental models. Over many years, her accumulated knowledge makes her an unusually effective and wise judge of challenging clients and complex product issues.

In contrast, *cognitive processes and fluid abilities* are capabilities that allow us to solve problems and engage in other such mental operations. Four key cognitive processes (Park, 2000) include perceptual speed, working memory, inhibitory function, and sensory function. Perceptual

speed is relevant for all cognitive tasks, not just speeded tasks, because it affects how we acquire

and process information (Salthouse, 1996); however, processing speed is especially important for

complex tasks (Park, 2000). Working memory is "the amount of online cognitive resources available

at any given moment to process information" (Park, 2000, p. 10). Inhibition refers to how well

individuals filter out irrelevant information that can distract from attending to relevant information.

Sensory function includes visual and auditory acuity which affects cognitive functioning

(Lindenberger and Baltes, 1994). Such processes underpin fluid cognitive abilities (Horn & Cattell,

1967), such as one's ability to solve novel problems, to make spatial judgements, and to engage in

reasoning. Cognitive processes and fluid abilities tend to be invariant across context and stable over

time, except for a decline as people age. Thus, in performing her work, the salesperson referred to

above will use various *cognitive processes*, such as working memory, and *fluid abilities,* such as

reasoning. Although the salesperson's opportunity to apply these cognitive processes will vary over

time, her underlying abilities will tend to stay stable, with perhaps gradual decline in some abilities

as she ages. Neurologically, such changes can be reflected in changes to brain structure (e.g., grey-

matter volumes) and function (e.g., cortex activation patterns) (Lövdén, et al., 2010).

Work Design

Work design is about the nature of people's tasks, activities, relationships, and

responsibilities at work, and how these are structured and organized (Parker, 2014). In the case of

the salesperson, the work might involve highly routine tasks with a tight script for talking to clients,

or it might involve complex tasks with high autonomy over what the person says to clients. These

jobs vary in their work design which, in turn, is likely to affect the salesperson's job satisfaction, job

strain, performance, and - our focus here - their knowledge and cognitive processes/ abilities.

Early interest in work design was captured by the classic Job Characteristics Model

(Hackman & Oldham, 1976), which posited that five key "work characteristics" (job autonomy, task

variety, task identity, task significance, and job feedback) generate internal motivational states

(experienced responsibility, a sense of meaning, and the knowledge of one's results) that in turn lead to greater employee job satisfaction, performance, and attendance. A related early theory is the demand-control model (Karasek, 1979), which proposed that each of low job autonomy and high demands cause psychological strain, yet that high demands are acceptable for strain if autonomy is also high. In such an 'active job,' employees can use their autonomy to manage the ensuing demands, thereby reducing their negative effects on strain and health.

Beyond these traditional theories, there have been expansions in the work characteristics considered to be important. These extensions include ensuring the core motivational work characteristics in the JCM capture all of the key aspects of work design (e.g., Parker & Wall, 1998; Morgeson & Campion, 2002) and, similarly, extending 'control' in the demand-control model to cover a broader set of 'resources' (the job demands-resources model; Demerouti, Bakker, Nachreiner, & Schaufeli, 2001). Job demands have also been argued to include both challenge demands and hindrance demands (Crawford, LePine, & Rich, 2010). A relational work design perspective focuses on the social aspects of work, such as social support and interdependence (Grant, 2007; Grant & Parker, 2009). Work design studies also sometimes consider physical work characteristics (e.g., noise levels), although these aspects are out of scope in the current review.

Work design theory has also expanded to consider outcomes beyond motivation and strain/health. Especially relevant here, authors have advanced a learning and development approach, arguing that key work characteristics foster knowledge acquisition and learning (Frese and Zapf, 1994; Parker, 2014; Taris & Feij, 2004; Wall, Jackson, & Davids, 1992). Although several earlier theories inform this perspective, most relevant is Karasek and Theorell's (1990) 'active learning hypothesis,' which proposed that active jobs (high in autonomy and demands) enable and motivate learning, mastery, and skill development. In a systematic review of this research, Wielenga-Meijer et al. (2010) concluded overall positive effects of work design on learning, and Parker (2017) summarized this evidence in a 'work design growth model.'

Here we extend and develop this work design-cognition perspective; the work design perspective comes from particular disciplines (especially those of applied/organisational psychology, organizational behaviour, management, and occupational health), it focuses on a particular level (the job level), and it focuses on a particular time frame (usually months or a few years). However, there is a larger literature to consider. At one extreme, some studies focus on momentary neurological and cognitive effects of task attributes; at the other extreme, lifespan studies link work to cognition over very long periods and operationalize work design at the level of an occupation. Synthesizing across these and other perspectives offers a more complete picture of how work design affects cognition.

Review Approach and Perspectives That Link Work Design With Cognition

To capture these multiple and diverse perspectives on work design and cognition, we adopted a broad approach to our review. After some initial backwards referencing from published reviews to get a sense of the literatures, we conducted a systematic review using Web of Science and articles in top-ranked journals across multiple disciplines (neuroscience, public health, aging, experimental psychology, gerontology, management, and more) to find publications that included both key work design variables and cognition, with both concepts defined broadly (see Appendix A, online resource, for more details of this process, as well as search terms). We identified approximately 180 articles from this process. We then subjected the articles that we obtained to a scientific bibliometric mapping process (Cobo et al., 2011; Ding & Yang, 2020), with the goal being to visually depict the diverse literatures on the topic of work design and cognition (rather than to conduct an in-depth analysis of the detailed topic clusters). We used the *VOSviewer* software (van Eck & Waltman, 2010) to analyse and visually depict the data (Figure 3). The program calculates the co-occurrence of scientific terms in abstracts, and the strength of association between terms is used as input for the map. The map visualizes the strengths of associations between terms such that relatedness among terms is indicated by position and relative distance (van Eck and Waltman,

2010, 2014; see Appendix A for more details). Clusters were identified using the VOSviewer

program; terms that are more similar to each other (and different from the terms of another

cluster) are grouped together into a common color (see van Eck and Waltman, 2010, 2014, for a

more detailed explanation of VosViewer parameters). We briefly summarize the diverse

perspectives, and provide example studies, in Appendix B (online supplementary resource).

Insert Figure 3 about here

Three main clusters emerged from the VosViewer analysis, and after discussion, we then

indicated the five perspectives included in this interdisciplinary review onto the scientific map. This

overlay shows the level of overlap among the five perspectives. The first perspective is a ***work design***

perspective, which we discussed above. As shown in Figure 3 (red/green cluster, purple square), this

perspective focuses particularly on job resources such as job autonomy, and the effects on outcomes

like motivation and learning, as well as topics such as team work.

The work design perspective is spatially close to a ***learning perspective*** (Figure 3, mostly red

cluster, aqua square, with terms such as feedback, learning, knowledge, training), which reflects the

fact that learning studies come from similar disciplines. Example topics in this perspective include

leadership development (DeRue & Wellman, 2009); effect of feedback on learning and performance

(Kluger & DeNisi, 1996); informal learning (Cerasoli et al., 2018); training motivation (Colquitt,

LePine, & Noe, 2000), knowledge sharing (Wang & Noe, 2010); team/ organizational learning

(Kozlowski, Chao, & Jensen, 2010) and learning engagement (Noe, Tews, & Michel, 2017). Some

learning theories focus on learning as a way to narrow discrepancies between goals and

performance, such as goal setting theory (Locke and Latham, 1990), social cognitive theory

(Bandura, 1989), and expectancy theory (Vroom, 1964). Other theories focus on how intrinsic

motivation fosters one's desire to learn (Colarelli, Dean, & Konstans, 1987), as well as learning-

oriented behaviours such persistence in the face of setbacks (Debowski, Wood, & Bandura, 2001).

Usually, in these studies, work design is one of many contextual antecedents rather than being the

focus. The indicators of cognition tend to be knowledge or change in knowledge. This is a large literature, so we discuss this perspective mostly with reference to reviews and meta analyses.

The **human factors perspective** is next closest to the work design perspective (gold square, mostly red cluster, terms such as feedback, automation, driver), and includes disciplines like human factors, cognitive ergonomics, and neuro-ergonomics. These studies mostly focus at the task level, examining questions such as the effect of task load, autonomy, or feedback on complex task performance, learning, and situational awareness (e.g. Young, Lenne, Beanland, Salmon, & Stanton, 2015). Depletion is the primary assumed mechanism. For example, drawing on theories of attention and resources, such as Wickens' (2004) multiple resources theory, Hockey's (1997) cognitive-energetical framework, and Sweller's (1988) cognitive load theory, it is assumed that high levels of mental work load consume attentional resources, and therefore impair learning and performance. Study designs in this perspective are mostly experimental simulations of complex systems. Some studies focus on learning mechanisms, such as the idea that when work is designed for automation in a way that the person is 'left out of the loop' (cannot exercise autonomy over the system), this impairs their situational awareness (Stanton et al., 2006). Such research is influenced by sociotechnical systems theory (Cherns, 1976) – a popular work design theory concerned with jointly optimizing the social and technical aspects of work. Attention and information processing theories, such as Endsley's (1995) model of situational awareness, also guide this literature.

The fourth perspective relevant to work design and cognition is the **lifespan or ageing perspective** (dark grey square, blue cluster, topics such as retirement, cognitive function, and dementia). These longitudinal or cohort studies come from disciplines such as sociology, epidemiology, gerontology, and developmental psychology. Research in the lifespan or ageing perspective is often concerned with understanding the role of work design as an environmental factor that might affect cognitive functioning and ageing over the lifespan. Thus this research has very long time spans, such as 10 to 20 years, and usually considers work at an occupational level.

Most often, lifespan/ageing focus on occupational-level complexity or autonomy as the key work variable (Finkel, Andel, Gatz, & Pedersen, 2009; Fisher et al., 2014), although some studies have considered other characteristics (Andel, Finkel, & Pedersen, 2015; Grzywacz, Segel-Karpas, & Lachman, 2016; Oltmanns et al., 2017). In terms of cognition, the focus is usually on cognitive processes/ abilities assessed using tests or using neurocognitive measures of brain structure and function (e.g., brain imaging, Stuss & Knight, 2013). The predominant theory focuses on cognitive preservation (use-it-or-lose-it or closely related processes) or, sometimes, a psychological strain/ health mechanism.

A fifth and approach, somewhat overlapping with the lifespan approach, is the ***occupational health perspective*** (grey square, blue and green cluster terms such as health, strain and risk). Disciplines are quite close to a lifespan perspective, and topics include healthy work design, occupational safety, ageing, psychosocial/physical exposures, and worker health and well-being. Cognition and brain health have received attention as key outcomes of work in this literature because cognition is necessary for everyday functioning (Clouston et al., 2013), and because cognition can be affected by unhealthy work in later life (Fisher et al., 2017; Grzywacz et al., 2016). Theoretically, this perspective draws on the demand-control model of strain (above,) as well as more dynamic theories of stress as a process that unfolds over time (Ganster & Rosen, 2013) and the allostatic load model (McEwen, 1998) that explains physiological stress processes (Ganster & Rosen, 2013, p. 1086). For example, the stressor-strain model indicates that work stressors can lead to strain outcomes such as poor mental health and, in turn, decreased cognitive functioning (Beehr, Jex, Stacy, & Murray, 2000). Most of the key studies in occupational health are longitudinal, and occasionally prospective cohort, studies that investigate how work relates to cognition over long periods.

Finally, although it does not show up on the vosviewer map, studies from a ***neurological perspective*** are also relevant. These studies do not empirically consider work design (hence their

invisibility in Figure 3), but they are relevant because they link stimuli in the environment with cognition-related brain structure and function. For example, some neurologically-oriented studies focus on environmental conditions that lead to changes to neural circuits, called neuroplasticity, which in turn affects cognitive functioning (Keller & Just, 2016) and may lead to longer term cognitive outcomes (Burzynska, Jiao, & Ganster, 2018). A classic study in this line of research by Rosenzweig, Krech, Bennett, and Diamond (1962) demonstrated that enriching the environment in rat cages changed their brain chemistry and brain weight. Subsequent research, often using animal models, shows the importance of cognitive, social and physical stimulation for environments to be considered enriched, with a key property being the maintenance of novelty, such as by regularly changing toys (e.g. Simpson & Kelly, 2011). We give examples of studies from this perspective where they help explain potential mechanisms linking work design and cognition.

In summary, the traditional work design literature has expanded to consider how the nature and structure of people's work shapes their use of knowledge and learning. However, our review shows that there is a wider evidence base from different disciplines, with shorter and longer time scales, and with work considered at lower and higher levels of analysis. Next we synthesize this research conducted to address the question as to whether and how work design affects cognition, focusing first on short-to-medium term cognitive processes and second on long-term cognitive processes.

WHETHER AND HOW WORK DESIGN AFFECT SHORT-TO-MEDIUM TERM COGNITION

In our review, we identified five categories of psychological work characteristics (work design) for which there is reasonable evidence of a link to cognition. The first two are core to the traditional Job Characteristics Model: job autonomy and feedback. *Job autonomy*, which we use interchangeably with the term "job control," refers to the degree of decision-making at work, such as one's influence over general decisions (decision-making autonomy), the opportunity to choose timing of work tasks (timing autonomy/control), and being able to choose one's work methods

(method autonomy/control). *Feedback* refers to information about the effectiveness of one's work behaviours (Ilgen, Fisher, & Taylor, 1979). Feedback can come from the job (as focused on in the Job Characteristics Model), or from formally structured systems such as performance appraisal systems, from others in the environment such as peers and supervisors, from electronic systems, and from self-driven efforts to obtain feedback (feedback seeking).

The remaining three categories of work characteristics - job complexity, relational aspects of work, and psychosocial demands - extend beyond the traditional Job Characteristics Model. *Job complexity* refers to the extent to which a job puts mental demands on a worker that require aptitude, skill, training, thought, and creativity, and independent judgment (Schaubroeck, Ganster, & Kemmerer, 1994). Some studies (e.g., Fisher et al., 2014) refer to mental demands rather than job complexity, and terms such as cognitive demands, intellectually stimulating work, or challenge demands also capture this aspect. *Relational aspects of work* concern the social context within which tasks are executed, such as the degree of social contact, support, task interdependence, and interaction outside the organization. Finally, *psychosocial demands,* key to the demand-control model of strain (Karasek, 1979), such as work load and emotional demands, include those social and organizational "aspects of a job that require sustained physical or mental effort and are therefore associated with certain physiological or psychological costs" (Demerouti et al., 2001, p. 501).

We identified multiple *work design-cognition pathways* by which these aspects of work design affect cognition (see Table 1). In this section, we focus on the ways in which cognition is affected in the short-to-medium term, including three cognitively-enriching pathways (*opportunity for use of cognition, accelerated knowledge acquisition, motivated exploratory learning*) and two cognitively-harmful pathways (*strain-impaired cognition, depleted cognitive capacity*). We unpack each mechanism, and review the evidence for the most important work characteristics within each.

Opportunity for Use of Cognition

A simple and direct path linking work design and cognition concerns the application of one's knowledge, and the use of one's cognitive processes and fluid abilities. Aspects of work design can create more, or fewer, opportunities for individuals to use their existing knowledge, and to apply their cognitive processes/ fluid abilities. For example, if a salesperson has high job complexity in which he has to repeatedly sort out challenging contractual issues, he not only has the opportunity to apply knowledge of contracting, but he engages in problem solving which relies on cognitive processes like working memory and uses cognitive abilities such as reasoning. Likewise, if a salesperson has no autonomy to address customer complaints, and instead needs to refer problems to her supervisor, this reduces the salesperson's chance to apply her product knowledge, as well as to engage in problem solving that draws on her expertise.

In fact, this 'opportunity for use of cognition' pathway has rarely been empirically investigated as a unique and separate path, although it is implied in tests of other pathways. For example, if work design accelerates knowledge acquisition, then that implies more opportunity for use of cognition. This pathway is also part of the longer-term cognitive preservation pathway that focuses on how 'using' cognition prevents 'losing' cognition. We can think of this pathway as similar to the effect on one's muscles of engaging in a physical workout. That is, a physical workout uses one's muscles, with attributes of the workout (e.g., ease of access, the type of activity like walk versus swim, length of time engaged in) influencing which muscles are used and to what extent. Likewise, work allows one to use knowledge and apply one's cognitive processes/ abilities, with the design of the work (e.g., complexity, autonomy) shaping which knowledge, cognitive processes and cognitive abilities are used, and to what extent.

Accelerated Knowledge Acquisition

Some physical workouts are highly oriented towards skill acquisition. For example, consider a tennis drills session in which the player engages in dynamic tennis play and receives feedback from the play itself, as well as from the coach. Such a workout does much more than use one's muscles: it accelerates the tennis player's acquisition of skill by virtue of the player's active engagement. Likewise, we assert that work can do more than "use" one's knowledge and cognitive processes/abilities. That is - when designed in ways that enhance individuals' active engagement – work can accelerate worker's knowledge acquisition, facilitating deeper and broader forms of learning. For example, because a salesperson has the autonomy to solve problems for clients, and then to get direct and immediate feedback on her approach, she very quickly acquires knowledge about what solutions are best, increasing her speed of learning.

Job autonomy, feedback, and combinations of autonomy, demands, feedback, and complexity, have had the most attention in relation to this path.

