Work Biographies as Facilitators of Cognitive and Brain Development: A Lifespan Perspective on Occupational Health

by

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ABSTRACT

In Germany as well as in most industrialized countries of the Western hemisphere, the workforce is constantly ‘aging’. Increasing age, however, is associated with a number of health risks. Cognitive decline may be a particular challenge to health at work. Long-term exposure to low mental stimulation at work has detrimental effects on brain and cognition. Low job complexity has repeatedly been associated with lower levels of cognitive functioning and with a higher risk of cognitive impairment and dementia. But good cognitive health is a necessary prerequisite to preserve well-being, work ability, and productivity. However, research has not yet found an effective way how to counteract these effects. This dissertation set out to fill this gap. Therefore, three studies were conducted: a conceptual literature review which systematized the available evidence on 'in vivo' mental stimulation as well as two experimental studies that investigated the effect of multiple work-task changes (WTC) on the cognitive functioning and brain anatomy of long-term industrial production workers. The findings reveal that (a) besides complexity, active learning and recurrent novelty can serve as valuable facilitators of positive plasticity in the cognitive system, (b) industrial production workers who underwent multiple WTC over 17 years showed higher levels of cognitive functioning, and displayed (c) more gray matter volume in hypothesized areas than a matched control group with 0 or 1 WTC. With this, the current dissertation extends the available evidence on the critical contextual features that foster cognitive plasticity; suggests recurrent exposure to WTC as strategic health management instrument to counteract cognitive decline; underlines the importance of cognitive health and cognitive aging as vital but neglected fields of occupational health psychology; and emphasizes the need for a lifespan developmental perspective on occupational health management.
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I. GENERAL INTRODUCTION

Occupational health psychology (OHP), that is, the contribution of applied psychology to occupational health (Houdmont & Leka, 2010), is a rather young discipline (Barling & Griffiths, 2003; Quick, 1999). As a sub-discipline of occupational health management, it is an interdisciplinary research field with historical roots in preventive work medicine, health psychology, and organizational engineering (Macik-Frey, Quick, & Nelson, 2007). Before OHP emerged at the end of the 20th century, occupational health management was mainly concerned with physical, biological, and chemical hazards. Within the last decades, however, psychological constructs such as stress and well-being have become established variables in occupational health research (Barling & Griffiths, 2003). Nowadays, modern OHP protagonists strive to create 'psychologically healthy workplaces' in which optimal health is generated constantly (Grawitch, Gottschalk, & Munz, 2006).

Cognitive and brain health—as particular topics in health psychology—have received only scant attention in OHP research thus far. Although there is no universally accepted definition of cognitive and brain health (Hendry et al., 2006), I will use the term cognitive health throughout this dissertation in order to describe a state of cognitive and brain functioning that is characterized by both the absence of any kind of cognitive or brain disease as well as the preservation (and improvement) of good cognitive functioning (Hendry et al., 2006; Jedrziewski, Lee, & Trojanowski, 2007). Cognitive functioning refers to the functioning of typical cognitive (in the sense of intellectual) abilities such as processing speed (i.e., the speed with which information can be processed) or working memory (i.e., the simultaneous short-term maintenance and manipulation of information; Hedden & Gabrieli, 2004). The lack of interest in cognitive health as an occupational health concern is surprising. First, because good cognitive health is a necessary prerequisite to preserve well-being, work ability, and
productivity; second, because increasing levels of technology use in the work environment can be assumed to place incrementally high demands on cognitive functioning; third, because the European and U.S.-American workforce is constantly 'aging'; and fourth, because it is well-known from lifespan research that many cognitive abilities on average decline with age (e.g., Baltes, Lindenberger, & Staudinger, 2006).

The disinterest in cognitive health is even more striking, however, against the background that ample research has repeatedly shown that working conditions can take great impact on cognitive functioning across the lifespan. Whereas high levels of mental stimulation at work have been associated with better maintenance of cognitive functioning and reduced atrophy in specified brain areas (Schooler, Mulatu, & Oates, 1999; Suo et al., 2012), low mental stimulation at work seems to be related with lower levels of cognitive performance and maladaptive neuropsychological functioning in task switching (Gajewski, Wild-Wall, Schapkin, Erdmann, Freude, & Falkenstein, 2010). And although the detrimental mechanisms of low mental stimulation at work have been well-established for decades (Kohn & Schooler, 1978), research has not yet found an effective way how to counteract these effects. With my dissertation, I aim to fill this gap. Adopting a lifespan perspective on occupational health, I intend to identify mechanisms that facilitate positive plasticity (i.e., the modifiability of developmental trajectories; see below) in cognitive and brain development in order to investigate their potential to diminish the negative long-term effects of low mental stimulation at work.

A Short History of Occupational Health Psychology: From Accident Prevention to Healthy Workplaces

First proof of medical interest in work-induced health problems dates back to the middle of the last millennium. For instance, in 1473 Ullrich Ellenbog, a German physician, reported on the harmful effects of poisonous fumes encountered by metal workers and in
1587, Paracelsus, a Swiss medical polymath, commented on the pulmonary diseases of mine workers (see Abrams, 2001). Notwithstanding these early observations, it took more than 200 years before worker health received serious scientific attention. The advent of the industrial revolution in the 18th and 19th century (and the fundamental changes in work organization that succeeded) sparked increased concerns about employee health (Barling & Griffiths, 2003). However, these early forms of occupational health management mostly aimed at accident prevention (such as in steel manufacturing and railroad injuries) and reducing the number of health risk factors. For many decades, the main purpose of occupational health researchers was to control and prevent injuries and exposure to work-related hazards (e.g., dust, heat, secondhand smoke, noise, and toxic exposures; Houdmont & Leka, 2010; Macik-Frey et al., 2007).

At the beginning of the 20th century, Frederick W. Taylor (1911) successfully promoted his idea of scientific management. In order to counteract low productivity and increase work efficiency, Taylor diligently analyzed work tasks and created simplified and standardized work routines. He ran, for instance, controlled empirical studies to optimize shovel designs and determine optimum weights per shovelful. Scientific management had the aim to reduce costs and the amount of skill required, remove worker control, and eliminate any influence of employee emotions (Barling & Griffiths, 2003). With this, Taylor laid the foundation for what would later be called industrial engineering, that is, a branch of management research which investigated the optimal use of tools and the human body in the workplace (Garg, 1991).

With advancing technological progress, however, work equipment became more and more complex and often exceeded the capabilities of human operators. That is why ergonomics (in the USA often synonymously used as human factors) evolved as one of the most dominant research fields of OHP in the 20th century. Ergonomics research seeks to reach "theoretical and fundamental understanding of human behavior and performance in
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"purposeful interacting socio-technical systems" (Wilson, 2000, p. 560) and aims at applying that understanding to create workplaces that fit the physiological or psychological requirements of the worker (and not vice versa; e.g., through optimized personnel selection and training; Garg, 1991). In the late 1960s, industry started to recognize the importance of ergonomics in order to reduce the number of errors, fatal accidents, injuries, and chronic diseases (Gainer, 2008; Garg, 1991). In the following, with increasing computerization and automation of work processes, ergonomics gained public attention and important influence on OHP throughout the second half of the 20th century. Central issues in ergonomics research refer to user-friendly computer software or ergonomic design for computer equipment, as well as to the prevention of back pain and chronic disorders of muscles and extremities due to poorly designed workplaces (e.g., in assembly-line work; Garg, 1991; Wilson, 2000).