Job autonomy. In the human factors literature, job autonomy is often considered important for enhancing knowledge acquisition because it allows for more active interaction with the work tasks, especially the opportunity to dynamically engage with problems that emerge. For example, in regard to automation, Endsley (2018) presented strong evidence from a review that higher levels of automation (which implies lower human autonomy over the system) reduce people's situational awareness because the lack of active interaction means that people become passive processors of information. Lower situational awareness, in turn, reduces people's ability to recover when automation fails. Endsley (2017, p. 8) referred to the automation conundrum in which "the more automation is added to a system, the more reliable and robust that automation is, the less likely that human operators overseeing the automation will be aware of critical information and able to take over manual control when needed." Endsley (2017) proposed the HASO (human-autonomy system oversight) model, which advocates the need for humans to retain autonomy over automated systems so that they maintain a sufficient level of situational awareness to be able to

take over effectively when required. A meta-analysis of 18 experiments by Onnasch, Wickens, Li, and Manzey (2014) supported this conclusion, demonstrating that, although higher automation (in which the machine autonomously decides/ implements actions) positively predicts routine performance when the machine is functioning well, as shown in nine studies, higher automation also means poorer recovery from system failure. The authors advocated: "if return-to-manual performance issues are of serious concern, human operators should be kept involved at least to some extent in decision and action selection as well as action implementation" (Onnasch et al., 2014, p. 486). Others studies reach similar conclusions (e.g. Onnasch & Hösterey, 2019).

Research from the work design perspective also points to the role of job autonomy in enabling the development of knowledge. Parker and Axtell (2001) showed that job autonomy, and the wider scope of action that autonomy generates, led to greater self-reported understanding about other departments, customers, and the wider organisation (which they referred to as 'integrated understanding'), which was in turn associated with employees being more able to adopt the perspective of their internal suppliers. At the team level, Aoki (1986) discussed how more Japanese-oriented forms of work design that have broader jobs, job rotation, more autonomy, and greater engagement of operators in problem solving, are more likely than traditional specialised American job structures to facilitate collective 'learning by doing', such as via joint problem solving, and are more likely to facilitate knowledge sharing across team members to solve emergent challenges, thereby broadening people's knowledge. Others have similarly argued that self-managing teams with team-level autonomy are especially likely to learn because of these teams' greater opportunity for engagement in active decision-making, as well as the high level of ownership and heedful relating that can occur. For instance, in their analysis of four studies of self-managing teams, Druskat and Pescosolido (2002) showed that learning was a dominant feature at the beginning of these autonomous teams, and helped to account for their effectiveness, although learning opportunities faded over time as formal training and knowledge sharing opportunities

reduced, and as the work system became more routine. In a study of 115 teams in five multinational corporations, team autonomy (but not team feedback) predicted team learning, which in turn predicted team performance (Zellmer-Bruhn & Gibson, 2006).

Some empirical studies focus on how work design can accelerate knowledge acquisition by allowing people to engage their cognitive abilities one at a time, and in a manner, that most suits them, thereby enabling more effective use of those abilities (e.g. de Lange et al., 2010). As a specific example, Elfering, Grebner, and de Tribolet-Hardy (2013) reasoned that high timing control (such as control over work hours and the timing of one's tasks) enables people to allocate their tasks according to their cognitive resources, such as to have breaks when they are fatigued or to do more difficult tasks when resources are highest, which should allow better cognitive performance. Consistent with this reasoning, these authors found that, timing control was associated with lower levels of self-reported cognitive failure (e.g., reports of memory failures), albeit not with accidents or near accidents. Similarly, Lawrie, Tuckey, and Dollard (2018) theorized that autonomy gives individuals the opportunity to organise their work more efficiently to allow attentional focus (mindfulness), whereas non-autonomous work is associated with automatized responding. Over two weeks, daily job control (as well as also lower levels of daily psychological demands) predicted mindfulness, and in turn self-reported learning, especially within workplaces that strongly valued employees' psychological health. Scholars have likewise argued that low control jobs with high levels of standardization foster the development of routines which, although helpful for efficiency, impair creativity and adaptivity as a result of functional fixedness. In support of such a process, Niessen and Volmer (2010) found that individuals with low autonomy did not transition well to high autonomy situations, with impaired performance in the new situation, suggesting reduced adaptivity and learning.

Feedback. Human Factors scholars often consider feedback as a key input from the environment for promoting situational awareness at the individual, team, or system level (for a review, see Stanton, Salmon, Walker, Salas, & Hancock, 2017). For example, a lack of feedback has been implicated in operator's inability to resume control after automation failure because of people being 'out of the loop' and not getting access to the knowledge they need (Endsley & Kiris, 1995). One way to keep people in the loop is to provide employees with continuous feedback about the state of the system (Norman, 1990). Such feedback has been shown to support performance and skill maintenance in aviation (Sarter, Woods, & Billings, 1997).

However, the effects of feedback on knowledge acquisition are inconsistent overall. In the context of automated driving, for example, results of simulation studies are mixed. Cohen-Lazry, Borowsky, and Oron-Gilad (2017) showed that verbal feedback to autonomous drivers' about the vehicle and its environment increased drivers' attentiveness, but not their ability to recover from an emergency situation, and a study that simulated robot use in battlefields (Chen & Barnes, 2012), showed no difference in situational awareness according to the degree of feedback. In contrast, Seppelt and Lee (2019) showed the superiority of continuous feedback in visual displays relative to discrete warnings in fostering drivers' situational awareness and performance. Another study showed that Mechanical Turk workers' trust in automation and their performance is enhanced with feedback, especially when the reliability of the system is unknown (Mishler et al., 2017).

Although there are many reasons for these mixed effects (we explain motivational ones later), scholars from the learning perspective have discussed how feedback can sometimes backfire because it becomes a crutch, focusing attention to the goal of getting positive feedback and shortcutting one's actual learning (Kluger and DeNisi, 1996). Several studies support this idea, showing that detailed feedback can promote better performance in an initial task, yet reduce transfer of training to a later task because the feedback provides too much guidance and inhibits information processing (Goodman, Wood, and Chen, 2011). Similarly, in the domain of error

training, highly detailed feedback has been shown to reduce exploration and learning (Keith & Frese, 2008). Some authors recommend feedback from the task itself, rather than from an external agent, because the former supports learning through discovery (Frese & Zapf, 1994; Kluger & DeNisi, 1996). This latter perspective is consistent with the research discussed next, which suggests that knowledge acquisition is best enhanced with combinations of feedback from the task plus other aspects of work design.

Combinations of job complexity, challenge demands, job autonomy, and job feedback. Most of the work design studies that focus on accelerated knowledge acquisition mechanisms consider some combination of job complexity or challenge demands, autonomy, and feedback. Theoretically, the expanded demand-control model of strain (Karasek & Theorell, 1990; Taris & Kompier, 2005) proposed that an 'active job' - which has both high demands and high control - promotes learning. High demands stimulate the need for employees to explore effective work strategies to achieve their goals, and on the other hand, and high job control allows exploration of, and experimentation with, these different strategies. Thus, together, demands and autonomy together facilitate the acquisition of knowledge. In a similar vein, Frese and Zapf (1994) summarized German action theory (Hacker, 1973) to argue that job autonomy, job complexity, and feedback together promote learning. Collectively, these work design attributes mean that individuals engage in a 'complete' action sequence involving goal setting, plan development, decision making, monitoring, and feedback, which then supports learning as to what plans are effective, and enables a process of deep "intellectual penetration" (p. 297).

More specifically, from the German Action Theory perspective, well-designed work involves the use of conscious forms of action regulation, or "decision necessities". In other words, work has some degree of complexity. When work is complex, over time problem-solving and meta-cognitive strategies get used more and more, and with repeated use, these strategies become routinized and automated, freeing up further resources for learning and yet

deeper intellectual penetration of the task. Importantly, by complex, these authors' argument is not that work should be 'complicated', but that work should involve a high level of action regulation. In other words, in contrast to a notion that work promotes learning because it requires a requires a high use of working memory, the argument is that work which involves the consideration of multiple diverse goals, plans, feedbacks, and the linkages amongst these elements, will enhance knowledge acquisition. Whereas complicatedness can cause fatigue and overload, complex decision necessities supports the acquisition of deep expertise. But it is not just about complexity - autonomy is an important part of this puzzle. Frese and Zapf argued that – if job autonomy or control (which they referred to as "decision possibilities") are lacking – then job complexity (decision necessities) can be experienced as overwhelming. When job autonomy is absent, the action sequence is incomplete, which impairs cognitive processes and the associated learning. Thus, autonomy is important - not because of motivation - but because "people who have control can do better because they can choose adequate strategies to deal with a situation" (Frese and Zapf, p. 319). In essence, autonomy promotes flexible responses to complex situations, and workers can then learn which responses work most effectively.

Building on arguments from German action theory, and similar to the arguments about autonomy and automation (above), work design scholars have argued that autonomy – usually in combination with feedback - changes the way people interact with their work tasks, thereby accelerating learning. In particular, Wall and colleagues (e.g., Wall and Jackson, 1995) have argued that autonomy means workers can control variances at the source (such as by fixing a minor machine fault him/herself, instead of having to call out a specialist), which then means the worker gets immediate feedback about the impact of his/her actions. This means the worker can learn about cause and effect from the task itself, which enhances the complexity of his/her mental models. Moreover, although not explicitly stated by Wall and colleagues, the

fact that there are variances to control in the situation, implies some degree of job complexity or challenge demands are necessary for fostering this mental model development.

Consistent with the idea that autonomy facilitates "deep" learning, a series of studies led by Wall have shown that machine operators given greater autonomy learn to anticipate and then prevent faults (Jackson & Wall, 1991; Wall, Corbett, Martin, Clegg, & Jackson, 1990; Wall et al., 1992). Using a novel methodology in which they analysed the pattern of machine breakdowns, the authors were able to rule out an alternative explanation, the 'quick response mechanism' (in which operators respond more quickly than calling out specialists) because they showed an initial decrease in downtime of 20% that was due to quick responses was followed by a large and delayed decrease of 70% of downtime, which the authors assumed was due to employees learning to prevent problems. Likewise, in studies that support the idea that autonomy combined with feedback can aid learning through discovery, Leach and colleagues investigated the effects of a combined empowerment/ feedback initiative. In an initial study, Leach, Jackson, and Wall (2001) reported that the organisation had introduced an empowerment initiative that was only partially successful in improving fault rectification. The authors observed that a lack of knowledge about some faults was limiting the scope for operators to engage in rectification (that is, to make use of their autonomy). Hence, a feedback process was carefully designed (participatively, with operators, engineers, and others) to provide specific feedback that was directed to faults only of relevance, that incorporated an opportunity to learn; and that was non-threatening to the self. After the intervention, time series analysis of data on engineer call outs and machine utilization data showed clear positive effects of the intervention, as well as evidence of improvement over time, suggesting learning. Motivation was not affected, but operators reported an increase in knowledge sharing and lower perceived likelihood in making expensive mistakes. In a follow up study of the same intervention, Leach et al. (2003) showed that job knowledge about faults

increased as a result of the intervention, especially for novices, which the authors attributed to the combination of autonomy and feedback fostering a deeper form of learning. In essence, job autonomy allows one to explore different learning strategies in the face of complexity and challenging demands, whilst feedback provides information about the effectiveness of these strategies. This idea of job aspects working together to promote learning is consistent with socio-technical systems theory which advocates that change in one part of the system (e.g. autonomy) needs to be accompanied by change in other parts of the system (Cherns, 1987; Trist & Bamforth, 1951; Clegg, 2000).

Summary. There is strong evidence that autonomy, feedback, and job complexity (or challenging demands) operate in a synergistic way to accelerate workers' knowledge acquisition, with theory and research across human factors and work design perspectives showing these work characteristics together accelerate learning. There is also some evidence for autonomy alone, such as that autonomy enables the acquisition of broader knowledge, and the promotion of mindful and flexible modes of operating. However, there is little clear evidence for complexity alone, and mixed evidence for feedback by itself, with the latter perhaps reflecting the fact that feedback systems can be poorly designed and that feedback might best support learning if it comes directly from the task.

Motivated Exploratory Learning

To continue the metaphor introduced above, compare a person engaging in a tennis drills session who loves tennis with a person engaging in a tennis drills session under sufferance (perhaps coerced by a parent). The person who loves tennis will be motivated to exploit the active learning opportunities created in the session. For example, s/he will be willing to experiment with different strategies, carefully observing the consequences of various shots, persisting if a tactic doesn't immediately work, and asking for and listening to feedback; all of which are likely to increase the quality of the workout and the skills acquired. In a similar vein, depending on their work design,

people vary in their motivation at work, which shapes their willingness to exploit any learning opportunities offered by the work or to create new learning opportunities. Those high in motivation as a result of well-designed work will be likely to explore and try things when completing their tasks, and indeed to take on ever more challenging tasks, and hence will enhance the extent to which they employ cognitive processes, use their cognitive abilities, and use and acquire new knowledge.

This pathway draws on theorizing from the classic Job Characteristics Model (Hackman & Oldham, 1976) that well-designed work fosters internalized motivation. But the present pathway goes further to suggest that motivation then stimulates workers' desire to learn and/or engage in learning-oriented behaviours. Also relevant to this path is Kanfer and Ackerman's (1989) motivation-based theory of skill acquisition, which proposes that learning is facilitated by challenging situations paired with motivation. For example, because a salesperson has an intrinsically-motivating job with complex problems to solve, she is open to learning new skills, and willing to explore new ways of solving problems; behaviours that boost her knowledge and mean she uses increasingly complex cognitive abilities. All five categories of work characteristics have been implicated in this motivated exploratory learning pathway, as we discuss next.

Job autonomy. Autonomy might be an especially important work characteristic for promoting learning via motivation because autonomy promotes a strong sense of responsibility for the work (Hackman & Oldham, 1976), as well as a broader and more flexible sense of ownership (Parker, Wall, & Jackson, 1997); both of which are likely to motivate a desire to learn so as to more effectively meet one's goals. Similarly, scholars have argued that trainees learn best when they autonomously try to gain knowledge and skills (Kozlowski et al., 2010). There are several empirical examples in the literature. For example, Holman and Wall (2002) showed that job control was related to both cognitive work-based learning strategies (such as working out which aspects of the job are important), and behavioural work-based

learning (such as asking for more information from others when needed), which in turn predicted idea generation. In a cross-sectional study, Parker & Sprigg (1988) showed that job autonomy predicted perceived mastery and, for proactive individuals, role breath self-efficacy (the belief in one's capability to engage in a broader arrange of tasks beyond technical ones); outcomes that the authors framed as learning-oriented. In a longitudinal study, de Lange et al. (2010) found – especially for middle-aged workers - reciprocal links between work and learning. Thus, job control (and also job demands, but not social support) predicted motivation to learn and active problem solving three years later, and active problem-solving behaviour predicted later work characteristics, in a positive spiral.

Showing further support for a motivation process, in an experimental puzzle task, Wielenga-Meijer et al. (2010) manipulated autonomy during practice trials, and then examined individuals' performance on a subsequent 'transfer' task. Findings showed that, although autonomy did not help participants to repeat previously learned behaviour in the same task (indeed, full autonomy was worse), those with moderate and full autonomy performed better in the transfer task than those with low autonomy because they were motivated to learn and they engaged in more exploration. Using the same manipulation, in a later study, Wielenga-Meijer, Taris, Wigboldus, and Kompier (2012) found that cognitively demanding interactions reduced learning in the low and full autonomy conditions, but did not impair learning in the moderate autonomy condition, suggesting that moderate autonomy helps people to learn from high cognitive demands. Foss, Minbaeva, Pedersen, and Reinholt (2009) showed in a cross-sectional study that job autonomy promoted intrinsic motivation, which in turn generated knowledge sharing (feedback and task identify also fostered knowledge sharing via other motivational processes); and in a meta-analysis, Cerasoli et al. (2018) showed the importance of job autonomy (also resources, demands, and support) as an antecedent of informal learning. Likewise, several studies (e.g. Kyndt, Raes, Dochy, & Janssens, 2013) have shown that 'choice independence' at work (similar to job autonomy/control; Kirby,

Knapper, Evans, Carty, & Gadula, 2003) and/or autonomy-supportive work contexts (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004) predict a 'deep learning' approach in which the person has a strong intrinsic interest in learning and hence uses an array of integrative learning strategies, and negatively predicts a 'surface-disorganised' learning approach in which the motive is mostly extrinsic and surface techniques like rote learning are used. These studies, however, tend to be cross-sectional and reliant on self-reported measures of learning. Bergman et al., (2012), in a large population-based sample used a longitudinal study with a three-year time lag to show that those with high autonomy were more likely to report using general problem-solving strategies.

Feedback. Traditional learning theory links feedback to learning via motivation. Thus, Thorndike's (1913) law of effect assumes that positive feedback reinforces, or motivates, the correct behaviour whereas negative feedback punishes and demotivates the incorrect behaviour. Subsequent theories are more complex, but have a similar focus on how feedback motivates discrepancy-reduction behaviours related to feedback. For example, control theory (Carver & Scheier, 1981) and goal setting theory (Locke & Latham, 1990) assume that behaviour is goal directed, and that feedback motivates people to assess their behaviour in relation to their goals and then to put in effort to reduce discrepancies between the goal and the feedback.

However, these theoretical perspectives are too simple, and do not account for the mixed effects of feedback in empirical studies (e.g., Balcazar, Hopkins, and Suarez, 1985; Wielenga-Meijer et al., 2010), the relatively small and varying effects of feedback interventions (Ivers et al., 2014), or the moderating role of factors such as the credibility of the source and the timing of the feedback (Lechermeier and Fassnacht, 2018). More nuanced theorizing suggests that feedback can be a double-edged sword for learning, in part because it isn't always motivating. Thus, Kluger and DeNisi (1996) argued that when feedback promotes

attention to the task itself, it enables learning, but that often feedback is evaluative about the self, and then is demotivating.

Specifically, these authors proposed that feedback affects three hierarchical processes: task-learning processes, task-motivation processes, and meta-task processes involving the self. Attention is normally at the mid-hierarchical level, that is, the task-motivation processes that involve eliminating feedback-goal discrepancies. But feedback can also direct attention down the hierarchy (e.g., if the feedback sign is negative and additional effort is not resolving the discrepancy), which prompts the individual to engage in learning strategies to meet the goal. Feedback can also direct attention up towards the self, causing negative affect and focusing attention on the self rather than the task. For example, feedback involving praise can impair performance because it focuses individuals' attention on their higher order self-goals. This theorizing was supported in Kluger and DeNisi's (1996) meta-analysis which showed that, although there was an average positive effect of feedback interventions on performance, more than one third of applications resulted in decreased performance, consistent with the three processes. For instance, highlighting the downside of evaluative feedback for learning, Foss et al. (2009) showed that when feedback is assessed formally, such as having a performance evaluation, it predicts extrinsic motivation, which in turn reduces knowledge sharing.