In the 1930s, a series of experiments that have become famous as the Hawthorne studies may have marked another milestone on the way to modern occupational health psychology. The Hawthorne experiments (which were conducted at the Western Electric Company at Hawthorne) initially attempted to extend the scientific management framework by Frederick W. Taylor. Investigating the impact of varying lighting conditions on productivity, the results surprisingly revealed that worker productivity invariably increased as soon as they were observed, no matter what manipulations to the lighting were undertaken. In subsequent experiments, it became apparent that the social, psychological, and cultural aspects of work were of great importance to the worker's motivation which in turn affected productivity (Mayo, 1933; Roethlisberger & Dickson, 1939). The impact of these findings was overwhelming. For the first time, industrialists and companies appreciated the relationship between the psychological work environment of their employees on the one hand and managerial outcomes on the other.

Work psychology in the remainder of the 20th century was in large parts characterized by this new focus on the psychological environment of the working individual. For instance,
in 1943, Abraham Maslow established his influential hierarchy of needs (Maslow, 1943) and concluded that satisfied psychological needs are a necessary prerequisite of work motivation, productivity, and health. In 1951, Trist and Bamforth observed increasing rates of anxiety, anger, and depression among mine workers as a function of changes in the social structure of the work system (from an ‘entire’ mining routine to a mechanized, fractured system; Barling & Griffiths, 2003). And some 20 years later, Herzberg (1966) as well as Hackman and Oldham (1976) published their seminal job design theories, stating that satisfaction, motivation, and productivity are contingent on specific characteristics of the work task (e.g., challenge, recognition, responsibility, skill variety, task significance, and autonomy). However, Robert Karasek’s job strain model (1979; Karasek, Baker, Marxer, Ahlbom, & Theorell, 1981) was probably most influential to the development of modern occupational health psychology. Controlling for age, education, smoking, and overweight, Karasek found that the combination of high job demands and low job decision latitude yields job strain symptoms such as depression, sleeping problems, and exhaustion that can eventually increase the risk of coronary heart diseases (Karasek et al., 1981). The job strain model inspired many researchers who scrutinized the psychosocial conditions of work as crucial variables in health promotion. In the following, work psychology sparked vivid scientific interest, stress and burn-out evolved into key concepts of occupational health research, and it became more and more apparent that the factors responsible for mental and physical health were the same as the factors associated with higher job performance and productivity (Barling & Griffiths, 2003).

The term occupational health psychology was first established in 1990 by a group of researchers around Jonathan Raymond who saw unfulfilled potential in the development of ‘psychologically healthy workplaces’ (Houdmont & Leka, 2010; Raymond, Wood, & Patrick, 1990). Since then, in the last two and a half decades, OHP has become increasingly popular (Houdmount & Leka, 2010). Modern OHP protagonists have entirely overcome their former 'pathogenic' focus on accident prevention and the reduction of work-related health problems.
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There has been a shift in the aims of OHP research, from preventing and resolving negative outcomes at work such as disease and dissatisfaction to studying and promoting positive outcomes such as well-being and job satisfaction (Macik-Frey et al., 2007). The objective of modern OHP work—be it of academic nature or in professional practice—lies in the creation of “healthy workplaces in which people may produce, serve, grow, and be valued” (Quick et al., 1997, p. 3). Health is being conceived as a continuum that ranges from mortality to vibrant well-being and which results from the interplay of multiple interconnected factors (Adkins, Quick, & Moe, 2000). It needs to be generated constantly even when optimal health is achieved (Grawitch, Gottschalk, & Munz, 2006). Physical health and psychological well-being are being viewed as only fragments of good OHP. Instead, healthy workplaces need to target the working individual as a whole, including the (1) work-life balance, (2) growth and development, (3) health and safety, (4) recognition, and (5) involvement.

A recent and very popular example of such 'holistic' OHP approaches is the concept of work ability (e.g., Ilmarinen, 2007; Ilmarinen & Tuomi, 2004; Ilmarinen, Tuomi, & Seitsamo, 2005). Work ability can be understood as “how good is the worker at present and in the near future, and how able is he or she to do his or her work with respect to the work demands, health, and mental resources” (Ilmarinen et al., 2005). Work ability is assumed to be contingent on the constant interplay between characteristics of the work environment (work content, work organization, leadership), the worker (health background, professional competence, attitudes, and motivation), and the private environment (family, society). High work ability can thus only be achieved if the worker perceives all of these parameters to interact optimally with another. Ilmarinen and his colleagues have provided evidence that work ability is related to, for instance, a lower risk for early retirement and higher quality of life (Ilmarinen & Tuomi, 2004).
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Occupational Health Psychology in the 21st Century: Zooming in on Cognitive Functioning and the Aging Process

Notwithstanding these positive developments in OHP research, cognitive health—as one particular health component—has received only scant attention. For instance, the *Journal of Occupational Health Psychology* (JOHP) and *Work & Stress*, the two leading journals in OHP, largely neglected the topic. In 2013, Piotrowski (2013) conducted a content analysis of articles in the JOHP. It revealed that since its inception in 1996, the JOHP published not a single article that dealt with cognitive health. Only recently, one year later, JOHP issued a study investigating the impact of retirement on cognitive decline (Fisher, Stachowski, Infurna, Faul, Grosch, & Tetrick, 2014). In *Work & Stress*, some research has been published on the effects of stress and burn-out on cognitive functioning (e.g., Diestel, Cosmar, & Schmidt, 2013; van Dam, Keijsers, Eling, & Becker, 2011; 2012; van der Linden, Keijsers, Eling, & Schaijk, 2005). A recent review in *Work & Stress* identified 15 studies between 2005 and 2013 that investigated the relationship between burn-out and cognitive malfunctioning. It suggested that attention, memory, and executive functions are particularly associated with burn-out symptoms. However, the authors also concluded that the available evidence is too scarce and too heterogeneous to make reliable statements about a causal relationship (Deligkaris, Panagopoulou, Montgomery, & Masoura, 2014). Other researchers scrutinized the link between fatigue and cognitive performance and found reduced cognitive performance, especially after one or more nights of sleep loss (see Krueger, 1989, for a review).

Apart from that, the interest of occupational health researchers in cognitive health is surprisingly low. A look into recent handbooks on occupational health and safety management such as the *Handbook of Occupational Health and Wellness* (Gatchel & Schultz, 2012), *Health Promotion in the Workplace* (O’Donnell, 2002), *Occupational Health and Safety Management: A Practical Approach* (Reese, 2008), or *Current Topics in Occupational
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Epidemiology (Venables, 2013) reveals that 'classic' occupational health topics (e.g., the prevention of accidents and chronic diseases, ergonomics, or hygiene) still prevail in the literature. Psychological handbooks of occupational health management such as the Handbook of Occupational Health Psychology (Quick & Tetrick, 2003), Contemporary Occupational Health Psychology (Houdmont, Leka, & Sinclair, 2012), or the Handbook of Psychology, Volume 9: Health Psychology (Nezu, Nezu, & Geller, 2013), primarily deal with topics such as stress, burn-out, and well-being. None of these books, however, discusses cognitive health.

The lack of interest in cognitive health is surprising, because good cognitive health is a necessary prerequisite to preserve well-being, work ability, and productivity; and because increasing levels of technology use in the work environment can be assumed to place incrementally high demands on the cognitive system. It is particularly striking, however, against the background that (a) in Europe and the USA as well as in most other countries of the Western hemisphere the workforce is constantly 'aging', while (b) it is well-established that many cognitive abilities on average decline with increasing age; and (c) ample research has repeatedly shown that working conditions can take great impact on the development of cognitive functioning across the lifespan (e.g., Schooler, Mulatu, & Oates, 1999).

The employment rate of older workers is known to increase continuously. The world's population over 60 years of age has been predicted to double from 11.6% in 2012 to 21.8% in 2050 (Shannon, 2013). In Germany, the employment rate of the work population between 50 and 64 years of age has stepped up by approximately 20% within the last decade whereas the share of working individuals between 30 and 49 years of age decreased by approximately 15-20% (Fuchs, Söhnlein, & Weber, 2011). In 2013, 76% of the 55-59-year-olds and 50% of the 60-64-year-olds were economically active (Statistisches Bundesamt, 2014). And according to estimations (Fuchs et al., 2011), labor participation of older men and women is still growing and will continue to do so over the next years.
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At the same time, it is known that increasing age is, among other health risks (e.g., chronic health risks and long-term sickness absence; Dekkers-Sánchez, Hovings, Sluiter, & Frings-Dresen, 2008; Lidwall, Bergendorff, Voss, & Marklund, 2009; Shannon, 2013), associated with cognitive decline (also referred to as 'cognitive aging'). Cognitive aging circumscribes the fact that the cognitive system changes with age. On a neurophysiological level, increasing age brings about fundamental transformations in the structure and function of the brain (Grady, 2012; Raz et al., 2005). On a behavioral level, these processes are (on average) associated with a decline in many cognitive abilities (e.g., processing speed, memory, and working memory) across adulthood (Schaie & Willis, 1993). Regardless of that, the interest in aging in OHP research is, as it is for cognitive functioning, rather low. More often than not, the factors 'age' or 'aging' have merely been used as covariates or confounders in occupational health research (De Lange, Taris, Jansen, Smulders, Houtman, & Kompier, 2006; Schalk et al., 2010).

For full-time employees, work takes up a large percentage of their waking hours. Therefore, working conditions can have a strong influence on the cognitive aging process. For instance, high job complexity (i.e., independent thought and judgment at work) has repeatedly been associated with better cognitive functioning (Schooler, Mulatu, & Oates, 1999; 2004) and lower rates of atrophy in specified brain areas (Suo et al., 2012). On the other hand, low levels of mental stimulation at work (e.g., through low job complexity, constrained decision latitude, repetitive work routines, and high standardization) seem to be linked with lower levels of cognitive performance (also see Kohn & Schooler, 1978) and maladaptive neuropsychological functioning in task switching (Gajewski et al., 2010) as well as with a higher risk of cognitive impairment (Bosma, van Boxtel, Ponds, Houx, Burdorf, & Jolles, 2003) and dementia (Andel et al., 2005; Potter, Helms, Burke, Steffens, & Plassman, 2007). Assembly-line and industrial production work is characterized by low levels of complexity, repetitive and monotonous work tasks, and high levels of routinization. There is recent
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Evidence, however, which suggests that routinization (at work or in general) is negatively associated with cognitive flexibility (Tournier, Mathey, & Postal, 2012) and positively related to cognitive decline (Bergua, Fabrigoule, Barberger-Gateau, Dartigues, Swendsen, & Bouisson, 2006). Industrial production work may therefore serve as good example of low complexity work with detrimental effects on cognitive functioning. Obviously, prolonged exposure to such disadvantageous working conditions can take great influence on cognitive aging.

With this in mind, and given the fact that modern OHP researchers explicitly aim at creating 'healthy workplaces' (see above, Quick et al., 1997), the lack of interest in cognitive health and cognitive aging as occupational health concerns is not plausible. OHP as a research discipline has taken a very positive development throughout the last centuries: from mere accident prevention at the start to the creation of healthy workplaces at present. Zooming in on the development of cognitive health across the lifespan and the impact of working conditions should become a central research concern of occupational health psychologists in the 21st century.

Aims of the Dissertation

Although the detrimental effects of low mental stimulation at work have been well-established for more than three decades (Kohn & Schooler, 1978), no research has been conducted on how to counteract these effects. With this dissertation, I aim to fill this gap. Adopting a lifespan perspective on occupational health, I intend to identify important mechanisms that facilitate positive plasticity in adult cognitive and brain development in order to apply these mechanisms to the work context and investigate their potential to diminish the negative long-term effects of low mental stimulation at work. Specifically, I will use the next two chapters to elaborate on the current state of research with regard to the
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processes of cognitive aging and the mechanisms of cognitive plasticity. In Chapter 4, I will present a conceptual literature review which aims at systematizing the available evidence on cognitive plasticity in epidemiological and experimental studies that investigated 'in vivo' mental stimulation (i.e., outside the laboratory; in everyday settings). In a subsequent transitional chapter, I will discuss how to apply the main conclusions of my literature review to low complexity occupations such as industrial production work. Afterwards, in chapters 6 and 8, I will present two experimental studies in which I have researched the effect of multiple work-task changes on the cognitive functioning and brain anatomy of long-term industrial production workers. Finally, in chapter 9, I will evaluate and discuss the main results of my dissertation project and provide a final conclusion.
II. A LIFESPAN PERSPECTIVE ON OCCUPATIONAL HEALTH

The Lifespan Psychology of Cognitive Health and Cognitive Aging

I approach both cognitive health and cognitive aging from a lifespan developmental perspective. That is, I conceive cognitive health and cognitive aging as lifelong developmental processes which are shaped by permanent transactions between biological determinants and contextual influences (Baltes, 1987; Baltes et al., 2006). In particular, lifespan psychology understands human development as neither biologically pre-determined nor a random result of contextual stimuli but an active and permanent process of transactions with contextual factors (Baltes, 1987). The individual actively transacts with his or her particular set of given biological and societal influences by reacting to them, acting upon them, and by making decisions (e.g., Greve & Staudinger, 2006). Due to age-graded decreases in biological potential and ongoing historical transformations (Baltes et al., 2006), these developmental contexts are part of permanent changes themselves and development can hence be understood as transactional adaptation to changing circumstances (Staudinger, Marsiske, & Baltes, 1995). Moreover, human development is understood as multi-dimensional and multi-directional in nature. That is, individuals age in different areas of functioning such as cognition, emotion, or motivation. It follows that aging is neither growth nor decline exclusively. It always includes the joint occurrence of growth in some behavioral domains and decline in others (Baltes, 1987).

One basic characteristic of development and aging is plasticity (Baltes, 1987). According to lifespan psychologists, plasticity refers to the notion that individuals may differ in their levels of functioning within one domain across different points in time (Staudinger et al., 1995). Depending on the life (or working) conditions and experiences by a given individual, the life course can take many forms (Baltes, 1987). Within a lifespan framework, contextual influences can be understood as developmental resources. The sum of such
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resources determines the range and limits of a given developmental trajectory (Staudinger et al., 1995). Health trajectories can therefore be conceptualized as the outcome of a complex interaction between internal (e.g., biological constitution, genetic configuration) and external health resources (e.g., the work environment). Contingent on the cumulative interplay of positive/negative health resources, individuals can follow more favorable or unfavorable health trajectories.

Figure 1. Possible trajectories of cognitive functioning across the adult lifespan. (Left panel) The blue dots indicate the average age trend for a given individual under typical circumstances. The upper and lower curves illustrate optimal and suboptimal boundaries that define the zone of possible development. Lifespan psychology assumes that vertical movement within this zone of possible cognitive functioning is influenced by biological, behavioral, and contextual influences. The functional threshold indicates a level of functioning at which goal-direct cognition in the ecology will be impaired. (Right panel) The letters A, B, C, and D represent four developmental curves of possible cognitive functioning as a result of the cumulative interplay between biological and contextual resources. [Cited from Hertzog, Kramer, Wilson, & Lindenberger, 2009, pp. 5 & 8]

Many illnesses develop slowly over time. This is true for well-established work-related chronic diseases (such as cancer or cardiovascular disease; Hämäläinen, Takala, & Saarela, 2007; Sorensen et al., 2011) but also for cognitive decline. Effective occupational health management therefore necessitates a lifespan perspective on the development of health
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and disease over prolonged periods of time. The lifespan perspective allows me to understand accelerated cognitive decline as the result of prolonged exposure to low mental stimulation at work. On the other hand, I believe higher levels of cognitive functioning to be based on prolonged exposure to more favorable levels of mental stimulation (see Figure 1). In order to scrutinize the effect of mentally stimulating work environments and their long-term impact on cognitive decline, however, large-scale longitudinal research designs are needed which carve out cumulative effects across time. At the same time, it is important to observe a given individual in all developmental environments (e.g., work, home, leisure time) to gain a comprehensive picture of the developmental resources and appreciate the effects of their complex interplay. Effective occupational health research thus necessitates a lifespan perspective, that is, comprehensive observational studies which target the individual as a whole and which span several years or even decades in order to investigate positive and negative health resources and their cumulative effect over prolonged time frames.