Such findings have led DeNisi and Kluger (2000) to recommend (amongst other recommendations) a focus on the task and task performance only, not on the person or any part of the person's self concept. It is interesting to observe how this recommendation dovetails with a focus on feedback from the job itself. Feedback from the job (that is, getting clear and direct information about one's performance from carrying out the work activities per se) has been the traditional focus of job design theory (Hackman & Oldham, 1976). As this feedback is not mediated through supervisors, feedback from the job itself is less likely to implicate self-focused processes such as evaluation, and therefore should be more supportive

of learning. Consistent with this reasoning, in their meta-analysis, Kluger and DeNisi (1996) found that computer-generated feedback was preferable to having supervisors deliver feedback, which they attributed in part to the lack of implication of the self (note that, contemporary versions of computer-generated feedback can be more negative due to their emphasis on control).

It is clear from the above discussion that the effects of feedback on motivation, and hence performance and learning, are complex. It might be surprising, therefore, to note that a meta-analysis of work design studies by Humphrey et al. (2007) showed that feedback from the job positively predicted job satisfaction, growth satisfaction, internal work motivation, and subjective performance, and it did so not only via knowledge of results, but also via the motivational states of experienced meaningfulness and experienced responsibility. Feedback from others also predicted various motivation outcome. The highly consistent impact of feedback on motivation in this literature can be explained by its holistic focus, relative to the feedback research in the learning literature. In other words, in the work design literature, less attention is given to fine-grained aspects of feedback (positive versus negative, etc.), and instead the focus is on an employees' overall judgement that they 'get information about how they are doing in their job'. In a similar vein, scholars (e.g., Steelman et al., 2004) introduced the notion of a 'supportive feedback environment' to capture multiple aspects of feedback covered in the more detailed goal-setting research (e.g., source credibility, feedback quality, feedback delivery). These authors showed that a supervisor-oriented version and a coworker-oriented version of supportive feedback environment each positively predicted employees' motivation to use the feedback. Gabriel, Frantz, Levy, and Hilliard (2014) found that, especially for those with a strong feedback orientation, a positive supervisor feedback environment predicted employees' sense of meaning, competence, and self-determination. Overall, when feedback is operationalized as a more holistic judgement or as a comprehensive concept that

covers evidence-based supportive elements, it seems that people find it motivating, which should in turn foster greater learning.

Job complexity. According to Humphrey, Nahrgang, and Morgeson (2007), knowledge characteristics of work, such as job complexity, are intrinsically motivating because they allow individuals to demonstrate and reinforce their sense of competence on the job. In their meta-analysis of work design and outcomes, Humphrey and colleagues found that information processing and job complexity were both positively related to job satisfaction, and job complexity also predicted job involvement. Based on these findings, we expect that individuals in complex jobs would be more motivated to learn, and more likely to engage in positive learning strategies. There are, however, few studies that have directly examined links amongst job complexity, motivation, and learning.

Relational work design. Some scholars have argued that relational aspects of work design affect cognition by creating a social context that motivates employees to learn. Thus Jiang, Jackson, and Colakoglu (2016) drew on Kanfer and Ackerman's (1989) motivation-based theory of skill acquisition to predict that team task characteristics would result in relational forms of learning. Cross-sectional results showed that team task interdependence and routineness interacted to predict personal skill development (defined as new skills and abilities that enable better working relationships). Specifically, when team task interdependence was high and routineness low (indicating high job complexity), skill development was higher, whereas team task interdependence had a negative effect on learning when tasks were high in routineness (low complexity). Putting aside the cross-sectional limitations of this study, it suggests that the aspects of jobs that make them complex (e.g., social plus cognitive aspects) might positively interact; a notion that most studies have not considered.

Studies from a learning perspective also show positive links between relational aspects of work and knowledge acquisition. For example, Cerasoli et al., (2018) argued that social support

motivates people to engage in informal learning because the latter is a discretionary behaviour that others can reinforce and encourage. Their meta-analysis identified eight studies linking support from peers/managers and informal learning behaviours, with the latter behaviours being shown to predict knowledge and skill acquisition. Supportive managers also motivate greater engagement in formal learning activities, as well as activities such as career planning (e.g. Birdi, Allan, & Warr, 1997) and supportive peers/ managers can motivate greater transfer of training to the workplace (Facteau, Dobbins, Russell, Ladd, & Kudisch, 1995). In another meta-analysis, Colquitt et al. (2000) showed that supervisor support and peer support predicted motivation to learn, as well as transfer of training, with motivation to learn being positively related to declarative knowledge and skill acquisition. Studies also show that successful teams develop shared mental models, or shared knowledge about the environment and expected behaviour, which aids team performance (e.g. Cannon-Bowers, Salas, & Converse, 1993). Not only is learning about the task and the environment enhanced through team work, but also people's learning about 'how to work in a team' is developed (Wilson, Goodman, & Cronin, 2007). In contrast to the above evidence linking relational work design to cognition, in their longitudinal study, de Lange et al., 2010 showed that supervisor support at baseline predicted *less* active problem solving three years later for middle aged workers, with no relationships between these variables for young or old participants.

Psychosocial demands. The findings linking demands, motivation, and learning are mixed. In their review, Wielenga-Meijer and colleagues (2010) identified 18 studies linking job demands with learning and found reasonable support for a positive associations between job demands and motivation, and between job demands and learning, with a handful of experimental studies showing positive links amongst job demands (operationalized as goal difficulty), motivation, and learning. They explained their findings as consistent with Karasek's such that it is the "*combination* of high demands and high autonomy that facilitates learning, meaning that whether demands will be overwhelming depends on the level of control offered

by the job" (Wielenga-Meijer et al., 2010, p. 357). However, another explanation for positive learning effects of demands is that the review mostly focused on demands such as goal difficulty, which is a type of "challenge" demand. The challenge stressor-hindrance stressor framework (LePine, Podsakoff, & LePine, 2005) proposed that job demands that are appraised as challenges (that is, which require effort but also are likely to result in development and/or rewards) are positively related to motivation and performance (LePine et al. 2005), and - we might assume - learning. Overall, even though most of the studies were experimental, it does indeed seem 'challenge' sorts of demands motivate learning, although usually in conjunction with autonomy. Another caveat may be stability. In two field studies, Rosen, Dimotakis, Cole, et al., (2020) identified that the positive association between challenge stressors and performance existed only when challenge stressors are stable (predictable), with unpredictable challenge stressors being associated with attentiveness and anxiety, and lowered performance, suggesting they might also interfere with learning.

From the perspective of the challenge stressor-hindrance framework, we would expect job demands appraised as hindrances (which involve excessive or undesirable constraints) to reduce the motivation for learning. Providing some support, in healthcare, Latif et al. (2019) observed that organizational constraints limited the opportunity to transfer learning from an educational program to improving service equity and outcomes for patients. Likewise, in an initial meta-analysis, Pindek and Spector (2016) found organizational constraints related to higher frustration, intention to quit, lower job satisfaction, and lower commitment, suggesting a negative impact on motivation. However, in another analysis, Pindek and Spector (2016) reported weak meta-analytic relationships between hindrance demands—organizational constraints—and performance, which they explained as due to mixed perceptions of this demand as both a hindrance and challenge. The latter finding is consistent with general critiques of the challenge-hindrance stressor model that question the simplistic conclusions of

this model (e.g., Mazzola & Disselhorst, 2019). Overall, there is some very weak evidence that hindrance demands might impinge on motivated learning, but perhaps the most striking finding is the lack of studies examining this link.

Summary. The clearest finding is that job autonomy and relational aspects of work design such as social support tend to enhance intrinsic motivation, the motivation to learn, and hence workers' engagement in exploratory and other learning-oriented behaviours. The motivated learning effects of job complexity have rarely been studied, although are often assumed. For feedback, the evidence is most strong for feedback from the job itself, and for holistic judgements of 'having information available about how one is doing'. The effects of demands on motivated learning are mixed: some evidence shows that challenge demands like goal difficulty promote motivated learning, especially in conjunction with autonomy, but there is little clear evidence that hindrance demands impair motivated learning. More attention has been given to the role of such demands for strain, as we discuss next.

Strain-Impaired Cognition

If engaging in a workout, such as tennis drills, causes physical strain or injury, then the potential benefits of the workout on muscle development and skill acquisition will be impaired, and in fact, the workout might be negative for these outcomes. Likewise, if engaging in work causes severe psychological strain, then one's use of knowledge and cognitive ability, as well as one's knowledge acquisition, are also likely to be impaired. As documented in occupational health and work design perspectives, work can include objective or perceived "stressors" (e.g., hindrance demands such as role conflict) that can trigger a stress response, involving psychological, psychosomatic, and physiological effects, that then affect cognition. These stressors can be acute (e.g., an immediate threat, such as a new impending deadline) or chronic (ongoing, such as continuously heavy workload, shift work, or dealing with a supervisor with poor leadership skills). In the short term (we discuss longer-term effects later), the stress response includes the more rapid secretion of cortisol and other

glucocorticoids which increase the amount of sugar, or glucose, in the bloodstream. Although the surge of glucocorticoids can increase energy and improve short-term immediate recall, research shows it can also impair longer term retrieval and executive functioning, and reduce attentional resources (Kuhlmann, Piel, & Wolf, 2005; Shields, Sazma, McCullough, & Yonelinas, 2017; Sliwinski, Smyth, Hofer, & Stawski, 2006). A meta-analysis of 133 studies by Shields and colleagues concluded a complex association between acute stress and cognition: stressors that occur prior to encoding or during retrieval generally impair memory, whereas stressors that occur post-encoding can improve memory, unless the stressor occurs in a context that differs from the original encoding process. Difficulty with encoding information means increased difficulty with learning.

There are many aspects of job design that may contribute to the stress process, including a lack of job autonomy, relational work design, psychological demands, and feedback.

Autonomy. Work design scholars have theorized that a lack of job autonomy causes psychological strain because it is an aversive state in which people do not meet their needs for autonomy, and because individuals do not have the control to adequately manage demands. Meta-analyses support the effect of low autonomy on psychological strain (Humphrey et al., 2007; Spector, 1986). Likewise, occupational health studies have linked lower job control to various indicators of allostatic load (e.g., Andel et al., 2015; Li et al., 2007; Sun et al., 2007). However, only a handful of studies have gone further to link autonomy and its effects on strain with learning or cognition more broadly. In three samples of call centre employees, including one assessed longitudinally, Holman and Wall (2002) showed that low job autonomy predicted higher levels of depression which, in turn, resulted in lower skill use (as well as the reciprocal relationship). Similarly, for a group of young workers new to their jobs, Taris and Feij (2004) found that learning (self-reported engagement in learning activities) was highest in high demand, high control jobs, and lowest in low control/ low demand jobs, providing cross-sectional support for the demand-control hypothesis. Longitudinally, over three time periods

each separated by one year, learning significantly increased from time 1 to time 3 for the low demand and high control group only. Consistent with the idea that strain impairs learning, there were also lagged effects of time 1 and time 2 experienced strain on time 2 and time 3 self-reported learning.

Relational work design. Although the role of social support for reducing strain is well established in the broader literature (e.g. LaRocco, House, & French, 1980), few studies have investigated how relational work characteristics might affect cognition through strain processes. In one exception, Porath and colleagues (2015) investigated workplace incivility, one type of work-related interpersonal stressor, and found that incivility reduces attentional resources and thus interferes with working memory, cognitive processing, and cognitive abilities such as problem solving and creativity.

Feedback. Providing feedback can, theoretically, reduce stress and strain because employees know better what is expected of them. Humphrey et al. (2007) presented meta analytic evidence of this process: feedback from the job (assessed as an overall judgement of having information about one's performance) was associated with lower role ambiguity, role conflict, anxiety, absenteeism, and stress; and feedback from others also predicted lower stress and burnout. However, feedback can invoke negative emotions when it implicates the self, suggesting the potential for increasing strain. In addition, feedback processes are also often part of broader performance management systems that aim to do much more than provide information to employees. For example, electronic performance monitoring can be intended to provide employees feedback to aid their learning and development, but they also can have the purpose of comparing employees, rewarding different levels of performance, and surveilling/controlling employees (Ravid, Tomczak, White, & Behrend, 2020). This means that feedback systems are sometimes invasive and lacking in transparency, with such factors explaining why electronic monitoring systems often cause psychological strain (Aiello & Kolb, 1995). Scholars advocate designing these

systems with a purpose of development, with transparency, and with a focus on work-related behaviours (Tomczak et al., 2018). Although there are few empirical studies, we might expect that feedback systems that are poorly designed act as psychosocial demands, as we discuss next.

Psychosocial demands. Excessive psychological work demands (e.g., long work hours, work role overload, role conflict, work/non-work conflict), sometimes referred to as hindrance stressors, are typically related to strain (Ice, Ang, Greenberg, & Burgard, 2020; LePine et al., 2005; Virtanen et al., 2009). Consequently, such demands could reduce learning via a stress response which, as explained above, can interfere with effective cognitive processing and cognitive abilities (e.g. memory, fluid reasoning). For example, Sliwinski, Smyth, Hofer, and Stawski (2006) examined between- and within-person change in daily stressful experiences, finding that reaction time was slower on days with lots of stressful experiences compared to low stress days. They concluded that cognitive interference resulting from the stress process competes for cognitive attentional resources. Hyun, Sliwinski, and Smyth (2019) studied the relation between stress *anticipated* for the next day and cognition later on that day and found that, for individuals of all ages, stress anticipation reported upon waking, but not on the previous night, was associated with poorer working memory later that day. Virtanen and colleagues (2009) found that British civil servants in the Whitehall II who worked longer hours performed worse five years later on both vocabulary and reasoning tests, thus pointing to important differences in both crystallized and fluid abilities. These findings add to a growing body of research indicating that cognition suffers in relation to demands, in part because of the cognitive burden of these demands.

In a survey study, Boström et al. (2013) surveyed Swedish diabetes nurse specialists and found role conflict exhibited a strong correlation with higher demands like workload, irregular work, overtime, and rapid pace of work; and similarly strong correlation with learning demands (including, managing various work tasks, training practical skills, and acquiring new knowledge). In Pindek and Spector (2016)'s meta analysis reported above, organizational

constraints positively related to behavioral (counterproductive work behaviors), physical (somatic symptoms), and psychological (emotions and job satisfaction) strains; although learning was not examined. Military nurses who must simultaneously fulfil two roles as they perform military duties and provide health care experience role conflict, and consequently experience moral distress when they face situations with conflicting obligatory courses of action (Rensburg & Zagenhagen, 2017). Three studies have found neither nurse educators nor students appear to have learned the skills needed to fullful both roles (Caka & Lekalakala, 2013; Caka, Van Rooyen & Jordan, 2015; van Rensburg & Zagenhagen, 2017); which could reflect the excess demands of carrying out both roles. Finally, in the domain of education, Chan and Sfard (2020) found role conflict undermined the effectiveness of learning mathematics-in-peer-interactions in 7th grade dyads.

Summary. Based on research in occupational health and work design, past research has demonstrated that some aspects of work design (e.g., a lack of job autonomy, a lack of feedback, relational work design characteristics, psychological job demands) can function as psychological stressors that lead to strain. In the short term, such stressors invoke physiological changes based on cortisol and allostatic load, which in turn is associated with less attention and worse cognitive functioning in the form of decrements in cognitive abilities. Overall, however, there is a need for more studies that specifically examine how work design affects learning via enhanced strain.

Depleted Cognitive Capacity

Imagine that your physical trainer has developed you a new program, which you embark on, but find to be so physically convoluted or overwhelming that you cannot actually execute the program. Under such a situation, benefits for your muscle development or skill acquisition are likely to be inhibited. Mentally, one can observe a similar process occurring when excessive cognitive demands of work exceed one's mental capacity, leading to depletion,

and thereby impairing learning. The dominant theory relevant to this pathway comes from the human factors perspective. Cognitive load theory (Sweller, 1988) espouses that human working memory and attention are limited. From this perspective, when intrinsic cognitive load is very high, with a task that has many informational elements that interact in multiple ways and a learner that lacks expertise, memory capacity can be exceeded and hence learning and performance impaired. This theory is frequently applied in research seeking to best understand how to teach people complex tasks. For example, when tasks are complex, cognitive load that is defined as 'extraneous' (that is, load that is not necessary for learning, such as poor instructions) can especially detract from learning (for more details on types of cognitive load, see Wickens, 2014).

The main work characteristics that have been considered with respect to this pathway include job feedback, complexity, and psychosocial demands.

Feedback. Many of the human factors studies that seek to understand how people learn focus on the role of feedback. These studies show that the role of feedback is different for complex tasks relative to simple tasks, and also that what might facilitate performance in the training task is not the same as what facilitates performance in a transfer task (that is, learning). For example, whereas frequent and complete feedback result in better performance on the initial task, it creates worse performance on the transfer task (see Van Meerienboer et al., 2006 for a review). Moreover, whilst infrequent feedback supports transfer if the task is simple, evidence shows additional strategies are needed for complex tasks (such as unpacking the task, and making it simpler in the beginning). Studies also compare delayed versus instant feedback, with some suggestion that delayed feedback is preferable for complex tasks. As with the literature on motivational aspects of feedback, the level of nuance of these studies with regard to different types of feedback, interactions with complexity and also learner

experience, have not been applied to how feedback helps people to learn from their day to day work tasks.