Cognitive Functioning Across the Lifespan

Adopting such a lifespan perspective, I intend to investigate specific contextual characteristics (at work) that facilitate positive plasticity in brain and cognition across time. Before focusing such changes, however, it seems necessary to take a closer look at the behavioral and neurophysiological changes that have been associated with cognitive aging and examine the research that has been conducted on 'normal' (i.e., average) trajectories of cognitive decline.

On a behavioral level, many cognitive abilities on average increase up to early adulthood and decline thereafter (Denney, 1984). For decades it has been known that older adults perform less well than young and middle-aged adults on a number of cognitive tasks such as the Piagetian classification tasks or various problem-solving tasks (e.g., Denney &
Lennon, 1972). However, this early research also provided evidence that the onset of this retrogression as well as its extent vary greatly depending on the particular ability in question. It was shown that there is very little decline and sometimes even slight increases in verbal abilities throughout most of the adult years. On the other hand, nonverbal tasks that tap rather basic information processing abilities such as processing speed or working memory on average depict a monotonous decline after early adulthood and throughout the lifespan (e.g., see Horn & Cattel, 1967).

P. B. Baltes and colleagues (Baltes, 1987; Baltes et al., 2006) proposed a theoretical framework that integrated these findings for the study of intellectual development. It sets apart two main components of intellectual functioning: the mechanics and the pragmatics of cognition. The mechanics of cognition are usually indicated by abilities such as processing speed, memory, logical reasoning, working memory, and spatial ability and therefore bear resemblance to the concept of fluid intelligence introduced by Horn and Cattell (1967). Mechanic abilities represent the more fundamental processes of the cognitive system. They determine the speed and accuracy of elementary information processing operations (Baltes et al., 2006; also see Craik & Salthouse, 2000) and have earned their name due to a close relationship with the biological and neurophysiological architecture of the mind. That is also why their predominant age-graded ontogenetic pattern is one of maturation first, but then shifts into a monotonic and roughly linear decline during adulthood with some further acceleration of decline in very old age (Baltes et al., 2006).

Pragmatic skills typically include knowledge-based abilities, such as vocabulary, verbal ability, (specific) numerical ability, general knowledge, or professional skills (Staudinger et al., 1995). The cognitive pragmatics resemble the crystallized abilities suggested by Horn and Cattell (1967) and are mainly based on and mediated through cultural influences (Baltes & Baltes, 1990; Baltes et al., 2006). They are acquired throughout the lifespan. In contrast to the mechanics, pragmatic abilities remain stable or increase up to late
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life. They often show little or no age decrements and only start to decrease in very old age (Baltes et al., 2006). Due to this often positive development of pragmatic abilities across the lifespan, the better part of plasticity research has been conducted on mechanic abilities. As will be seen in the empirical part of my dissertation, I will do the same.

One of the most impressive studies that were able to systematically demonstrate this average pattern of adult intellectual development was the so-called ‘Seattle Longitudinal Study’ (Schaie & Willis, 1993; also see Schaie, 2005). Using a cohort-sequential design, it displayed adult age gradients based on multiple indicators for six cognitive abilities. The results were affirmative: verbal ability and numerical ability (i.e., rather pragmatic skills) peaked during middle adulthood and showed little or no age decrements before very old age, whereas processing speed, inductive reasoning, spatial orientation, and memory (i.e., mechanic skills) showed a steady and monotonic decrease with advancing age. Since then, ample research has been conducted to scrutinize trajectories of cognitive aging and ample research has repeatedly confirmed the prototypical findings elucidated above (e.g., Li, Huxhold & Schmiedek, 2004; Salthouse, 1991; 1996).

The Neurophysiology of Cognitive Aging

On a neurophysiological level, aging is associated with fundamental transformations in the structure of the brain. According to estimations, cognitive aging entails an overall volume loss of 14% in gray matter (GM) across the adult lifespan (Jernigan et al., 2001; Kalpouzos, Persson, & Nyberg, 2012).1 Other studies report estimates between 0.2% and 0.5% volume loss per year (Salthouse, 2011). GM loss has mainly been linked to a combination of cell body shrinkage, dendritic regression, and reduced synapse density.

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1 For the purpose of this dissertation, I will focus on gray matter volume exclusively. There is evidence that white matter volume increases throughout adulthood up to 50 years of age and shows decline only thereafter (Greenwood, 2007). This is different with regard to GM volume (see text). As will be seen in Study 2 and 3, the average age of participants in the behavioral and neurophysiological experiments is below 50. That is why white matter volume may be less relevant in the context of this dissertation.
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(Grady, 2012; Greenwood, 2007). Negative age relations with brain volume have been reported in a large number of both cross-sectional and longitudinal studies (Salthouse, 2011). However, the degree of decline varies by region. Although there is considerable variability among the existing studies, there is a general trend which indicates that frontal and parietal areas are more strongly affected by age than, for instance, the occipital lobe (Hedden & Gabrieli, 2004; Salthouse, 2011). Some studies also suggest that the striatum (especially the caudate) is particularly prone to age-related regression (Raz et al., 2005; Walhovd et al., 2011). There is evidence that GM volume begins to decline already early in life, after ages 11-12 in frontal areas and after age 16 in temporal regions. Whereas this early loss of GM volume has been attributed to neurophysiological remodeling processes in adolescence (such as synapse pruning), GM volume loss after young adulthood seems to reflect processes of age-related neural degeneration (Greenwood, 2007). The visual cortex seems to be an important exception to this more or less linear trend (Raz et al., 2005). Mixed results exist for hippocampal volume. Some studies reported significant volume loss with age (Persson et al., 2006; Raz et al., 2005), whereas others found no shrinkage in hippocampus volume at all, or only after age 50 (Greenwood, 2007; Walhovd et al., 2005).

Many studies indicate that regional GM volume could be positively related to cognitive performance. And although it must be stated that the available literature is far from conclusive (Raz & Rodrigue, 2006; Salthouse, 2011), there is ample evidence in favor of such a positive link. For instance, higher levels of executive functioning have been associated with larger GM volume in the prefrontal cortex (Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998), hippocampal shrinkage seems to mediate age differences in episodic memory (Head, Rodrigue, Kennedy, & Raz, 2008), and speed of processing was positively correlated with GM volume in several frontal, parietal, and occipital regions (Chee et al., 2009). With regard to general cognitive functioning, two comprehensive meta-analyses reported correlations of .33 (McDaniel, 2005) and .40 (Rushton & Ankney, 2009) with overall brain size (for a recent
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overview on the relationship between brain volume and cognitive performance, see Salthouse, 2011).

Apart from volume loss, increasing age is associated with a number of changes in the functioning of the brain (such as age- and task-specific neural activation patterns). There is reason to assume that these changes in brain functioning are contingent on the age-related volume loss elucidated above. That is, changes on the functional level could (at least partly) be a consequence of the structural brain changes that come with age (but see Salthouse, 2011). Despite the fact that I will focus on anatomical brain changes throughout the remainder of this dissertation, the most important functional changes shall be introduced briefly.