One of the very few work studies that considers feedback in relation to a load and depletion perspective, at least conceptually, is that by DeRue and Wellman (2009). These authors showed that, when job feedback is high, 'developmental challenge' at work predicts leadership development, whereas when feedback is low, there is no positive effect of challenging work activities on leaders' skill development. The authors attributed this finding to the uncertainty-reducing effects of feedback, which the authors suggested makes the demands less intense and frees up employees' cognitive resources for learning and skill development. Although this study might seem contrary to the human factors studies, the feedback focused on here is general in nature, likely to be dispersed relatively infrequently (certainly not continuously), and likely to involve delays (it is quite rare for feedback from others to be immediate).

Complexity. The human factors and ergonomics literature is replete with studies that have examined the effect of task complexity on mental workload, showing that complex tasks are harder to learn in the short-term than simpler ones (Sweller, 1988). These studies focus on cognition during short time frames (e.g., seconds to minutes or hours). Many studies investigate task complexity in driving and other situations in which mental workload is the focal dependent variable, whereas other studies focus on mental workload as a mediator in relation to performance (e.g. Galy, Paxion, & Berthelon, 2018). For example, Haji, Rojas, Childs, de Ribaupierre, and Dubrowski (2015) conducted an experiment in a surgery simulation, and showed that mental effort ratings were higher, and task performance was lower in the more complex condition. As another example, drawing on cognitive load theory, in a cross-sectional study, Lin (2010) showed that task complexity was associated with greater role conflict, which in turn predicted lower self-rated learning effectiveness. Trust, however, was associated with

lower role conflict, suggesting positive social factors might offset the effects of complexity.

More generally, most of this literature has moved beyond investigating whether high

complexity of a task makes it more difficult to learn (which seems clear) to understand what

can be done to support learning when tasks are more complex (Van Meerienboer et al., 2006).

Some studies show how task complexity affects neurological functioning. For example,

in a study of a Go/NoGo task (which is a computerized task used to assess inhibitory control),

EEG and behavioural data showed that task complexity imposes higher working memory

demands that in turn, impacted negatively on executive functioning, specifically inhibitory

control, measured in the brain (Chmielewski, Mückschel, Stock, & Beste, 2015. As another

example, Keller and Just (2016) showed how a complex task resulted in changes in the

hippocampus, leading them to conclude that high complexity impairs learning.

Psychosocial Demands. The type of demand that has had most attention from a cognitive

load perspective is a high level of vigilance, that is, the need to maintain attention for long periods

of time. A common finding in neuroscience and human factors studies is that sustained vigilance

results in cognitive resource reduction that, in turn, increases mental fatigue on task (e.g. Lim et al.,

2010). Ironically, vigilance demands can be greatest for monotonous and intellectually

unchallenging tasks, in part because very high levels of self-regulation are required to keep the

person focused on the task. In a systematic review of experimental studies that investigated neural

mechanisms related to vigilance and attention, Langner and Eickhoff (2013) found that high

vigilance demands involve a complex interaction of brain regions, suggesting multiple cognitive

processes at play.

Summary. There is a general consensus that mental load increases when dealing with

complex tasks, which can exceed people's memory capacity and impair short-term performance

and, possibly, learning. However, we cannot be sure about this implication for work design since

most studies of complexity and depletion focus on a single task, usually simulating a training

situation, and as such have a short time-span (e.g., minutes), as well as a focus on immediate performance. As we consider later in the Discussion, it is possible that there are different findings over time, and at a higher level of analysis. Moreover, literature from cognitive load theory provides guidance as to how to help people learn at very high levels of complexity (e.g. through simple to complex sequencing), and it could be that some of these ideas could be applied to work design. Research is clear that tasks requiring sustained attention (especially monotonous ones) can be depleting, not only because of the attention required but also the self-regulation to stay on task. As we discuss later, this finding is increasingly relevant to the topic of work design and cognition given rising levels of automation.

WHETHER AND HOW WORK DESIGN AFFECTS LONG-TERM COGNITION

In the review, we identified evidence that work design can potentially affect cognition in the longer-term. Most evidence focuses on a longer-term positive pathway in which cognitive abilities are maintained over a lifespan, or the degree of decline in abilities is slowed (*cognitive preservation*). Cognitive preservation, sometimes referred to as 'use it or lose it,' is assumed to arise from the repeated 'use' of one's cognitive abilities, that is, the cumulative effects of the Opportunity for Cognition pathway we described above. A further theoretically plausible longer-term positive pathway also potentially arising from the repeated occurrence of this pathway over time is an *accumulated expertise/wisdom* pathway, which we indicate in the model and discuss here briefly, even though there is currently little evidence for this process (we return to this point in the Discussion). A further long-term pathway (*ill-health impairment*) is the negative effect of ill-health, especially cardiovascular ill health, on longer-term cognitive functioning; a pathway that is likely to be an accumulation over time of the strain-impaired cognition pathway discussed above.

Cognitive Preservation

As discussed above, work characteristics can affect workers' opportunity, motivation, and capacity to use and develop their knowledge, and to use their cognitive processes/

abilities. Here we consider the intriguing idea that, over time, work designs that allow for workers' greater use of cognition can help to maintain cognitive abilities and prevent decline as a result of ageing, likely as a result of changing brain structure or function. With respect to the physical analogy, by using one's muscles repeatedly and over time, one prevents the deterioration in muscle strength that can otherwise occur with ageing.

Three inter-related theories have been offered to explain the mechanism by which work design affects cognition over the longer term. First, according to the "use it or lose it" hypothesis (Hultsch, Hertzog, Small, & Dixon, 1999; Salthouse, 1991, 2006), an individual's level of cognitive functioning is determined by the mechanism of differential preservation (which compares to the mechanism of preserved differentiation[1]) in which an individual's functioning is presumed to depend on his or her current mental activity. In other words, individuals who are consistently mentally active ('use it) will 'preserve' their cognitive function (that is, fail to 'lose it') more so than those who are not consistently mentally active. Second, the cognitive reserve hypothesis proposes that being engaged in mentally stimulating environments is associated with increased neuronal development, which in turn leads to the development of a cognitive reserve (Stern, 2012). Third, Schooler's theory of environmental influences purports that if a person's environment has variable environmental stimuli, this requires individuals to make more complex decisions, which in turn affects their intellectual functioning (Schooler, Mulatu, and Oates, 1999). But if high levels of cognitive functioning are not needed, intellectual abilities will not be maintained and cognitive functioning will decrease, consistent with the cognitive reserve hypothesis.

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[1] Preserved differentiation suggests that individuals who have had higher levels of cognitive functioning previously in their lives are those who maintain beneficial levels of mental activity as they age.

Three work design variables seem to shape cognition via use it or lose it processes: job autonomy, job complexity, and relational work design. These work design variables have also been conceptualized as psychological work demands and resources, as explained below.

Job autonomy. Studies have theorized that exercising job autonomy involves the active use of cognitive processing and abilities, which, over time, builds up cognitive reserve and leads to preserved differentiation. In a systematic review of longitudinal studies investigating the effect of work on cognition and dementia, Then et al. (2014) identified four studies focused on job autonomy, from which they concluded positive evidence. First, Seidler et al. (2004) showed that more control at work (as well as higher challenge and high social demands) was associated with a smaller risk of dementia. Second, Andel et al. (2012) used twins to show a link between high job control (and high social support) and a lower risk of dementia. Third, in a cohort study, Wang, Wahlberg, Karp, Winblad and Fratiglioni (2012) reported a link between low job control (also high job strain) and higher dementia risk; and, fourth, in a Swedish population study, Andel, Crowe, Kåreholt, Wastesson, and Parker (2011) identified a positive link between job control and cognition. Nexø et al. (2016)'s later review identified three further studies: Andel et al., (2011), which found that low job control predicted poorer cognitive functioning over 32 years; Elovainio et al. (2009), which showed that job control predicted later phonemic fluency; and Yu, Ryan, Schaie, Willis, and Kolanowski (2009), which demonstrated that job control predicted verbal memory and inductive reasoning, and improved these functions over 14 years. On the basis of these studies, Nexø et al. (2016) concluded that there is "moderate evidence" that job control improves cognition.

Since these reviews, several studies have provided further evidence. For example, Andel, Infurna, et al. (2015) used the Health and Retirement Study to track the effects of the level of job control and psychological job demands in one's job held for at least ten years prior on episodic memory up to and beyond the time of retirement. Although low job control was not associated

with any change in episodic memory during the period leading up to retirement, it was correlated with poorer episodic memory at the time people retired, and there was a faster rate of decline in memory following retirement for those with low job control; job demands was unrelated to episodic memory. Unfortunately, it is not possible to rule out selection effects (i.e., that cognition affects occupational choice) with this design. Similar issues apply to Sabbath, Andel, Zins, Goldberg, and Berr (2016), who drew on N=2149 participants who retired from the French GAZEL cohort study and found that low job control assessed four years before retirement predicted lower cognitive scores (e.g., executive function) after retirement, after adjusting for controls.

Dong et al. (2018) found that those with low job control had greater decreases in cognition and memory 11 years later, controlling for baseline scores, with the largest decreases being for those with high demands combined with low job control. Hülür, Ram, Willis, Schaie, and Gerstorf (2019) provided a rare example of a longitudinal lifespan approach based on perceptions of work characteristics rather than occupational proxies to assess work design. Using data from the Seattle Longitudinal Study (like Yu et al., above), as expected, they found that later-born cohorts (1939-1966) performed better on cognitive tasks and had less age-related decline in word fluency than earlier-born cohorts (1901-1938); later born cohorts also had more enriched work designs as shown by high worker control (defined as a lack of prescriptive rules about work processes) and high work innovation (defined as work involving variety, change, and new approaches, and therefore is similar to job complexity). Using latent growth curve modelling, they further found that average levels of worker control, work autonomy (independent decision-making), and work innovation (like job complexity) predicted greater cognitive performance, with work control and work autonomy also predicting a less steep age-related decline in various cognitive measures (mostly inductive reasoning). This study strengthens existing evidence linking job autonomy and cognition, although it is still possible that more cognitively-able individuals self-selected into, or crafted, more autonomous work over time. Pan et al. (2019) used a Swedish cohort study to consider exposure, or

the length of time of having job autonomy. They followed up more than 2000 dementia-free 60 year-olds for nine years and found that those with high job control and high demands (i.e., an "active job") in the longest-held job had lower cognitive decline, compared to other combinations of demand and control. Also, a longer duration in an active job was associated with slower cognitive decline, providing further evidence of the theorised complexity mechanism.

Job complexity. Studies have shown that being engaged in more complex jobs is positively related to cognition. But these studies simply establish a link between these variables, and it is likely that people with higher cognitive abilities choose more cognitively complex jobs (that is, the reverse causal pathway to our focus here). Job complexity can also be conceptualized as a mental work demand (Fisher et al., 2014); the more complex the job, the more cognitively demanding the job will be, requiring the use of cognitive processing and cognitive abilities. Thus, the strongest evidence for a 'use it or lose it' process triggered by work design comes from showing a link between work design and a later *change* in cognition. Several studies provide such evidence. For example, Bosma and colleagues (2003) found that workers in less complex jobs showed more rapid declines in processing speed, memory, and general cognitive status three years later. In addition, their results indicated that those with lower levels of education may be more likely to reduce cognitive decline with an increase in mentally stimulating work. As another example, Marquié et al. (2010) used the VISAT longitudinal study of over 3000 workers, and showed that cognitive stimulation both at work and outside of work predicted cognitive efficiency (e.g., processing speed) and more favourable changes in cognition over ten years. Likewise, Potter and colleagues (2008) found that among World War II veterans work in more mentally demanding jobs was associated with higher levels of cognitive functioning in later life when controlling for age, education, and general intelligence in early adulthood. Potter et al. also reported that individuals with lower intelligence earlier on seemed to benefit more from doing work that was characterized as

intellectually demanding compared to those with higher ability levels. Fisher et al. (2014) analyzed episodic memory scores (from an immediate and delayed recall task) collected in the U.S. Health and Retirement Study over an 18-year period and found that workers in more mentally demanding (complex) jobs (measured at the occupational level) had higher levels of cognitive functioning and declined less compared to those in less complex jobs. Pool and colleagues (2016) also investigated occupational-level complexity among participants in the Chicago Health and Aging Project using the same measure of mental demands as Fisher et al. and found similar results: higher occupational complexity is associated with better cognitive functioning and less decline in later life.

However, there are also some findings that appear contrary or mixed. One study found more rapid cognitive decline for people in complex work (Singh-Manoux et al., 2011), and two studies have identified no effect of complexity on cognitive change (Gow, Avlund, & Mortensen, 2014; Lane, Windsor, Andel, and Luszcz, 2017). To help resolve these inconsistencies, a recent study by Hyun, Katz, Lipton, and Sliwinski (2019) shed light on rates of cognitive decline using data from the Einstein Aging Study. Although their results supported prior research showing that job complexity demonstrated a protective effect on cognitive decline, individuals in more complex jobs exhibited faster rates of cognitive decline in cognitive processing speed and executive functioning after retirement. This finding is consistent with the use it or lose it notion; individuals in complex occupations build up higher levels of cognitive reserve and therefore have slower rates of cognitive decline in earlier stages of aging, but when the brain reaches a point of advanced aging, then the decline is steeper. Steeper cognitive decline after retirement is consistent with the idea that the environment has changed, and therefore the protective effects of work no longer apply. One implication from this finding is that it might be cognitively beneficial for individuals in complex jobs to stay in their

work longer in order to "keep the beneficial effect of mental stimulation accumulated throughout life" (p. 8).

Studies examining neurological changes also support the use it or lose it hypothesis. For example, Oltmanns and colleagues (2017) reported results of a workplace intervention that introduced work task changes (i.e., novelty) among automotive manufacturing workers in Germany. Workers who experienced more work task changes (which we assume is associated with job complexity) over a seventeen-year period demonstrated better cognitive processing speed and working memory, as well as more gray matter volume in brain regions associated with learning and age-related cognitive decline. Likewise, in a study using MRI data based on 151 retired participants age 70 years or older from the Sydney Memory and Aging Study Suo et al. (2012) found that management experience in midlife was the dominant contribution to increased grey volume matter in the hippocampus. For a smaller subset of people with longitudinal neuroimaging data, there was much less atrophy in the hippocampal structure over the period for those with high level supervisory experience in midlife. Although supervising others involves work characteristics in addition to job complexity (for example, higher job autonomy, relational work design), this study is intriguing in suggesting similar findings to those found in the lifespan/aging perspectives.

Relational work design. Drawing on similar logic to the studies described above, it has also been assumed in some literatures that many interactions with people at work, or lots of social contact, creates a form of 'social complexity,' which then affects cognition through differential preservation. In an early twin study, Andel et al. (2005) showed psychological demands in the form of complexity of work with people (involving, for example, organizing tasks, supervising, and negotiation) was associated with a lower risk of Alzheimer's disease. Likewise, using data from a Scottish cohort study, Smart et al. (2014) showed that jobs with high complexity based on high social/interpersonal demands in one's main lifetime occupation predicted cognitive ability after controlling for cognitive ability at 11 years of age, and was

more important than complexity with data and things. In a similar study with a stronger design (cognition assessed over 6 time points, and survey data assessed four times), and using twins from the Swedish Adoption/Twin Study of Aging (SATSA), Finkel, Andel, Gatz, and Pederson (2009) found that the complexity of people from one's main occupation resulted in increases in verbal ability and buffered against declines in spatial ability, up until retirement, after controlling for education (complexity with data or things was again not significant in this model). Providing further evidence of differential preservation, following retirement, high complexity based on social/interpersonal demands related to a steeper decline in spatial abilities, consistent with the idea that complexity based on social job demands is a protective form of mental exercise. In other studies, Seidler et al. (2004) showed that high social demands were associated with a lower risk of dementia; and Andel et al. (2011) in a two-wave study showed that low complexity based on social demands predicted higher cognitive impairment, and more so than low complexity based on other aspects of jobs.

Most lifespan studies, however, have neglected to consider what happens outside of work when investigating the link between work and cognition. An exception is Andel, Silverstein, and Kåreholt (2015). Using longitudinal data from two Swedish studies, and with a broad range of controls, the study showed that complexity of work with people (and data) related to better late-life cognition, as did social leisure activity. The authors also found a compensatory mechanism such that - when complexity of work with people was high - cognitive leisure activity was no longer significantly related to late-life cognition, and at moderate levels of complexity with people, social leisure activity showed no relationship to late-life cognition. The authors argued these results show that engaging in complex environments in mid-life – be it through leisure of work – 'grows' cognitive reserve for later life. However, this study did not examine change in cognition.

Summary. Taken together, job complexity, job autonomy and social complexity can all be conceptualized as specific types of mental work demands (Fisher et al., 2014) that 'use' greater

levels of cognitive processes and use of cognitive abilities to mentally process information, make decisions, solve problems, and interact with others. Overall, there is fairly strong evidence supporting the use it or lose it pathway, with several studies indicating that job complexity, job autonomy and social complexity protect against long-term cognitive decline, with the evidence most consistent for job autonomy. Some challenges of this literature, however, include a handful of contradictory studies, a failure to actually test the use-it-or-lose-it mechanism, and the use of occupational-level proxies to assess work design. With regard to the latter issue, as an example, "complexity with people" is coded by matching a person's occupation to the Dictionary of Occupational Titles, and then using the tasks from the occupation to infer the work design. This is a very indirect way of assessing complexity, and such a measure likely conflates very different work characteristics such as the degree of mental stimulation and social contact.

Accumulated Knowledge

Previously we discussed how work design can accelerate the acquisition of deeper and broader knowledge. Extrapolated over time, we would expect that, via this accumulation process, work design fosters learning, which over time can lead to the development of expertise. A related terms used in the cognitive aging literature is crystallized intelligence, which is defined as knowledge or acculturation, and is a type of cognitive functioning that remains stable or increases with age (Horn & Cattell, 1967). Wisdom is conceptually similar and refers to the application of knowledge, often using judgment acquired through experience (Grossmann, 2017; Staudinger & Glück, 2011). No studies have linked work design to these sorts of accumulated knowledge outcome at this stage.

Although the cognitive aging literature has identified consistent age-related declines in fluid cognitive abilities such as memory and reasoning, Ng and Feldman's (2008) meta-analysis examining the association between age and job performance found that job performance does not decline with age. One explanation for this result is the accumulation of knowledge and expertise

over time, such that declines in memory and processing speed can be offset by increasing knowledge and experience. Another explanation is cognitive load theory (Sweller, 1988), in which the attentional resources and memory capacity needed to complete a task are reduced when the task is familiar. A physical example of this accumulated knowledge phenomenon is the development of long-term muscle memory, which develops based on increasing neuronal connections in the motor cortex as well as strengthening muscle fibers (Bachtiar et al., 2018). Muscle memory can improve athletic performance, such as physical agility or specialized skills (e.g., perfecting a golf swing).

Chronic Ill-health Impairment

Earlier, we discussed how work stressors such as hindrance demands can cause a stress response, which interferes with learning. In the longer term, consistent with the allostatic load model of stress (Ganster & Rosen, 2013; McEwen & Stellar, 1993), exposure to chronic stressors (e.g., stressful life events) is associated with a higher prevalence of cognitive decline (e.g., memory impairment, dementia) among older adults (e.g., Peavy et al., 2009; Seeman et al., 2001). Cortisol might be a key explanatory mechanism, with studies showing increased cortisol predict reduced cognitive functioning (Lupien, et al., 2004). In addition, the occupational health literature has found consistent support for a positive association between low autonomy/ high demands jobs and cardiovascular disease (e.g., the Whitehall studies; Kuper & Marmot, 2003; Marmot, Rose, Shipley, & Hamilton, 1978). This link may result from increased cortisol levels that weaken immune system functioning (Segerstrom & Miller, 2004), and/or other factors associated with chronic stress (e.g., obesity, poor sleep) that are known risk factors for cardiovascular disease. In turn, poor cardiovascular system functioning hampers attention and cognitive processing, and learning.

Nevertheless, despite the above theory and evidence suggesting it is plausible to expect a link between work design and cognitive impairment over time via health processes, few studies have examined this link. Andel et al., (2012) provided some evidence from an analysis of a

population-based Study of Dementia in Swedish Twins that work characteristics (extrapolated from

occupational data) relate to the risk of dementia. The authors found that lower job autonomy, in

combination with lower social support and higher job demands, predicted a greater risk of any

dementia, especially vascular dementia, as well as Alzheimer's disease, with the vascular dementia

results suggesting to the authors the possibility of a strain/ health mechanism in which chronic

stress caused dysregulation of body systems such as the cardiovascular system (or allostasis).

Interestingly, low autonomy alone predicted dementia risk for women. Although the specific

mechanisms are not assessed, a handful of studies link psychosocial demands to declines in

cognitive functioning over moderate to long time periods. For example, in the study described

above, as well as showing a decline in vocabulary (crsyallized intelligence), Virtanen and colleagues

(2009) showed that people who worked longer hours performed worse five years later on

reasoning tests, thus pointing to a change in fluid abilities. Ice et al. (2020) investigated work hours

and work-family histories among women in 14 countries studied in the Survey of Health, Ageing,

and Retirement in Europe (SHARE) and reported that partnered women who worked part-time

performed best on tests of cognitive functioning, and partnered mothers who were unpaid

caregivers performed lower on cognitive measures compared to full-time working mothers. The

authors suggest that partnered women working part-time experience less stress, although the

retrospective nature of the study has obvious limitations.

INTEGRATION AND IMPLICATIONS

In this section, we bring together the core findings from the review and identify key implications.

Implications for Work Design Research and Theory

Traditional work design theory, such as the Job Characteristics Model, has focused on the

motivating potential of work, with the associated implications for outcomes like performance and

turnover. Other theories have considered the stress and strain implications of excess demands and

protective job resources. But what has been relatively neglected to date is that idea that work

design can be a powerful force for enhancing or impairing cognition. Altogether, although the perspectives and time scales are diverse, we conclude from our review that *job autonomy, job feedback, relational work aspects, job complexity, and psychosocial demands, can affect workers' cognition in the short-to-medium term and in the long term, through multiple pathways*.

More specifically, research from work design, human factors, and learning perspectives, shows that work design can enhance or harm cognition in the short-to-medium via multiple pathways. To date, the strongest evidence is for the *accelerated knowledge acquisition* and *motivated exploratory learning* pathways. The former emerges especially from a synergistic combination of autonomy, complexity (or demands) and feedback, although some evidence suggests for autonomy alone, and the latter arises especially from autonomy and relational characteristics such as social support. Feedback can also motivate learning, especially when it is quite general in form and comes from the job itself. Evidence is also strong at the task level (less so at the job level) that *depleted cognitive capacity* and hence reduced learning arises from excessive task complexity and highly monotonous vigilance tasks because of the high load on working memory and attention, respectively. In support of the *strain-impaired cognition* pathway, many studies show that low levels of autonomy, poorly designed feedback, and hindrance demands cause strain, and much evidence shows strain impairs learning, although only a handful of studies examine the links from work design to learning to strain. Finally, although few studies have explicitly focused on this process as a unique path, it is logical that well-designed work shapes workers' *opportunity for cognitive use*.

This short-to-medium term work design-cognition literature is important because it shows that work design is a powerful way to foster learning within a job, with consequences for individual job performance and, in aggregate, organisational performance, as well as consequences for individuals' skill development. Returning to the salesperson example, if a salesperson has job autonomy, this allows more complex decision-making that uses cognitive abilities (opportunites for

cognitive use) as well as more opportunity to deal with variances at the source and hence to develop complex mental models about the work system (accelerated knowledge acquisition), greater ownership and hence a desire to learn to solve complex problems (motivated exploratory learning), and a greater capacity to mitigate stressful demands thereby reducing both strain (strain-impaired cognition) as well as depletion (depleted cognitive capacity). All of these processes mean the salesperson is likely to not only use his/her cognition, but also develop and learn deeper and broader knowledge about the sales process and his/her clients, and thereby be more effective in his/her job.

Our review went beyond the short-to-medium term to consider the longer-term cognitive outcomes of work design. Deriving from different disciplinary perspectives including occupational health and lifespan gerontology, reasonably strong evidence has emerged to link occupational-level work design to long-term cognitive ability outcomes, such as the prevention of cognitive decline or lowered risk of Alzheimers disease. This longitudinal research base, in which studies examine change in cognition, suggests that having autonomy and complexity in one's occupation can, over multiple years, protect against decline in cognitive abilities. Although the mechanisms are rarely assessed in this research, there is strong theory and evidence in other fields that these protective effects of work design occur via a 'use it or lose it' process of *cognitive preservation*. For these occupational-level work characteristics, there is even some evidence of 'dose' effects such that longer-term exposures have stronger effects on preserving cognitive functioning. The fact that several studies show a decline in cognition after retirement for people in complex and autonomous jobs adds to the evidence base. Additionally, there is a small amount of evidence that work design features such as low autonomy and excessive demands can impair longer-term cognitive functioning through a *chronic ill-health pathway*. No studies that we are aware of have examined how long-term

exposure to particular work designs result in *accumulated knowledge*, and in turn crystallized intelligence, deep expertise and wisdom, despite the plausibility of this path.

The long-term research suggesting that work design can accumulate over time to affect the cognitive functioning of workers, has multiple important organizational, societal, and economic implications. A salesperson who works for many years in a complex and autonomous job is more likely to maintain their cognitive functioning right up until retirement, whereas a salesperson working long-term in a tightly prescribed job with routine tasks is more likely to experience a decline in cognitive processes like working memory over time. As we discussed at the outset, maintaining cognitive functioning of employees is set to become more important for society and the economy because of the growing aging population. Staying in work longer increases the need to take steps to maintain mature workers' cognitive functioning, and our review suggests that work design is one vehicle by which this need might be better achieved.

Focusing on cognition as an outcome of work design will expand work design theory in new ways. For example, the idea that complex work promotes learning suggests more attention to work characteristics that generate a discrepancy between one's current level of knowledge or ability and that required in the task/ job. A focus on 'discrepancy' goes against traditional theories often drawn on in work design research, such as person environment-fit theory, which considers a misfit between the demands of a job and someone's abilities as a negative motivational state to be avoided. In fact, some misfit – such as work that stretches one knowledge, skills, and abilities - is what our brains need in the longer-term to stay cognitively healthy. As Lovden et al., (2010, p. 662) discussed, a "prolonged mismatch" between environmental demands and functional capacity is what drives brain plasticity. Of course, our review also shows that excess misfit will be problematic in so far as it is also important that workers manage the demands of their jobs, minimizing exposures to stressors or coping with unavoidable stressors in a way that limits strain. Lovden et al., reached a similar

conclusion, arguing that "mismatches must be located between these two extremes (e.g., a too easy and a too difficult task) to trigger and direct plastic changes". The key point is that work can be deliberately designed to 'use' and develop one's cognitive abilities, and to support the use and development of one's knowledge.

Practice and Policy Implications

Crucially, in most contexts, work can be redesigned. There is a long history of organisational interventions such as job enrichment, empowerment, and self-managing teams which increase variety and autonomy within work (Cordery, Mueller, & Smith, 1991; Kirkman & Rosen, 1999; Knight & Parker, 2019). These are mostly considered from the perspective of motivation and performance, but our review highlights their wider value for using employee knowledge and cognitive abilities, for fostering learning, and for cognitive health. Leader behavior can also affect work design, as do organisational cultures and technologies; which provides further avenues for intervention. For example, managers should aim to design and structure work in a way that can minimize job stressors, boredom, and fatigue and to provide instrumental and social support to employees when possible to help alleviate or buffer potential stressors. Avoiding overprescribed work procedures and excessively standardized protocols, such as increasingly prevalent in knowledge work (e.g., teachers being required to follow highly prescribed lesson plans), is one example of how organizational practices need to be altered to foster greater job autonomy and its associated cognitive benefits.

Earlier we depicted how work design is also embedded within a broader public policy and legislative context, beyond the organisation (see Figure 1). Change at this broader level might well be needed to bring about improved work designs that foster cognition over longer time spans. Large-scale population studies tend to show that well-designed work is lacking for many workers. For example, the sixth European Working Conditions survey (Eurofound, 2017) of over 44,000 workers showed that one out of five workers holds a 'poor quality' job (e.g., with low skill use,

autonomy, poor conditions), and a further 13% hold an 'under pressure' job (e.g., with excess

demands) (see Parker et al., 2017, for further such data). Likewise, levels of over-qualification, in

which people's skills, experience, and education exceed the job requirements, are rife. For example,

one US study estimated that 34% of college graduates, and 44% of new college graduates, work in a

job in which college education is not required (Federal Reserve Bank of New York, 2017), and other

studies show that particular groups are vulnerable to over-qualification, such as migrants and

minority groups (Nielsen, 2011). Such large-scale studies suggest that evidence-based knowledge

about what constitutes work design is not being acted upon, with potential spill-over consequences

for the long-term cognitive functioning of large numbers of people.

National-level policies on aspects that affect the quality of work design, such as precarious

employment, health and safety, and even automation and digitalization, should be considered from

the perspective of the cognitive well-being of society. Take the case of automation and

digitalization. On the one hand, there are projections for greater job complexity as a result of more

routine tasks being carried out with the help of algorithms, robots, or other forms of digitalization

(e.g., Brynjolfsson & McAfee, 2014); a trend which implies both the greater need for fostering

cognition in the work place (Cohen & Levinthal, 1990), as well as the greater potential opportunity

for work to promote cognitive development. On the other hand, digitalization has the potential to

increase computer-based control in the work place, which can hamper autonomy and reduce

opportunities for learning (Parker & Grote, 2020). Evidence shows that applications of automation

in manufacturing sometimes mean that workers become passive monitors who lose knowledge and

skills, making it harder for them to recover operations should the automation break down. Even in

professional contexts like surgery, learning can be hampered with new technologies. Beane (2018),

for instance, showed that robots in surgery can reduce the opportunities for trainees to engage in

challenging tasks, thereby impairing their learning. This research highlights the need to ensure

positive work designs that support learning when implementing digital technologies. From a policy

perspective, this means expanding consideration of the ethical implications of digital technologies beyond the current emphasis (e.g., biased algorithm-based decision-making) to include how these technologies affect work design. It also means going beyond the predominant focus on how many jobs will be replaced by technology to also considering the quality of the remaining jobs (Parker & Grote, 2020).

Individual Implications

Individuals likely understand the value of attending formal training for their development, but they may have less awareness of the importance for their learning and cognitive health of well-designed work. Likewise, individuals often understand the need to choose an 'occupation' that is going to be intellectually stimulating, but they are less likely to recognize that – irrespective of occupational choice – the quality of jobs *within* their occupation will shape their life-long learning. Thus, individuals should be encouraged to proactively achieve better work designs for themselves. Job crafting is one important "bottom up" mechanism by which workers can mould their jobs to create better work designs (e.g., Tims, Bakker, and Derks, 2012); and this review especially highlights the importance of deliberately negotiating more job autonomy, building networks to increase social support, taking on more complex projects, and seeking feedback; all of which have positive cognitive consequences. O'Mahony and Bechky's (2006) research showed that some contract workers intentionally engage in 'stretchwork' (work that includes some tasks that exceed existing competencies) to build skills over their career. Other self-initiated career strategies such as seeking promotions, and/or moving to new jobs or occupations, will help to foster cognitive outcomes if these moves result in better work designs. As noted above, such strategies will need to be balanced alongside recognizing limits and being aware of stressors that contribute to strain, depletion of cognitive resources, and poor health, that then lead to impaired cognitive functioning.

Nevertheless, evidence also shows some individuals are less likely to engage in crafting and other such proactive strategies to achieve better work designs. For example, people high in approach temperament, promotion focus, proactive personality, extraversion, conscientiousness, and openness, future-oriented thinking, are more likely to engage in approach forms of crafting (see Zhang & Parker, 2019 for a summary) and to gravitate towards jobs with a richer task content (Brenninkmeijer, Vink, Dorenbosch, Beudeker, & Rink, 2018). Individuals lacking low in approach or promotion focus might need additional support to craft their work. Socioeconomic status and age are also relevant factors to consider (Strenze, 2007). For example, Truxillo, Cadiz, Rineer, Zaniboni, and Fraccaroli (2012) argued, based on socioemotional selectivity theory, that younger workers will give knowledge-related goals higher priority because they perceive time as being more open ended, whereas older workers will give emotional goals a higher priority. Such a strategy might not be in the best interests of mature workers. At the same time, older people are less likely to craft their jobs (Ng & Feldman, 2008), even though this activity might in fact be more important for mature workers, some of whom face cognitive decline.

FUTURE DIRECTIONS

In Figure 4 we propose an integrative model to bring together the work design and cognition literatures that have been disconnected not just temporally, but in terms of attention to distinct mechanisms, different types of cognition, and even different work design variables. Synthesizing these elements has identified important future directions, as we elaborate next (Table 1).

Insert Figure 4 and Table 2 about here

Connecting and expanding the pathways linking work design and cognition

We have identified multiple pathways, yet know little about whether and how these pathways interrelate. On the one hand, there are likely to be positive synergies, such as when work design motivates learning behaviors (*motivated exploratory learning*), with the ensuing behaviors, such as exploring alternative solutions, then *accelerating knowledge acquisition* and expanding

the *opportunity for cognitive use*. On the other hand, there could well be tensions. For example, high levels of demands and autonomy can result in cognitively-enhancing processes such as motivated exploratory learning, but high demands are also likely to create some strain, and even cognitive depletion, so these processes could both be activated by enriched work, albeit potentially with different relative impacts. Example questions to consider include: *how do work-design cognitive pathways interrelate and interact, and do they have similar or different effects?*

More specifically, in Figure 4, we depict how short-to-medium term links between work design and cognition can accumulate over time to create longer-term outcomes. But little research has theorized, let alone tested, such temporal interactions. For example, conceptually, research linking work design to change in long-term cognitive abilities has mostly assumed (but not tested) a cognitive preservation process in which particular work characteristics such as complexity use more cognitive abilities which prevents their loss over time. But as our model shows, work characteristics affect people's more immediate use of cognition in multiple ways (accelerates learning, motivated exploration, etc), and these additional pathways are also likely to have cumulative effects over time, aggregating over a career to increase people's use of cognitive ability and hence preventing decline. We recommend developing and testing theory about the underpinning pathways linking work design and long-term cognitive ability to address the questions: *Do short-to-medium term cognitive effects of work design on knowledge accumulate over time to affect cognitive abilities? If so, exactly how does work design prevent a decline cognitive abilities (that is, through which pathways)?*

As our review demonstrated, most short-to-medium term studies linking work design and cognition have focused on knowledge or change in knowledge as the cognitive outcome. No studies that we are aware of have examined how work design affects either the use of cognitive processes/abilities or any change in cognitive processes/abilities. Instead, cognitive abilities tend to be either antecedents to work design choices, or occasionally, moderators of work design effects.