One of the most consistent findings is that young and older adults show considerable deviations in the amount, laterality, and specificity of activation. Older participants often resort to unspecific, bilateral, mostly prefrontal activity to solve tasks that typically yield rather focal and lateralized activity in younger subjects (e.g., Cabeza et al., 1997; Carp, Gmeindl, & Reuter-Lorenz, 2010; Dennis & Cabeza, 2011; Reuter-Lorenz et al., 2000). These age-specific phenomena have been described as compensation and dedifferentiation. Older adults tend to activate diffuse brain areas, particularly the frontal lobes, above the level seen in young adults. Many researchers have assumed this over-recruitment of resources to compensate for the age-related decline in brain volume in order to maintain former levels of cognitive performance (Gutchess et al., 2005; also see Park & Reuter-Lorenz, 2009). However, some authors suggest that an increase in brain activity among older adults can also be associated with poorer, not better cognitive performance (e.g., Stevens, Hasher, Chiew, & Grady, 2008).

Similarly, functional connectivity changes with age. Typically, the temporal correlation between activity patterns of functionally related brain regions is used as an indicator of functional connectivity (Biswal, 2012). For instance, older adults demonstrate reduced connectivity within some (e.g., hippocampal-parietotemporal) networks relative to
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young adults, but increased connectivity within other (e.g., parahippocampal-frontal) networks (for an overview, see Grady, 2012). Resting state functional connectivity, that is, the connectivity of networks that are mainly active during periods of rest, has received particular attention. The Default Mode Network (DMN) maintains a strong interconnection of parietal and prefrontal regions (e.g., Fox et al, 2005). In young adults, these areas typically demonstrate great synchronous resting state activation which is immediately closed down when an individual starts to engage in cognitive tasks (Persson, Lustig, Nelson, & Reuter-Lorenz, 2007). In older adults, however, deactivation of the DMN as well as its functional connectivity is less distinct (Hafkemeijer, van der Grond, & Rombouts, 2012), what seems to be related to lower levels of cognitive performance (e.g., Damoiseaux et al., 2008; Prakash, Heo, Voss, Patterson, & Kramer, 2012; Sambataro et al., 2010).
Notwithstanding the changes in cognitive functioning and brain anatomy that come with age, research has also indicated that brain and cognition stay malleable and open to enhancement throughout the lifespan. Individuals can outgo average trajectories of cognitive aging and increase (or decrease) their level of cognitive performance and spark positive neurophysiological short- and long-term changes in specified brain regions.

Such plasticity is contingent on an individual’s reserve capacity which in turn is constituted by internal (e.g., biological potential, health) and external (e.g., family, friends, work environment) resources (Staudinger et al., 1995). The sum of resources available to an individual determines the shape and limits of a given developmental trajectory. Lifespan researchers further distinguish between baseline reserve capacity and developmental reserve capacity. Baseline reserve capacity “denotes an individual’s current maximum performance potential, that is, the most an individual can do with current internal and external resources.” (Staudinger et al., 1995, p. 808). In contrast, developmental reserve capacity refers to an individual’s prospective change potential, because “resources, however, can be activated or increased, for instance, through optimizing interventions or new age-related changes of the positive or negative kind.” (Staudinger et al., 1995, p. 808). In terms of cognitive performance, baseline reserve capacity therefore describes the highest level of functioning that is possible under all currently available conditions whereas developmental reserve capacity points out how a given individual could perform if the available resources were changed (e.g., by optimizing working conditions). That is, in order to activate plasticity and capitalize on the full developmental potential, the availability as well as the interplay of beneficial resources has to be increased and optimized.

The term cognitive plasticity describes the modifiability of cognitive performance levels throughout the lifespan (as opposed to average trajectories of cognitive aging). Within
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the neurophysiological literature, the term plasticity is often referred to as the functional or structural changes that occur in the central nervous system as a consequence of perturbations such as brain injuries (Draganski & May, 2008) or as a consequence of mental stimulation in healthy brains (e.g., Holtmaat & Svoboda, 2009). Manifestations of neural plasticity have been observed on the synapse level (hebbian or synaptic plasticity), the cellular level (cellular plasticity) as well as on the level of cortical representations (representational plasticity; Buonomano & Merzenich, 1998; Mercado, 2008). Typical examples include enhanced postsynaptic potentials, shifts in cortical representation, or gray and white matter volume gains (also see Thomas & Baker, 2013). Throughout the remainder of this dissertation, I will use the term cognitive plasticity in reference to the modifiability of (behavioral) cognitive performance levels and employ the term neural plasticity with regard to the modifiability of the central nervous system, be it in terms of structural or functional plasticity. Obviously, there is reason to assume that these two concepts are causally interrelated (see Mercado, 2008). However, the distinction between cognitive and neural plasticity may help to maintain conceptual accuracy. Regardless of that, it is apparent that both forms of plasticity have in common the modifiability of their domains, that is, the cognitive or the neural system. Therefore, on a more abstract level of discussion, I will use the more general term plasticity to allude to the modifiability of developmental trajectories across different domains of functioning in the process of aging, independent of the specific area of observation.

Recent Theories of Plasticity

Lövdén and colleagues (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010) provided an influential framework for the study of plasticity. The core assumption holds that manifestations of plasticity occur only to the extent that an individual encounters a “mismatch between supply in the form of the functional capacity of the system and the
environmental demands” (Lövdén et al., 2010, p. 662). That is, if the cognitive system can effortlessly respond to a specific demand, no mismatch arises and no cognitive changes are induced. On the other hand, if environmental demands exceed the current range of cognitive capacity, a mismatch (and thus cognitive change) is absent as well. Cognitive plasticity needs an optimal gap between the current capacity of a given cognitive system and the environmental demands to unfold. Interestingly, this assumption takes a basic principle of cognitive development in childhood as described by Piaget (1971) and applies it to adulthood and old age.

It is important to note, however, that the authors differentiate between flexibility and plasticity. Flexibility hence describes the capacity of an individual to process environmental stimuli by activating already existing neural representations (that have developed on the basis of experiences already made). It refers to the range of potential performance within the limits of the current state of functional supply and is therefore similar to the concept of baseline reserve capacity elucidated above (Staudinger et al., 1995). Plasticity, in contrast, is defined as the capacity for changes in flexibility. It displays the potential for changes in the range of cognitive performance (i.e., the developmental reserve capacity; Baltes, 1987). A more flexible individual can handle a larger range of environmental stimuli (Lövdén et al., 2010). That is, the degree and likelihood of positive changes in cognitive performance depends on the range of flexibility. The bigger the range of flexibility, the less likely (or the less severe) is a mismatch between functional supply and environmental demands and the less likely are manifestations of plasticity. In addition to that, the authors attach two more assumptions to their theory. First, in order to activate plasticity, a given supply-demand mismatch must reach a certain (yet unknown) duration. Since the underlying neural mechanisms take a while to induce synaptic alterations, a particular mismatch needs to be prolonged. Second, plasticity itself has a possible range that is subject to inter-individual differences. Every individual has a unique potential for plasticity that is not only constrained by primary contextual influences
but also by genetic factors, such as the level of nerve growth factors and energy supply (Lövdén et al., 2010).