Yet it would be interesting to explore, for example, whether the move to self-managing teams (say), is associated with greater use of working memory or engagement in reasoning (i.e., enhanced use of cognitive abilities), as well as whether – as a result of this greater use - there is better preservation of cognitive ability over a five year period, compared to similar workers whose jobs are deskilled. In other words, we recommend asking: *Does work design have any impact on the use of, or maintenance of, cognitive abilities in the short-to-medium term?*

The main focus of long-term studies linking work and cognition has been on changes in cognitive abilities, notably the prevention of decline. However, we suggest in our integrative model that work design might not only change cognitive abilities, but also result in knowledge acquisition in the long-term, that is, greater cystallized intelligence and wisdom. Indeed, it is well understood in the ageing literature that mature workers possess crystallized intelligence and wisdom, but this is assumed to derive from their 'work experience'. What we propose here is that enriched work designs - high in autonomy, feedback, complexity, and support - can enhance workers' 'work experiences', and thereby – in the longer term – accelerate and maintain mature workers' development of wisdom and deep expertise. Frese and Zapf (1994) discussed how exceptional performers in work can anticipate work situations better, plan, and achieve deep intellectual penetration of the task, resulting in an ability to perform fewer work activities yet be more effective. Perhaps quality work design helps to foster such advanced expertise? Such knowledge accumulation might also be important from a compensatory perspective. The notion of successful ageing captures the idea that engaging in life-long learning can help people to compensate for declining cognitive capabilities (Baltes, 1987). Imagine our salesperson working for many years in an enriched job which then fosters the development of complex mental models about the products, situational awareness about the company, and wisdom about handling difficult clients. Such accumulated knowledge will enable the salespersons' outstanding job performance, rapid promotion, further allocation of complex responsibilities, and so on, in a positive spiral over a

career, rendering the sales person a deep expert in the longer term, and allowing her to compensate for any deficit in cognitive abilities. This potential longer-term value of work design for knowledge accumulation has been neglected. We thus recommend asking: *Are there long-term effects on work design on crystallized intelligence, such as the development of wisdom, or accelerating the likelihood of an individual becoming a deep expert?*

In a similar vein, with rare exceptions (Oltmanns, et al., 2017), studies have not considered the neurological effects of work design. We think it would be possible and worthwhile to explore, using experiments and simulations, the effects on brain function of engaging in enriched, autonomous work versus simplified work in the same way that studies have examined the neural mechanisms underpinning the effects of various types of leadership (e.g. Molenberghs, Prochilo, Steffens, Zacher, & Haslam, 2017). For example, evidence shows that an increased use of working memory processes can result in changes to the density of dopamine receptors (Lövdén, et al., 2010). We expect to see considerable new knowledge about the effects of job design on cognition over the next 10-20 years deriving from the application of the neuro-cognitive and neuroanatomy approaches. We recommend asking: *Are brain functions and/or structures affected by work design in the short and long term, and if so, which structures and functions are affected and how do they relate to changes in cognitive processing and abilities?*

Dynamics and timing of cognitive processes

Once we begin to connect short-to-medium term and long-term cognitive processes, important questions about the timing and dynamics of change arise. For example: *how long do protective effects of well-design work last?* If one has spent twenty years in well-designed work, but opts for a low quality and precarious position just before retirement, are cognitive benefits of the earlier work maintained? As depicted in the integrative model, we also need to consider recursive relationships among work characteristics and cognition. In other words, we focused here on how work design affects cognition, but of course cognition also affects work design. From a lifespan

perspective, there is evidence of that an individuals' initial cognitive functioning predicts their aging success, presumably in part from the work designs they opt in to or craft; and, from a career perspective, there is evidence of the gravitational hypothesis (McCormick, Jeanneret, & Mecham, 1972) in which individuals gravitate towards jobs and occupations that fit their mental ability. This means that positive spirals might occur in which individuals with higher cognitive abilities select into, or craft, better work designs which, in turn, are likely to maintain those cognitive abilities.

Indeed, it might be that, over time, as the cyclical relationships repeat among these variables, effects on cognitive functioning amplify. Such a process would be similar to what de Lange, Taris, Kompier, Houtman, and Bongers (2005) referred to as an "upward selection mechanism" in which cognitively effective workers are more likely to be promoted to stimulating work, or to be allocated more challenging tasks, and a "drift" mechanism in which cognitively less effective workers tend to end up in poorer quality work. Theoretically, such time-based mechanisms are consistent with similar arguments that have been made in relation to work and personality change. For example, the corresponsive principle (Roberts, Caspi, & Moffitt, 2003) proposes that life experiences will strengthen individual characteristics that bring people to such life experiences in the first place (Frese, Garst, & Fay, 2007). Research from other work design domains support such spirals. For example, using a four-wave study across four waves, Frese et al. (2007) showed that work characteristics affected personal initiative via control orientation; and control orientation and personal initiative affected later work characteristics, in a positive spiral. Altogether, therefore, we need to ask questions such as: *What are the dynamic effects of work design and cognition, such as the recursive effects of cognition on work design and the possibility of amplifying spirals?*

Work design antecedents of cognition

Our review shows that work design affects cognition, but there is more to do to unpack about the 'work design' part of this equation. One important set of questions is: *how "much" exposure to*

well-designed work is needed to engender long-term cognitive benefits, and how continuous does this exposure need to be? Thus there is emerging evidence about the 'dose' of well-designed work, but this research is in its infancy. We know little about the impact of multiple jobs over a career. Lifespan effects of work design on cognition are largely based on the concept of "lifelong" jobs and/or occupations. Yet the idea of staying in one job or one occupation for the entirety of a career is increasingly outdated. This gives rise to questions such as: *What combinations of work design across a career are likely to be cognitively beneficial? What impact will more frequent and varied career changes have?* High switching means more uncertainty and reduced ability to make longer term plans, which might reduce people's sense of control. For people working in multiple jobs at one point in time, perhaps they will need to balance their various jobs based on the work design of each, and check that they are getting key work design ingredients from their portfolio rather than a single job? Such questions have yet to be explored.

A further question is: *what sequencing of work designs across a work life is most important*? That is, when is it most important for work designs to help people preserve their cognitive functioning? Is it best to maximise the opportunity for cognitive development when one is younger by designing the most challenging work, or in fact, does it mean that during this time, since cognitive mechanics are at their peak anyway, that challenging work makes less difference? Answers to such questions have important implications for choices about work design. For example, cognitive speed (important for higher-order cognitive processes) is higher at younger ages (Hartshorne & Germine, 2015), which might lead to a recommendation that managers should give the most intellectually challenging work to younger employees. But perhaps it is more important to have complex work designs at the end of one's career, to maximise the cognitive reserve available for retirement?

There is also more to learn about *which aspects of psychosocial work design are important, and for which pathways*? Lifespan and occupational health studies focus mostly on job (and people)

complexity and job autonomy, and, to some extent, psychosocial demands. To the extent that relational aspects are considered, most attention is given to people complexity, rather than the amount of social contact people have at work or even their level of social support they receive. There is a great deal of evidence from the aging literature showing the strain-reducing effects of support (see Sherman, Cheng, Fingerman, & Schnyer, 2016), and the work design literature shows that support is motivating (Parker, et al., 2017), so support at work might play a stronger role in mitigating against cognitive decline than hitherto assumed. Likewise, there are many work design aspects that have had almost no attention in relation to cognition, either in the short or long term. For example, role clarity might increase the likelihood that a worker can retain cognitive benefits from a complex environment; and task significance (the perception of doing something worthwhile) or contact with beneficiaries (e.g., connecting with end users of the work) might provide a strong motivation to learn to do one's job better, thereby fostering more learning over a lifespan. Lifespan theories of ageing would predict that older workers might especially respond positively to task significance because they are more focused on meaning in their work (Kanfer & Ackerman, 2004).

The existing research has also mostly glossed the surface in terms of the effects of demands, with human factors research being more nuanced in the types of demands it considers (e.g., visual, auditory, psychosocial, physical). As work changes, new or amended work characteristics will also emerge. For example, there might be wider, yet weaker, sets of network ties, more often mediated through electronic systems rather than in-person interactions. Could this lead to more superficial conversations, sharing, and hence less learning from each other? As previously discussed, the potential for invasive monitoring through digital devices is also now much greater, which might impair cognition because of the heightened stress and intensity these systems can cause. In sum, we recommend investigating the question: *Beyond complexity, autonomy, and stressful demands, what work characteristics positively impact on workers' long-term and short-to-medium term cognition?*

There has also been some attention to the combination of demands and control, but overall, there is much more scope to consider combinations of work characteristics (Parker, 2014). For example, a complex job without social contact and support might increase stress, which narrows attention and restricts learning, implying the value of examining complexity and support together. Likewise, a challenging and stimulating job, which this review suggests might positively affect cognition, might well be associated with much greater sitting, with this review suggesting that sedentary work might impair cognition, resulting in a net null effect. We recommend asking: *What are the cognitive effects of profiles of work characteristics?*

Broader questions

Our focus in this review has been on the psychosocial aspects of work design, but we need to consider: *How do psychosocial aspects of work design interact with physical aspects of work, and other factors outside of work?* For instance, one study we reviewed suggested that leisure might compensate for social complexity at work, suggesting that cognitive stimulation is important in one domain or other, but not necessarily both. This result is important, especially in light of prior research by Potter and colleagues (2008), who found an interaction between earlier life cognitive ability, cognitive job complexity, and cognitive functioning such that workers with lower levels of cognitive abilities in earlier life seemed to benefit more from cognitively complex work. Nevertheless, there is much scope to examine further how aspects of work might interact with factors outside of work. For example, physical activity outside of work might be especially important when individuals engage in mentally stimulating work that means they are rather sedentary at work. On the other hand, physical activity outside of work might have negligible effect for people with high physical work demands. Another outside work aspect that has had little attention in relation to work design is sleep. For example, the effects of work demands on cognition might actually be mediated through disruptive sleep patterns. Alternatively, achieving reasonable sleep might be an important complement to stimulating work. Such interactions between work and

non-work/sleep have not been considered. At the least, future research should control for such activities.

Our model depicts a potential role for individual differences as a moderator of the link between work design and cognition (see brown arrow, Figure 4). It is well recognised in the neurological studies on environmental enrichment that "enrichment" for humans arises not only from environmental complexity, but also one's inclination to participate in the environment and the frequency of participation (Sale et al., 2014). The idea that environment and individual factors interact to affect outcomes is also consistent with work design research showing that individuals react differently to work characteristics depending on their personality (Parker, 2014), and is also consistent with studies that examine leader development over time (DeRue & Wellman, 2009). With the exception of some studies showing that less educated or lower cognitive ability individuals might benefit most from enriched work, the predominant perspective in long-term lifespan studies is that work factors such as occupational complexity have main effects on cognition. We ask: *Who benefits cognitively most or least from well-designed work, and are extra supports needed for some?*

It is important to acknowledge that our focus in this article has been on how work design affects cognition, rather than how cognition shapes work design, and especially the idea that work can be designed to accommodate people's level of cognitive ability as well as changes in cognition. For example, evidence suggests cognitive processing involving social intelligence peaks later in life (around 45-50; Hartshorne & Germine, 2015). Perhaps managers can leverage this enhanced cognitive ability to recognize emotions in faces, and increase relational aspects of work design for older workers? In terms of accommodating changes in cognition through work design, according to Craik and Byrd (1982), environmental supports can be developed to assist older adults by decreasing cognitive processing requirements. Such changes can allow mature workers to be effective in their work. Finally, some highly innovative work redesign interventions deliberately

creative inclusive work designs that offer new roles for intellectually disabled individuals (Zilstra, et al., 2017).

METHODOLOGICAL IMPROVEMENTS

Here we identify improvements that will strengthen the evidence-base going forward.

Measurement

Empirically, the effects of work design on long-term cognition might have been underestimated. Focusing on occupation-level attributes in the lifespan approach likely understates the role of work design in influencing cognition. Whilst there are undoubtedly occupation-level influences levels on work characteristics, work design is affected by many factors beyond occupation, such as national-level factors (e.g., institutional regimes), the design of the organisation in which the job is conducted, the behaviour of one's leader, and the job incumbent's own actions within the job (e.g., crafting; Parker et al., 2019). Indeed, occupations have a relatively small influence on psychosocial work characteristics. Dierdorff and Morgeson (2013) showed the percentage of variance in work design due to occupation was low for most psychosocial work characteristics, such as job complexity (5.1%), job autonomy (13.6%), task variety (1.9%), social support (2.3%), and feedback from others (4.8%), with feedback from the job (17.2%) being somewhat of an exception, and physical work characteristics being quite well captured by occupational data (32.8%). In addition, when work design is measured indirectly, such as by matching a person's occupation to the Dictionary of Occupational Titles or Occupational Information network (O*NET) and then using the tasks for the occupation to infer the work design, this approach is imprecise. For example, the "taking instructions" task in the Dictionary is coded as low social complexity, when in fact this task might also be low in autonomy. Therefore, when the influence of work on cognition is modelled using occupational proxies, work design is only loosely captured, likely underestimating the effect of work on long-term change in cognitive functioning and creating

uncertainty as to which characteristics matter. We recommend: *Use direct measures of work design rather than occupational proxies.*

As previously discussed, cohort studies with non-experimental designs comprise the bulk of studies that investigate change in cognitive functioning as one ages, but explanatory mechanisms have almost never been assessed. In part this is because most of these studies have been designed with other purposes in mind. As new studies are designed, we recommend *directly assessing the full range of possible mechanisms* that might link work design and cognitive abilities. In terms of assessing cognitive processes/abilities, we advocate: *using specific measures to assess particular domains of cognitive ability,* rather than collapsing aspects into a single score as has often been done. Specific cognitive abilities exhibit different trajectories of change (Horn & Cattell, 1967; Park, 2000), and pooling functions into one score might attenuate or mask significant effects of work design. Another issue with using an overall cognitive score is that work design might differentially impact specific cognitive functions. For example, a job with high complexity buffers cognitive aging, yet sedentary time does the reverse (Lane et al., 2017). In addition, future research would benefit from *complementing measures of cognition with neurocognitive assessments*.

Research design and levels of analysis

To further advance the literature, we recommend: *direct assessments of work design and cognition multiple times over one's career*, so that it is possible to examine issues such as the degree of 'exposure' required for a work characteristic to have an impact. For example, as recommended by Parker, Andrei, & Li (2014), using multi-wave panels with evenly and unevenly spaced waves allows the chance to examine or control for time-variant effects (via evenly-spaced time lags) whilst examining how work design affects outcomes (via unevenly spaced time lags). Across-time change in work characteristics can also be considered (e.g., Landsbergis & Theorell, 2000) and reverse causal/reciprocal processes should be routinely

tested. Particularly useful for understanding causality might be the opportunity to examine the effect of change in work characteristics on change in cognition, ruling out beta and gamma change in perceived work characteristics as rival explanations (Golembiewski, Billingsley, & Yeager, 1976). This might mean conducting research during important transitions such as when a person moves to a new job, or when a person's job is automated.

In this domain of research, it is also crucial to *consider levels of analysis issues*. As we showed in the review, complexity at the task and job level can have opposite effects. For example, whilst cognitive load at the within-person task level can be negative with respect to learning a specific task (e.g., because of the greater drain on working memory), cognitive load in the form of complex work within a job can be positive for motivation and learning. It it important to avoid the "fallacy of the wrong level" (Klein, Dansereau, & Hall, 1994) by designing studies to disentangle effects at different level.

CONCLUSION

Our review and analysis of the psychosocial work design and cognition literature identified five perspectives: work design, learning, human factors, lifespan/aging, and occupational health. Based on these distinct perspectives we described cognitively-enriching and cognitively- harmful mechanisms by which work characteristics can lead to short-to-medium term use and maintenance of cognitive abilities, as well as change in knowledge, followed by the prevention of cognitive decline for working adults over the lifespan, longer term acquisition of knowledge/crystallised intelligence and possible and change in brain structure and function. The empirical evidence regarding the ways in which our work can shape our short-to-medium and longer-term cognition is growing, suggesting it is important to design work in ways that will foster cognitive enrichment through autonomy, feedback, learning, and motivation, and minimize cognitively harmful effects (e.g., work-related stress, lack of feedback). The benefits of well-designed work and positive cognitive outcomes apply to workers, organizations, and society as a whole.

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TABLE 1. MAJOR PATHWAYS LINKING WORK DESIGN AND COGNITION IDENTIFIED IN THE REVIEW

Pathway	Description	Physical Analogy	Example	Relevant Work Characteristics
Short-to-Medium Term Cognitive Processes				
Opportunity for Cognitive Use	Work affects people's opportunity to apply knowledge and to use their cognitive abilities, with work design influencing the extent and type of cognition used.	A physical workout uses one's muscles, with attributes of the workout (e.g., the type of activity like walk versus swim, length of time engaged in) influencing which muscles are used and to what extent.	If a salesperson has to sort out complex contractual issues, she uses her knowledge of contracting, and engages in problem solving, which in turn relies on cognitive processes like working memory and uses cognitive abilities such as reasoning.	Rarely empirically examined, although theoretically assumed in the preservation pathway. Especially linked to job complexity
Accelerated Knowledge Acquisition	Work, when designed in ways that enhance individuals' active problem solving, accelerate worker's knowledge acquisition, facilitating deeper and broader forms of learning.	Some physical workouts are highly oriented towards skill acquisition, such as a tennis drills session in which the player engages in dynamic tennis play and receives feedback from the play itself, as well as from the coach. This active engagement accelerates the tennis player's acquisition of skill.	Because a salesperson has the autonomy to solve problems for clients, and then get direct and immediate feedback on her approach, she very quickly acquires knowledge about what solutions are best, increasing her speed of learning.	Evidence is strongest for job autonomy alone, and combinations of autonomy, demands or complexity, and feedback.

Motivated Exploratory Learning	Work designs that are intrinsically motivating stimulate workers to learn and engage in learning-oriented behaviors that enhance their use of cognitive abilities, and lead them to use and acquire new knowledge.	An internally motivated person who engages in a tennis drills session will fully exploit the active learning opportunities created in the session (e.g., experimenting with strategies, persisting if a tactic doesn't immediately work, asking for feedback), and will therefore learn more.	Because a salesperson has an intrinsically-motivating job with complex problems to solve, she is open to learning new skills, and willing to explore new ways of solving the problems; behaviours that boost her knowledge and mean she uses increasingly complex cognitive abilities.	Evidence is strongest for job autonomy, relational aspects of work design (such as social support), and feedback from the job itself/holistic feedback assessments. Some evidence of positive effects of challenge demands in conjunction with autonomy.
Strain-Impaired Cognition	Work stressors increase psychological strain, which invokes physiological stress responses that impair learning and cognition.	If engaging in a workout, such as tennis drills, causes physical strain or injury, then the benefits of the workout on muscle development and skill acquisition will be impaired and even negative.	A salesperson is exposed to regular high work pressure, which increases cortisol in his body, which impairs his attention and interferes with learning.	Clear evidence that a lack of job autonomy/ feedback/ relational work design characteristics, and excess psychological job demands can lead to strain; also evidence that strain impairs learning. Few studies examine how work design affects learning via strain.
Depleted Cognitive Capacity	Excessive cognitive demands of tasks exceed one's mental capacity, leading to depletion, and thereby impairing learning.	A new training program is so physically convoluted or overwhelming that it means one cannot fully execute the program, which inhibits the	A salesperson attempts to learn a new IT system at the same time as monitor a large number of complex incoming queries, which makes it difficult for the person to learn the new skill.	Complex tasks can exceed people's memory capacity and impair learning. Sustained vigilance tasks also deplete cognition due to excess attention and self-regulation requirements.

chance for muscle development
or skill acquisition.