On a neurophysiological level, cognitive challenge and supply-demand mismatches may induce scaffolding processes. According to the Scaffolding Theory of Aging and Cognition (STAC; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014), the aging brain buffers the consequences of neurophysiological decline with neural scaffolding, that is, with the recruitment of additional neuronal "circuits that provide supplementary, complementary, and, in some cases, alternative ways to achieve a particular behavioral output or cognitive goal" (Park & Reuter-Lorenz, 2009, p. 185). The concept of scaffolding has originally been put forward to illustrate neuronal mechanisms in response to skill acquisition (Petersen, van Mier, Fiez, & Raichle, 1998). It was observed that, during the learning of new tasks, the brain areas used to perform these tasks changed over time, suggesting that learning processes in general may be accompanied by scaffolding mechanisms which are used to cope with novel task demands. Reuter-Lorenz and Park (2014) adopted the scaffolding concept and employed it to explain inter-individual differences in the maintenance and efficiency of brain structure and function despite the average trend of age-related neurophysiological and cognitive decline. However, the authors hypothesize that scaffolding may not only help to describe neuronal changes during learning processes and biological aging. Rather, scaffolding is suggested to serve as the brain's standard response to any kind of cognitive challenge, be it stress, vascular diseases, and neural resource depletion but also cognitive training, intellectual engagement, and physical exercise (Reuter-Lorenz & Park, 2014). In other words, scaffolding may be the manifestation as well as the instrument of neural plasticity.²

² With its assumptions, STAC bears resemblance to the concept of cognitive reserve (Stern, 2002; 2012). Cognitive reserve is defined as "the ability to optimize or maximize performance through differential recruitment of brain networks" (Stern, 2002, p. 451). However, since the concept is mainly being used in clinical settings to explain how the brain compensates for damage and neural regression it may be of less importance to the aims of the current dissertation (despite its popularity in epidemiology and medical science).
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Facilitators of Cognitive Plasticity

Both theories agree on the assumption that plasticity (Lövdén et al., 2010) and more efficient scaffolding (Reuter-Lorenz & Park, 2014) will manifest themselves through substantial and sustained demands on the cognitive system. Positive plasticity seems to require tasks or contextual influences that repeatedly challenge core cognitive processes like processing speed, working memory, episodic memory, or reasoning (also see Park & Bischoff, 2013) and which necessitate interactions between the cognitive and neural components of the intellectual system (Greenwood & Parasuraman, 2010). It is not yet clear, however, which specific characteristics of a task or an environment provide such challenges. Ample research investigated a kaleidoscope of behaviors that may serve to facilitate plasticity. Many of these studies produced intriguing results. The two frameworks elucidated above suggest physical exercise, cognitive training, and intellectual engagement in order to induce changes in cognitive functioning. Other theorists also claimed novelty and new learning as essential characteristics for plasticity to manifest (Park & Bischoff, 2013; Bowen, Noack, & Staudinger, 2011). In summary, however, the empirical evidence is inconsistent. Recent discussions of the existing literature have come to contradictory conclusions (Bielak, 2010; Hertzog et al., 2009; Salthouse, 2006). The mechanisms underlying cognitive plasticity are not well understood (Greenwood & Parasuraman, 2010; Salthouse, 2013). What is needed is thus a systematic review which takes a closer look at the available evidence, tries to resolve the existing inconsistency of findings, and identifies the specific task or environmental characteristics that are critical to cognitive plasticity.
IV. STUDY 1

Mental Stimulation and Cognitive Aging in Real-Life –
A Systematic Review of 'in Vivo' Evidence

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Abstract

Ample research has investigated the mental stimulation hypothesis, that is, the idea that cognitive aging processes can be attenuated by engagement in everyday (i.e., 'real-life') activities, at work or in leisure time. However, despite its appeal, the mental stimulation hypothesis is still under debate. The available evidence is inconsistent. The present conceptual review analyzes the existing literature on mental stimulation in everyday settings systematically in order to scrutinize possible reasons for the inconsistency of findings. Results suggest the somewhat unsystematic use of composite activity scores as one reason for the inconsistencies. Composite scores combine varying sets of behavior and rely on a priori assumptions of mental stimulation. These assumptions, however, are not tested. The review further indicates that only activities demonstrating certain characteristics are mentally stimulating. Novel information processing (but not active versus passive behavior) and high job complexity were repeatedly associated with changes in cognitive functioning. Promising evidence has also been found for creative problem-solving. Different domains of cognitive functioning such as memory, processing speed, and working memory do not seem to respond differently to everyday mental stimulation. Consequences and avenues for future research are discussed.

Keywords: mental stimulation, mental exercise, use it or lose it, activity engagement, job complexity, mental work demands, cognitive aging, cognitive performance, cognitive functioning
Many cognitive abilities such as memory, executive functioning, inductive reasoning, and processing speed decline across the lifespan. On average, these mechanic or fluid abilities demonstrate a monotonic and roughly linear decline after they peaked in early adulthood. Only pragmatic or crystallized abilities such as verbal and numerical knowledge tend to remain stable (or increase) up to late life. There is ample empirical evidence to support this pattern of trajectories (Baltes, Lindenberger, & Staudinger, 2006; Salthouse, 2006; Schaie, 1994; Schaie & Willis, 1993). However, research has also indicated that cognition stays malleable and open to enhancement throughout the lifespan. Individuals can outgo average trajectories of cognitive aging and increase (or decrease) their level of cognitive performance. Different paradigms have been used to study the plasticity of cognitive aging. Here we divide the available literature into 'in vitro' and 'in vivo' approaches. In particular, we aim to systematize the existing evidence on the latter class of research. We use the term mental stimulation to refer to complex and naturally occurring everyday behavior that is presumed to primarily (though not exclusively) affect the adult mental system. Much research has been conducted to scrutinize the mental stimulation hypothesis, that is, the idea that cognitive performance can benefit from an active lifestyle.

**Inconsistency of findings on the mental stimulation hypothesis.** The mental stimulation hypothesis which has also been referred to as the ‘use it – or lose it’ hypothesis (Hultsch, Hertzog, Small, & Dixon, 1999, Salthouse, 1991; also see Denney, 1984) assumes that one can stimulate his or her mental system and slow down the pace of cognitive loss in adulthood by engagement in certain types of everyday (i.e., 'real-life' as compared to artificial laboratory) behaviors. In contrast, non-engagement is assumed to result in a faster and more pronounced decline. However, despite its appeal, the mental stimulation hypothesis is still under debate. The existing evidence is inconsistent and researchers have raised doubt about its validity (e.g., Salthouse, 2006; 2007). We argue that the unsystematic use of composite scores can be part of the problem. Many researchers combine varying sets of behavior although the
mechanisms that underlie mental stimulation are not understood and important questions have not yet been answered (Bielak, 2010). With this article, we address some of these questions and aim to resolve the inconsistency of results.

Within the last decades, research on the mental stimulation hypothesis has revealed promising effects. Older individuals who expose themselves to cognitively stimulating leisure time activities or work environments over a prolonged period of time demonstrate higher levels of cognitive functioning and lower levels of cognitive decline. There is correlational (Arbuckle, Gold, & Andres, 1986; Kohn & Schooler, 1973; Wilson, Barnes, & Bennett, 2003), longitudinal (Bosma et al., 2002; Hultsch et al., 1999; Schooler, Mulatu, & Oates, 2004), and lately even experimental work (Park et al., 2014; Stine-Morrow, Parisi, Morrow, & Park, 2008) to support this notion.

Notwithstanding such encouraging effects, the mental stimulation hypothesis has been subject to debate. The available results are inconsistent and their interpretation is controversial. For instance, Salthouse (2006; 2007) argued that there is no causal evidence that performance levels could be preserved differentially throughout adulthood as a function of mental stimulation. According to his view, the available work merely suggests preserved differentiation, that is, that individual baseline differences in cognitive performance are mainly preserved across adulthood, independent of the level of mental stimulation. And indeed, there are studies that corroborate this hypothesis. Typically, these studies find baseline correlations between mental stimulation and cognitive functioning but fail to establish change relationships between these two variables (e.g., Bielak, Anstey, Christensen, & Windsor, 2012; Gow, Mortensen, & Avlund, 2012; Salthouse, 2013).

**Inconsistency in the approaches to study mental stimulation.** Failure to establish change relationships may occur for several reasons. First, there is evidence to suggest that the relationship between mental stimulation and cognitive functioning is reciprocal. For instance, longitudinal work by Schooler, Mulatu, and Oates (1999; 2004) on the effects of job
complexity indicated that individuals with high baseline cognitive functioning were more likely to be selected into complex job environments. However, they also found that exposure to these environments entailed better cognitive functioning over 30 years. Second, there is huge disparity between many studies with regard to (a) which cognitive domains are assessed and how, (b) what kind of behavior is analyzed, and (c) how these activities are categorized (Bielak, 2010; Hertzog, Kramer, Wilson, & Lindenberger, 2009). Researchers have investigated a kaleidoscope of behaviors and often subsumed them all under one umbrella of mental stimulation. Composite measures of cognitively stimulating leisure time behavior typically include reading and writing (Wilson, Barnes, Krueger, Hoganson, Bienias, & Bennett, 2005), playing board or card games (Iwasa, Yoshida, Kai, Suzuki, Kim, & Yoshida, 2012), and using the computer (Small, Dixon, McArdle, & Grimm, 2012) but also comprise behaviors like attending a religious service (Bielak et al., 2012), watching TV (Mackinnon, Christensen, Hofer, Korten, & Jorm, 2003), or even naps (Christensen, Korten, Jorm, Henderson, Scott, & Mackinnon, 1996). Similarly, research on the effects of the work environment has often restricted itself to composite measures of mental stimulation (e.g., Bosma, van Boxtel, Ponds, Houx, Burdorf, & Jolles, 2003; Gow, Avlund, & Mortensen, 2014; Schooler et al., 2004). Furthermore, very few studies have directed their attention to more specific kinds of complexity at work such as complexity with data, people, and things (e.g., Finkel, Andel, Gatz, & Pedersen, 2009). Obviously, there is great heterogeneity in the level of mental stimulation that is linked with these activities. This is a well-known problem of real-life/"in vivo" research. Due to a lack of experimental control, researchers cannot manipulate levels and types of mental stimulation. Many researchers have a priori assumptions of which activities are mentally stimulating and which are not. On the basis of these assumptions, they look for and assess a certain selection of behaviors, mostly without having tested their assumptions about underlying mechanisms first. We believe that the
somewhat unsystematic use of composite scores may be one reason for the inconsistency of results extant in the literature. It is one aim of this review to support that assumption.

**Specific effects of specific activity?** A third reason for failing to establish change relationships may be that only specific characteristics of mental activity provide mental stimulation. Early researchers have often differentiated between active and passive behavior and mostly come to the conclusion that active rather than passive behavior fosters better cognitive functioning (e.g., Christensen et al., 1996; Christensen & Mackinnon, 1993; Hultsch, Hammer, & Small, 1993). However, researchers appear to have moved beyond questioning the frequency of participation. Lately, greater emphasis has been placed on novelty/variety and cognitive challenge (e.g., Bielak, Hughes, Small, & Dixon, 2007; Bowen, Noack, & Staudinger, 2011; Hultsch et al., 1999; Park et al., 2014). For instance, Carlson et al. (2012) observed over a 10-year period that greater variety of participation in activities (regardless of cognitive challenge) was associated with a ~10% lower risk of verbal memory impairment and global cognitive outcomes. The protective effect of novelty in older adults has been conceptualized as a counter weight to non-adaptive routinization (Tournier, Mathey, & Postal, 2012). Other recent findings suggest that activity demands, or how challenging the activity is, could be most relevant to cognitive enhancement. In an experimental study, Park et al. (2013) found that sustained effort to acquire a demanding new skill improved episodic memory.

**Aims of the review.** Many studies merely reported composite scores (e.g., active and passive kinds of activities added up) which make it impossible to investigate the mechanisms of mental stimulation. A deeper look into more specific characteristics of mentally stimulating behavior is needed. Therefore, we have reviewed studies which only reported composite scores of mental stimulation separately from studies that investigated specific types of activities such as activities requiring novel information processing or active versus passive behavior. Our hope is that this approach can help to corroborate extant hypotheses about
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mediating mechanisms and perhaps even provide some new perspectives on potential mediators.

Another question that is yet unanswered refers to the specificity of effects. Specific characteristics of behavior may have effects on specific domains of cognitive functioning (Bielak, 2010). Researchers have investigated the effect of mental stimulation on a number of cognitive domains such as memory, reasoning, or processing speed. More often than not these studies found that mental stimulation was related to some domains but not to others (e.g., Mackinnon et al., 2003; Stine-Morrow, Parisi, Morrow, & Park, 2008; Wilson et al., 2005). It is possible that not all domains are fostered by mental stimulation to the same degree. Specific domains may respond to specific behavior (or characteristics). Therefore, we will organize the existing literature also according to cognitive domain in order to be able to identify potential domain-specificities in the effect of mental stimulation.


We understand cognitive aging from a lifespan perspective. That is, we conceive aging as a developmental process which is shaped by permanent transactions between biological determinants and contextual influences (Baltes, 1987; Baltes et al., 2006). Plasticity is one basic characteristic of this development. It describes the modifiability of cognitive performance levels in the process of cognitive aging (also see Staudinger, Marsiske, & Baltes, 1995). Plasticity, however, is contingent on the sum of internal and external resources available. One such external resource can be mental stimulation.

We use the term mental stimulation in order to point out that we are interested in the 'in vivo' effects of everyday behavior (i.e., in leisure time or at work). Other researchers investigated related (but different) concepts. For instance, Salthouse (2006) reviewed the effects of mental exercise on cognitive aging. The term exercise, however, implies mental training. We will
not discuss this strand of research, despite the tremendous contribution mental training studies have made 'in vitro' to the cognitive aging literature. Impressively large intervention studies such as the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE; Ball et al., 2002) as well as the Berlin COGITO study (Shing, Schmiedek, Lövdén, & Lindenberger, 2012) have produced distinct results which indicate that practicing cognitive tasks yields substantial and persisting training gains. And although transfer to untrained tasks was problematic for some time, recent work starts to accumulate support for such effects, for example, after multi-tasking interventions (Anguera et al., 2013) and working memory training (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). However, the scope of this review is different.

Hertzog and colleagues (Hertzog et al., 2009) used the term cognitive enrichment to scrutinize the wide range of enriching influences on cognitive functioning. The focus of the present review, however, is different. With regard to the great variety of everyday activities that have been studied in association with cognitive functioning, three distinct constructs have been differentiated over the years: physical (e.g., walking or running), social (e.g., visiting others or voluntary work), and mental activity (e.g., learning a language or playing chess; see Bosma et al., 2002; Wang et al., 2013). We use the term mental stimulation to underline our specific interest in the latter class of genuinely mental activities.³

**Leisure time and work activity.** Mental stimulation in the work context has been assessed quite differently. Schooler and colleagues (1999) established the complexity of an occupation as an indicator of mental stimulation. According to their definition, job complexity requires thought and independent judgment, that is, many decisions that involve ill-defined or contradictory contingencies (also see Schooler et al., 2004). However, note that high

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³ We note that this tripartite classification of activity into mental, physical, and social is often somewhat artificial. Many activities cannot be assigned unambiguously. Playing chess, for instance, may have a mental and a social component. Likewise, gardening may imply cognitive as well as physical stimulation. However, we will discuss physical and social activity only as far as they have been included in composite scores of mental stimulation. Apart from that, they will not be considered in this review.
complexity is almost exclusively accessible for highly educated individuals (which in turn are associated with higher levels of cognitive functioning). Other studies have assessed mental stimulation at work via the opportunity to learn new things and participate in trainings (Marquie, Duarte, Bessières, Dalm, Gentil, & Ruidavets, 2010), via strong requirements on concentration, precision, and time pressure (Bosma et al., 2003), or via variation and intellectual demands versus routine (Gow et al., 2014). One strand of research has investigated the effects of specific occupational groups such as academics versus blue-collar workers (Christensen, Henderson, Griffiths, & Levings, 1997) or teachers versus non-teachers (Van der Elst, van Boxtel, & Jolles, 2012). Since the investigation of mental stimulation in leisure time and of mental stimulation at work is embedded in rather different research traditions, we will discuss them separately. In addition to that, it is important to note that we have excluded studies that merely described age differences within one occupational group without including a control group or another standard of comparison (e.g., architects; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990).