	Long-Term Cognitive Processes			
Cognitive Preservation	Work designs that allow for workers' greater use of cognition can help to maintain cognitive abilities and prevent decline as a result of ageing.	By using one's muscles repeatedly and over time, one prevents the deterioration in muscle strength that can otherwise occur with ageing.	Because a salesperson has regularly engaged in complex tasks and used brain in her career, the salesperson has preserved functioning so his/her cognitive decline is reduced at age 60	Job autonomy, job complexity, and social complexity appear to protect against long-term cognitive decline, with the evidence most consistent for job autonomy
Accumulated Knowledge	Over time, by promoting and accelerating learning, work design can lead to the development of long-term cystallized intelligence, wisdom, and expertise.	Long-term development of skill creates muscle memory that enable ease of skill use later on in life.	A salesperson working for many years in an enriched job acquires deep expertise that, in turn, results in the allocation of more enriched work, promoting greater knowledge and wisdom, in a positive spiral. At age 65, the salesperson mentors juniors in how to manage complex projects.	Currently no evidence for this pathway, but long-term exposure to work characteristics that promote learning should foster this process.
Chronic Ill-health Impairment	Work that is chronically stressful can impair physiological systems, and even cause cardiovascular disease, which increases	Continued engagement in workouts that cause damage can create long-term injuries that then affect muscular and physical health in the long-term.	A salesperson is exposed to chronic levels of low control and high demands, contributing to a heart attack in middle age, which causes loss of cognitive function.	Some initial evidence that stressful work characteristics (eg low autonomy/ high demands) can affect vascular systems and contribute to cognitive decline.

cognitive decline as one
ages.

TABLE 2: FUTURE DIRECTIONS AND METHODOLOGICAL IMPROVEMENTS

	FUTURE DIRECTIONS
Connecting & expanding the pathways	• How do work-design cognitive pathways interrelate and interact, and do they have similar or different effects • Do short-to-medium term cognitive effects of work design on knowledge accumulate over time to affect cognitive abilities? If so, exactly how does work design prevent a decline cognitive abilities (that is, through which pathways)? • Does work design have any impact on the use of, or maintenance of, cognitive abilities in the short-to-medium term? • Are there long-term effects on work design on crystallized intelligence, such as the development of wisdom, or accelerating the likelihood of an individual becoming a deep expert? • Are brain functions and/or structures affected by work design in the short and long term, and if so, which structures and functions are affected and how do they relate to changes in cognitive processing and abilities?
Dynamics and timing of cognitive processes	• How long do protective effects of well-design work last? • What are the dynamic effects of work design and cognition, such as the recursive effects of cognition on work design and the possibility of amplifying spirals?
Work Design Antecedents	• How "much" exposure to well-designed work is needed to engender long-term cognitive benefits, and how continuous does this exposure need to be? • What sequencing of work designs is most important? • "Beyond complexity, autonomy, and stressful demands, what other work characteristics positively impact on workers' long-term cognition?
Broader questions	• What are the cognitive effects of profiles of work characteristics? • How do psychosocial aspects of work design interact with physical aspects of work, and other factors outside of work?

- Who benefits cognitively most and least from well-designed work, and are additional supports needed for some individuals?

- How should work be designed to accommodate cognition?

METHODOLOGICAL SUGGESTIONS	
Measurement	• Use direct measures of work design rather than occupational proxies • Assess mechanisms directly and comprehensively • Use specific measures to assess specific cognitive abilities • Complement studies on cognition by using neurological techniques
Research Design	• Measure work design, mechanisms, and cognition multiple times over the lifespan so that issues of exposure, timing, and causality, can be unravelled • Design studies to disentangle level effects
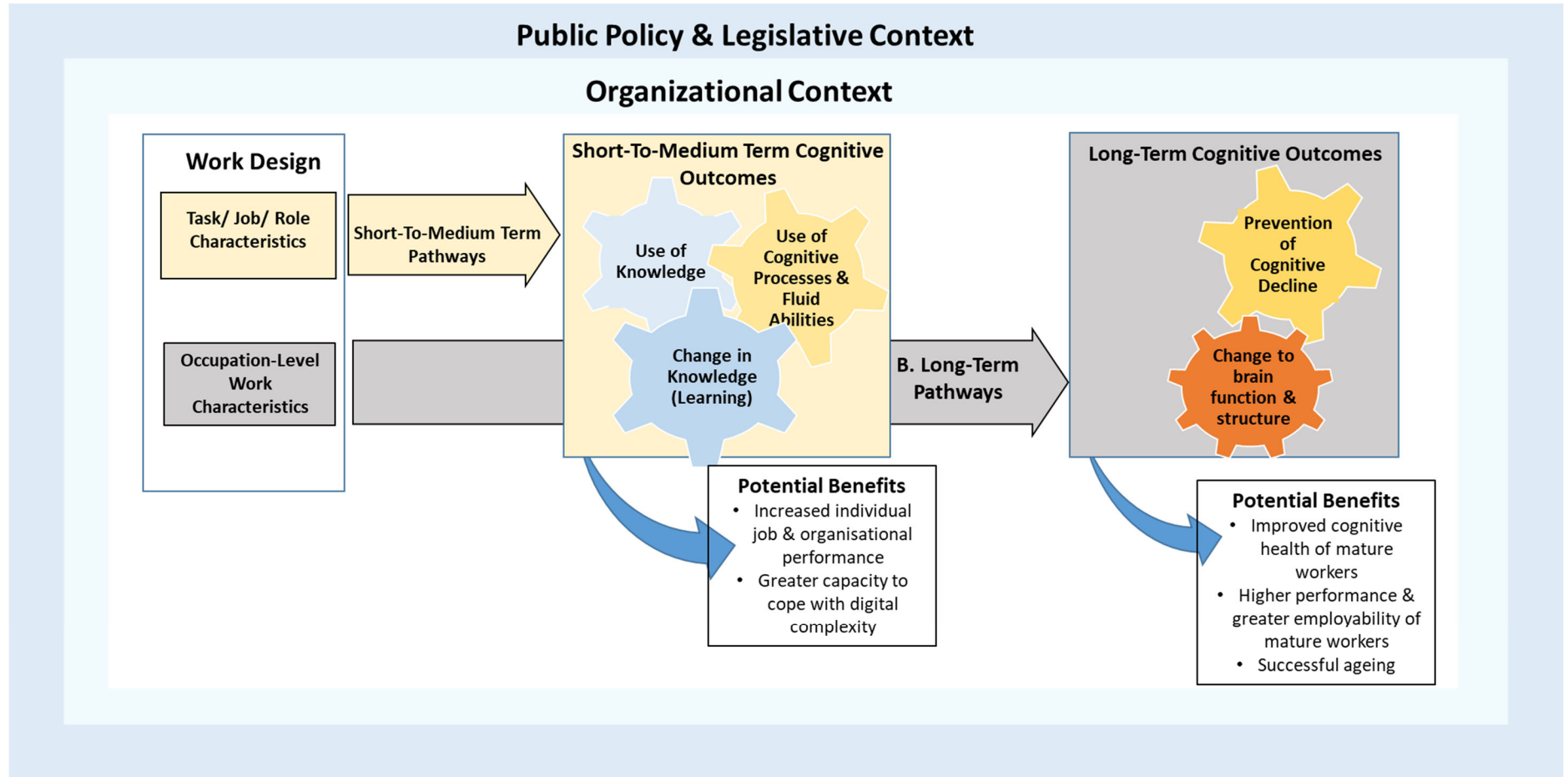
FIGURE 1: OVERVIEW OF WORK-DESIGN COGNITION LINKS IN THE SHORT-TO-MEDIUM TERM AND IN THE LONG TERM, AND THEIR POTENTIAL BENEFITS

Main Cognitive Variables

Knowledge
- Factual & procedural knowledge
- Contextual knowledge
- Tacit knowledge
- Knowledge about using knowledge

Cognitive Processes & Fluid Abilities
- Cognitive processes (working memory, perceptual speed, sensory function, inhibition)
- Fluid abilities (reasoning, problem solving, etc)

Short-to-medium Term Change in Cognition

Short-Term Change in Knowledge
- Learning
- Mental model development
- Knowledge / skill acquisition

Long-term Change in Cognition

Long-term Change in Knowledge
- Development of expertise
- Increase in crystallised intelligence
- Wisdom

Change to brain function & structure
e.g., neuronal development

Prevention of Decline in Cognitive Processes & Fluid Abilities
- Maintaining processes & abilities
- Reduced cognitive decline
- Reduction of cognitive disease

FIGURE 2. OVERVIEW OF COGNITIVE VARIABLES OF INTEREST IN THIS ARTICLE

Note. We also depict changes in brain structure and function to show where they fit, although not a direct focus in this review.

FIGURE 3: FINDINGS FROM A VOSVIEWER ANALYSIS AND HOW THE IDENTIFIED TOPICS MAP ONTO DIVERSE PERSPECTIVES IN THE

LITERATURE

Individual Differences Affect Cognitive Impact of Work Design
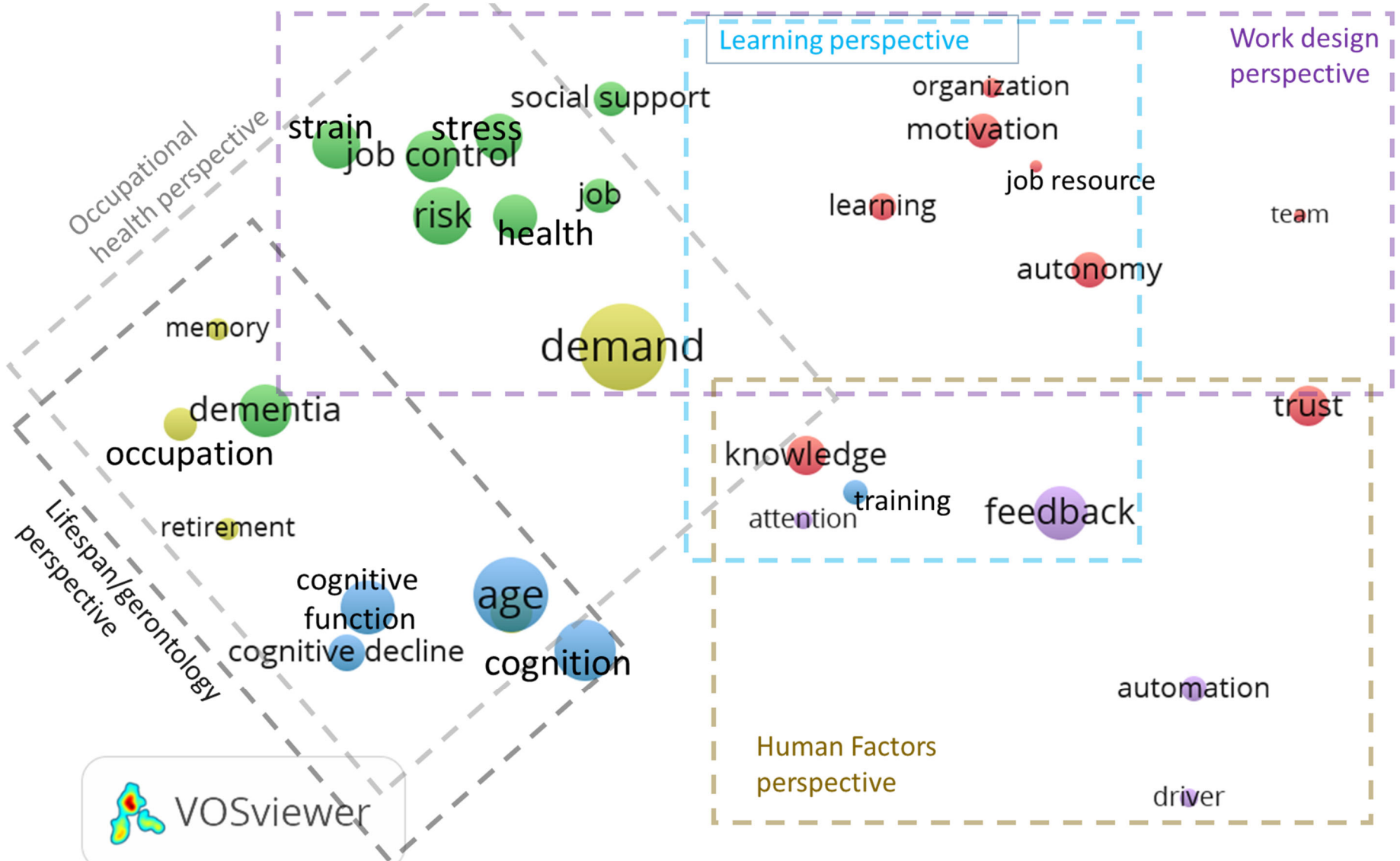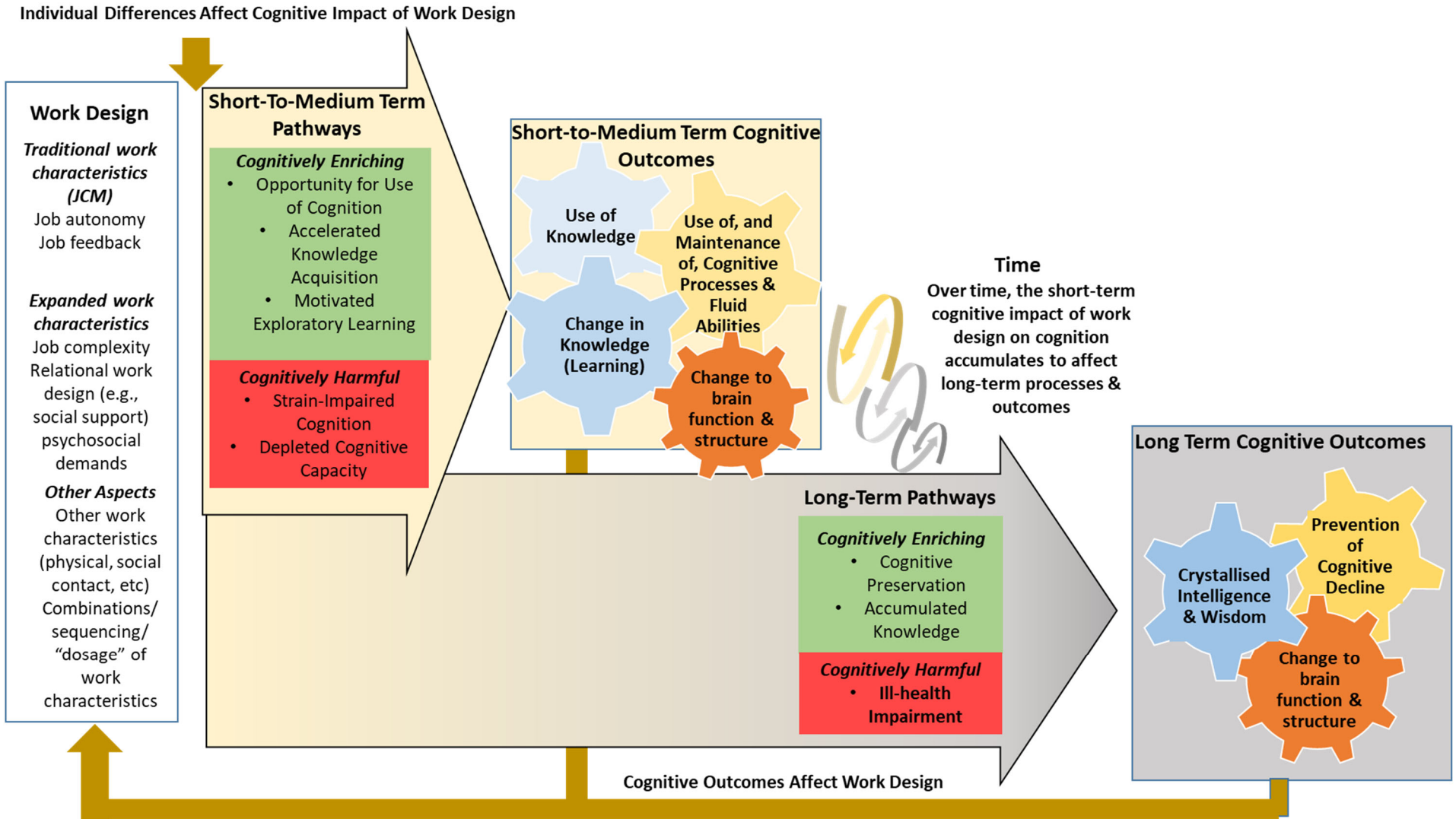
Work Design

Traditional work characteristics (JCM)
Job autonomy
Job feedback

Expanded work characteristics
Job complexity
Relational work design (e.g., social support)
psychosocial demands

Other Aspects
Other work characteristics (physical, social contact, etc)
Combinations/ sequencing/ "dosage" of work characteristics

Short-To-Medium Term Pathways

Cognitively Enriching
- Opportunity for Use of Cognition
- Accelerated Knowledge Acquisition
- Motivated Exploratory Learning

Cognitively Harmful
- Strain-Impaired Cognition
- Depleted Cognitive Capacity

Short-to-Medium Term Cognitive Outcomes

Use of Knowledge

Use of, and Maintenance of, Cognitive Processes & Fluid Abilities

Change in Knowledge (Learning)

Change to brain function & structure

Time
Over time, the short-term cognitive impact of work design on cognition accumulates to affect long-term processes & outcomes

Long-Term Pathways

Cognitively Enriching
- Cognitive Preservation
- Accumulated Knowledge

Cognitively Harmful
- Ill-health Impairment

Long Term Cognitive Outcomes

Crystallised Intelligence & Wisdom

Prevention of Cognitive Decline

Change to brain function & structure

Cognitive Outcomes Affect Work Design

FIGURE 4: INTEGRATIVE MODEL OF WORK DESIGN AND COGNITION OVER DIFFERENT TIME FRAMES

APPENDIX A: APPROACH TO REVIEW AND SCIENTIFIC MAPPING

The review process was extensive, entailing multiple steps to ensure we captured relevant articles from a range of relevant disciplines. There was an initial review, a review conducted within Web of Science, and backwards referencing. VosViewer was then used to map the literature.

Procedure for Initial Literature Review

First, we backwards referenced Fisher et al.'s (2017) review article, as well as other review articles, and searched for more recent articles that may not have been included in their review. Thus, in Google Scholar we searched for articles published after 2016 that included the terms: "work design" OR "job design" OR "work complexity" AND cognition. Sorted by relevance, the second author reviewed the first 30 pages of 3,270 search results. There were 64 articles to screen for inclusion or exclusion.

Procedure for Web of Science Systematic Review

Search terms used in Web of Science were created based on terms used in research literature in work design, cognition, and neuroscience. For work design, we included search terms relevant to the job characteristics model, job demands-control model, job demands-resources, sociotechnical systems theory/ autonomous work groups, and role theory (Parker, Morgeson, and Johns, 2017). We also use terms that we observed are more commonly used in other fields, but which are closely aligned with work design concepts (e.g., 'occupational complexity' is often used in lifespan research, and 'task complexity' is often used in human factors research). We initially restricted all of our searches to articles published within the last 10 years (2009-2019). This is an appropriate cut-off to retrieve relevant and timely publications based in part on the observation that empirical work in organizational neuroscience began to be published around 2009. There were too many work design search terms to include in a single search. We created two groups of terms that were searched, and then combined with the "OR" Boolean operator. Work design search terms returned 47,719 search results. Cognition (1,950,761 results) and neuroscience (352,211 results) search terms were grouped and then combined using the "OR" operator, returning 2,174,221 results. Next, to find articles that included any of the work design search terms and any of the cognition or neuroscience search terms, we combined work design and cognition/neuroscience groups of search terms using the "AND" operator. This resulted in 9,994 articles that had any of the work design search terms *and* any of the cognition or neuroscience terms in the title, abstract, or keywords.

To retrieve quality publications in relevant disciplines, we identified top-ranked journals according to Scimago's 2017 H-index values in: neuroscience, neuroscience miscellaneous, developmental neuroscience, behavioural neuroscience, cognitive neuroscience, cellular and molecular neuroscience, applied psychology, developmental and educational psychology, psychology miscellaneous, neuropsychology and physiological psychology, social psychology, public health, environmental and occupational health, occupational therapy, ergonomics, aging, computer vision and pattern recognition, experimental and cognitive psychology, occupational health, and gerontology. We focused on publications since 2009 to capture more recent work, knowing these later publications would cite key earlier studies. To do this, we generated lists of sources in each those fields of study, creating four separate searches in Web of Science for all articles published

between 2009-2019 in any of the journals listed. Then, we used the "AND" operator to restrict search results of articles that had both work design terms *and* cognition or neuroscience terms to only articles published in top organizational behaviour journals (375), cognition (115), neuroscience (95), and gerontology/occupational health (91). Then we combined results from each of those four searches using the "OR" operator to give a full list of 619 search results where we manually reviewed the abstracts for inclusion/exclusion from the current paper.

Our initial review combined with the systematic review revealed over 650 articles. After excluding irrelevant papers, we identified approximately 80 empirical studies that examined the link between work design and cognition, and 7 review/conceptual articles. Finally, to check our search process was comprehensive, we used backward reference searching from previous reviews and pivotal papers. In this broader review, we included papers that were published earlier than 2009. We obtained over 100 further articles via this process.

List of Search Terms Used in WOS Systematic Review

Work design search terms. (TS=("Skill Variety") OR TS=("Task variety") OR TS=("Problem-solving demands") OR TS=("Information processing demands") OR TS=("work speciali$ation") OR TS=("job speciali$ation") OR TS=("work complexity") OR TS=("job complexity") OR TS=("work feedback") OR TS=("job feedback") OR TS=("Feedback from job*") OR TS=("Task Identity") OR TS=("Role Clarity") OR TS=("role ambiguity") OR TS=("Feedback from other*") OR TS=("work * ambiguity") OR TS=("performance * ambiguity") OR TS=("schedul* ambiguity") OR TS=("job autonomy") OR TS=("autonomy in the job") OR TS=("work autonomy") OR TS=("autonomy in work") OR TS=("job control") OR TS=("control * job") OR TS=("work control") OR TS=("control at work") OR TS=("control in work") OR TS=("work-scheduling autonomy") OR TS=("autonomy * Work-scheduling") OR TS=("decision-making autonomy") OR TS=("autonomy * decision-making") OR TS=("work method* autonomy") OR TS=("autonomy * work methods*") OR TS=("work social support") OR TS=("work * social support") OR TS=("social support * work") OR TS=("social support * job") OR TS=("job social support") OR TS=("job * social support") OR TS=("Task significance") OR TS=("work significance") OR TS=("perceived social worth") OR TS=("manager* support") OR TS=("colleague support") OR TS=("coworker support") OR TS=("work* interdependence") OR TS=("job* interdependence"))

Work design search terms (continued). (TS=("interaction out* organi$ation") OR TS=("contact with beneficiar*") OR TS=("beneficiar* contact") OR TS=("work *role conflict") OR TS=("job *role conflict") OR TS=("work *time pressure") OR TS=("job *time pressure") OR TS=("task *time pressure") OR TS=("monitor* demand*") OR TS=("emotion* demand*") OR TS=("role conflict* work") OR TS=("work* role conflict") OR TS=("job role conflict") OR TS=("role conflict* job") OR TS=("work*load") OR TS=("job demand*") OR TS=("work demand*") OR TS=("cost responsibilit*") OR TS=("work-to-family conflict*") OR TS=("work home conflict*") OR TS=("emotional labo*") OR TS=("cognitive work demand*") OR TS=("cognitive job demand*") OR TS=("physical demand*") OR TS=("work design*") OR TS=("job design*") OR TS=("job characteristic*") OR TS=("work characteristic*") OR TS=("task characteristic*") OR TS=("job redesign*") OR TS=("work redesign*") OR TS=("team redesig*") OR TS=("job enlargement*") OR TS=("work enlargement*") OR TS=("job enrich*") OR TS=("work enrich*") OR TS=("job reorgani$ation*") OR TS=("job rotat*") OR TS=("work

rotat*") OR TS=("team empower*") OR TS=("work empower*") OR TS=("participative redesign") OR TS=("participative work redesign") OR TS=("participative work design") OR TS=("autonomous work team*") OR TS=("autonomous work group*") OR TS=("self-manag* team*") OR TS=("self-manag* group*"))

Cognitive search terms. TS=("memory") OR TS=("attention") OR TS=("executive function*") OR TS=("higher order problem-solving") OR TS=("language") OR TS=("visual processing") OR TS=("visual perception") OR TS=("learning") OR TS=("social processing ") OR TS=("emotional processing") OR TS=("cognition") OR TS=("cognitive") OR TS=("self-regulation") OR TS=("systems supporting regulation") OR TS=("learning") OR TS=("speed of complex cognitive processes ") OR TS=("cogniti* processing speed") OR TS=("cognitive speed") OR TS=("mental model") OR TS=("situational awareness") OR TS=("intelligence") OR TS=("neural structures") OR TS=("synap* density") OR TS=("dementia") OR TS=("Alzheimer*")

Neuroscience search terms. TS=("hippocamp*") OR TS=("fronto-temporal systems*") OR TS=("prefrontal cortex") OR TS=("frontostriatal network*") OR TS=("frontostriatal circuit*") OR TS=("temporal lobe") OR TS=("temporal cortex") OR TS=("prefrontal cortex") OR TS=("*frontal lobe") OR TS=("parietal lobe") OR TS=("parietal cortex") OR TS=("occipital") OR TS=("*plasticity") OR TS=("limbic system") OR TS=("inferior prefrontal") OR TS=("dorsal and ventral lateral prefrontal cortext") OR TS=("posterior medial prefrontal cortex") OR TS=("amygdala") OR TS=("ventral striatum") OR TS=("dorsal premotor regions") OR TS=("temporal-parietal junction") OR TS=("dorsal medial prefrontal cortex") OR TS=("precuneus") OR TS=("*plasticity") OR TS=("right dorsolateral prefrontal cortex") OR TS=("default mode network") OR TS=("right superior parietal lobe") OR TS=("myelination") OR TS=("gr$y matter") OR TS=("white matter") OR TS=("inferior temporal cortex") OR TS=("perirhinal cortex") OR TS=("parahippocampal cortex") OR TS=("entorhinal cortex") OR TS=("lateral entorhinal area") OR TS=("medial entorhinal")

List of Journal Outlets Used to Restrict Search Results

Organizational behaviour journal outlets. SO=(Academy of Management Annals OR Academy of Management Executive OR Academy of Management Journal OR Academy of Management Perspectives OR Academy of Management Review OR Administrative Science Quarterly OR Applied Psychology Health "AND" Well Being OR Applied Psychology An International Review OR Asia Pacific Journal of Management OR British Journal of Management OR California Management Review OR Decision Sciences OR European Journal of Work "AND" Organizational Psychology OR European Review of Applied Psychology OR Group "AND" Organization Management OR Harvard Business Review OR Human Performance OR Human Relations OR Human Resource Management OR Human Resource Management Journal OR Human Resource Management Review OR International Journal of Management Reviews OR Journal of Applied Psychology OR Journal of Behavioural Decision Making OR Journal of Business "AND" Psychology OR Journal of Career Assessment OR Journal of Career Development OR Journal of Experimental Psychology Applied OR Journal of International Business Studies OR Journal of Management OR Journal of Management Studies OR Journal of Managerial Psychology OR Journal of Occupational "AND" Organizational Psychology OR Journal of Occupational Health Psychology OR Journal of Organizational Behaviour OR Journal of Organizational Behaviour Management OR Journal

of Vocational Behaviour OR Leadership Quarterly OR Management "AND" Organization Review OR Management Science OR Motivation "AND" Emotion OR International Journal of Management Science OR Organization OR Organization Science OR Organization Studies OR Organizational Behaviour "AND" Human OR Decision Processes OR Organizational Dynamics OR Organizational Research Methods OR Personnel Psychology OR Psychological Bulletin OR Research in Organizational Behaviour OR Sloan Management Review OR Work "AND" Stress OR ENTREPRENEURSHIP THEORY "AND" PRACTICE OR JOURNAL OF BUSINESS VENTURING OR Small Business Economics OR Strategic Entrepreneurship Journal OR ANNUAL REVIEW OF ORGANIZATIONAL PSYCHOLOGY "AND" ORGANIZATIONAL BEHAVIOUR OR ORGANIZATIONAL BEHAVIOUR "AND" HUMAN DECISION PROCESSES)

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=2009-2019

Cognition Outlets. SO=(Trends in Cognitive Sciences OR Neuropsychologia OR Cognition OR Behaviour Research "AND" Therapy OR Psychophysiology OR Physiology "AND" Behaviour OR Journal of Experimental Psychology Learning Memory "AND" Cognition OR Journal of Experimental Psychology General OR Journal of Experimental Psychology Human Perception "AND" Performance OR Psychonomic Bulletin "AND" Review OR Journal of Memory "AND" Language OR Behaviour Research Methods OR Brain "AND" Cognition OR Memory "AND" Cognition OR Cognition "AND" Emotion OR Brain "AND" Language OR Cognitive Psychology OR Neurobiology of Learning "AND" Memory OR Attention Perception Psychophysics OR Journal of Experimental Child Psychology OR Evolution "AND" Human Behaviour OR Cognitive Science OR Cortex OR Consciousness "AND" Cognition OR Acta Psychologica OR Cognitive Therapy "AND" Research OR Applied Cognitive Psychology OR Cognitive Neuropsychology OR Perception OR Social Cognitive "AND" Affective Neuroscience OR Intelligence OR Developmental Review OR Journal of Experimental Psychology Applied OR Visual Cognition OR Cognitive Development OR Language Cognition "AND" Neuroscience OR Motivation "AND" Emotion OR Multivariate Behavioural Research)

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=2009-2019

Neuroscience outlets. SO=(Neuroepidemiology OR Neuropsychology OR Annals of Neurology OR Neuron OR Journal of Neuroscience OR Nature Neuroscience OR EMBO Journal OR Nature Reviews Neuroscience OR NeuroImage OR Stroke OR Biological Psychiatry OR Annals of Neurology OR Trends in Neurosciences OR Trends in Cognitive Sciences OR Pain OR Journal of Neurophysiology OR Annual Review of Neuroscience OR Cerebral Cortex OR Annals of the New York Academy of Sciences OR PLoS Biology OR Journal of Neurochemistry OR Progress in Neurobiology OR Current Opinion in Neurobiology OR Neuroscience "AND" Biobehavioural Reviews OR Neuroscience OR Investigative Ophthalmology "AND" Visual Science OR Journal of Cognitive Neuroscience OR Journal of Comparative Neurology OR Molecular Psychiatry OR Cellular "AND" Molecular Life Sciences OR European Journal of Neuroscience OR Brain Research OR Neuropsychologia OR NeuroReport OR Journal of Cerebral Blood Flow "AND" Metabolism OR Epilepsia OR Journal of Abnormal Psychology OR Human Brain Mapping OR Movement Disorders OR Experimental Neurology OR Cognition OR Neurobiology of Aging OR Schizophrenia Research

OR Clinical Neurophysiology OR Neuroscience Letters OR Experimental Brain Research OR Journal of Neuropathology "AND" Experimental Neurology OR Behavioural Brain Research)

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=2009-2019

Gerontology and Occupational Health outlets. SO=(Journal of Occupational Health Psychology OR Work Aging "AND" Retirement OR Journal of Epidemiology "AND" Community Health OR Journal of Occupational "AND" Environmental Medicine OR American Journal of Industrial Medicine OR Journal of Geriatric Psychiatry "AND" Neurology OR Journal of the American OR Geriatrics Society OR International Psychogeriatrics OR Alzheimer's Research "AND" Therapy OR Journal of Applied Gerontology OR Journal of the American Geriatrics Society OR Journals of Gerontology Series A Biological Sciences "AND" Medical Sciences OR Neurobiology of Aging OR Psychology "AND" Aging OR Journals of Gerontology Series B Psychological Sciences "AND" Social Sciences OR Age "AND" Ageing OR The Gerontologist OR International Journal of Geriatric Psychiatry OR Critical Reviews in Oncology/Hematology OR American Journal of Geriatric Psychiatry OR Journal of Alzheimer's Disease OR Dementia "AND" Geriatric Cognitive Disorders OR Alzheimer Disease "AND" Associated Disorders OR Alzheimer's "AND" Dementia OR Drugs "AND" Aging OR Parkinsonism "AND" Related Disorders OR International Psychogeriatrics OR Gerontology OR Aging "AND" Mental Health OR Journal of Nutrition Health "AND" Aging OR Ageing "AND" Society OR Clinics in Geriatric Medicine OR Biogerontology OR Journal of Geriatric Psychiatry "AND" Neurology OR Journal of Aging "AND" Health OR Aging Clinical "AND" Experimental Research OR Archives of Gerontology "AND" Geriatrics OR Research on Aging OR Clinical interventions in aging OR BMC Geriatrics OR Aging Neuropsychology "AND" Cognition OR Rejuvenation Research OR American Journal of Alzheimer's Disease "AND" other Dementias OR Journal of Aging "AND" Physical Activity OR International Journal of Aging "AND" Human Development)

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=2009-2019

Scientific Mapping using VosViewer

We subjected all of the articles that we obtained from our full review process to a scientific bibiometric mapping process, which represents connections in a structure to visualize a focal research area and its evolution (Cobo et al., 2011; Ding & Yang, 2020). The maps in the current paper visualize the strengths of associations between scientific terms such that larger terms represent higher frequency in the included articles. We followed recommendations by van Eck and Waltman (2014) regarding proper use of VosViewer, and the grouping processes we used follow similar steps to extant publications. Relatedness among terms is indicated by position and relative distance. Shorter distances between terms co-occur more frequently that terms at a distance; terms in more central positions in the map (versus the periphery) co-occur with more terms; and clusters of similar terms are designated by color (see van Eck and Waltman, 2010, 2014) for a more detailed explanation of VosViewer parameters). The VosViewer map in the current paper was based on references that included the one of the following terms in the title and/or abstracts: "autonomy," "control," "complex," "demand," "feedback," "resource," or "support." Co-occurrence of terms was 10, attraction 10, repulsion of 1, and VOSviewer cluster resolution

was set to three, which asked VOSviewer to increase number of clusters by increasing level of detail for each cluster. As per the VOSviewer manual, this is set iteratively based on how logical the clusters appear, considering the articles that were input to VOSviewer (van Eck & Waltman, 2010), minimum cluster size was set to four (meaning at least four constructs needed to co-occur in each cluster). resulting in the emergence of five clusters. Irrelevant words such as "paper" and "way" were excluded. Based on analysis of the resulting VosViewer findings, paired with inspection of each article included in our review (e.g., its approach, journal of publication), we identified multiple disciplinary perspectives linking work design and cognition.