**Differentiating between outcomes of mental stimulation.** Concerning the *outcome of mental stimulation*, past research has investigated a great variety of cognitive tasks. We sorted the available evidence into six domains: memory (we included tests of immediate and delayed word list recall, paired associates, and story recall), processing speed (including symbol digit substitution, visual search, cross-out tasks, and Trail-Making-Test-A), inductive reasoning (e.g., letter, number, and figure series, analogies tests), spatial abilities (e.g., paper folding, hidden figures, and block arrangements), working memory (e.g., forward and backward digit span), and executive functioning (inhibition tasks such as the Stroop, Flanker, and Simon test). Additionally, we reviewed the literature that employed general factors of
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fluid functioning (aggregated scores of fluid ability). We structured our literature analysis according to these seven domains.  

**Distinguishing different paradigms of 'in vivo' research.** The study of mental stimulation 'in vivo' has followed a number of different pathways (see the decision tree in Figure 2). Observational studies, that is, the documentation of everyday activity patterns, can be cross-sectional or longitudinal. *Cross-sectional studies* of this kind typically assess the frequency of participation in mentally stimulating activities or complexity of work in retrospect (over the last 2 years, for instance) and correlate the level of engagement with measures of cognitive functioning (e.g., Arbuckle et al., 1986; Wilson et al., 2005). In contrast, *longitudinal-observational studies* assess mental stimulation and cognitive performance repeatedly, for instance, over five to six or more years and relate changes in stimulation to subsequent changes in cognition and vice versa (e.g., Bielak et al., 2007; Newson & Kemps, 2005). Both kinds of studies come with a number of methodological weaknesses. The lack of randomization in observational work bears the risk of pre-selection biases and endangers the representativeness of the study samples (Campbell, 1957; Holland, 1986). Cross-sectional studies are particularly prone to selection biases due to their one-shot research designs (without baseline assessment). Longitudinal work may be able to ‘control’ for baseline selectivity as long as change effects are considered but often struggle with selectivity through sample attrition, especially in comprehensive study projects that span several decades. This is why 'in vivo' research has detriments in terms of conclusiveness and internal validity (Salthouse, 2006). Real-life behavior depends on manifold individual and environmental factors. Disentangling these factors is not always possible. Potentially

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4 We will not report data on crystallized intelligence. Similarly, we will not discuss specific indicators of crystallized cognition (e.g., vocabulary). We understand these knowledge-based abilities as higher level outcomes of more fundamental components of intelligence such as memory, working memory, and processing speed and restrict ourselves to the latter class of fluid functions. We will also not discuss odds ratios for age-related cognitive dysfunctions (e.g., mild cognitive impairment, Alzheimer's disease, and dementia). The review focuses on healthy cognitive aging and as such excludes research on cognitive disease.
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confounding processes may be at work which cannot be explained or controlled in observational studies. Therefore, researchers have called for experimental studies of mental stimulation with random samples and rigorous control of the treatment conditions (Salthouse, 2006; Stine-Morrow et al., 2008). A relatively young generation of randomized controlled trials (RCT) has started to satisfy this request. These studies diligently 'engineered' mentally stimulating behaviors and reported short-term effects of, for instance, learning and practicing photography and quilting (Park et al., 2014) or working with a computer (Chan, Haber, Drew, & Park, 2014; also see Klusmann et al., 2010). For instance, Stine-Morrow et al. (2008) found that the number of sessions attended by the experimental group was predictive of an increase in a fluid composite score. The intervention included working in groups to solve long-term problems that required design, implementation, and effective presentation. In a similar vein, Tranter and Koutstaal (2007) observed changes in fluid ability (Cattell’s Culture Fair test) after 10-12 weeks of training in which participants were asked to increase their participation in cognitive leisure activities (e.g., creative drawing or word-logic puzzles).

It must be noted, however, that behavioral engineering may be of limited value in everyday settings. In many cases experimental manipulations of mental stimulation are difficult to realize. This may not be so much the case when specific behaviors such as quilting or professional photography are in focus. But when combinations of activities such as the complexity of a job are in question, researchers cannot simply instruct stimulation (or non-stimulation), especially in large-scale intervention studies with prolonged treatment phases. That is also why experimental studies can only investigate short-term effects. Long-term studies with treatment phases over several years or decades are simply not feasible.

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5 The level of experimenter interference varies greatly in the experimental literature. Some studies (e.g., Chan et al., 2014; Park et al., 2014) have guided participant behavior rather rigorously, for instance, through weekly instruction sessions and course assignments. Other studies have restricted themselves to create mentally stimulating environments without any kind of experimental interference (e.g., Carlson et al., 2008).
Conclusions about the role of mental stimulation in cognitive aging, for instance, cannot be drawn from experimental work.

How will we evaluate study quality given the reported limitations of experimental and observational models? Both experimental and observational research designs have their pros and cons. There is less experimental interference in observational work and the transfer of results to everyday life is much easier. Experiments, on the other hand, are less likely to fall prey to pre-selection biases. In order to accommodate these differences, we will discuss observational studies (that tapped behavior 'in vivo') and experimental studies (that engineered behavior 'in vitro') separately (see Figure 2).
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Based on these assumptions, we approached the literature on mental stimulation. In total, we scanned 120 studies. Of these, 54 studies were excluded because they either (1) used dependent variables other than one of the seven cognitive domains elucidated above (but were interested in, for instance, cognitive dysfunction or constructs like 'visual imagery'; e.g., Newson & Kemps, 2006; 44 studies), (2) due to their primary interest in social instead of mental stimulation (six studies), or (3) because they researched age differences within specific occupational groups without reference to any standard of comparison (four studies).

Eventually, we identified 66 articles that investigated the effect of (real-life) mental stimulation on cognitive functioning. First, we sorted these 66 studies according to the cognitive domain they targeted, that is, either memory, processing speed, working memory, executive functioning, reasoning, spatial abilities, or general fluid functioning. Since a number of studies measured more than one cognitive domain, such studies appear multiple times in the tables that we compiled. Next, we separated composite score studies from studies that researched more specific behavior in order to scrutinize specific effects of specific behavior. In a final step, we differentiated between correlational, longitudinal, and experimental work. Of the 66 articles, 50 studies dealt with leisure time mental stimulation. Sixteen studies investigated work-related effects. Leisure-time activities are presented and discussed first.

Review I – Leisure Time Mental Stimulation and Cognitive Functioning

Of the 50 studies that reported evidence on the relationship between mentally stimulating leisure time behavior and either fluid intelligence or episodic memory, processing
speed, working memory, executive functioning, inductive reasoning, and spatial abilities, 34 studies built composite scores of mental stimulation and 17 researched more specific characteristics (one study did both; Mitchell et al., 2012). We listed all 50 studies and their results, separated for cognitive domain and composite score versus specific mental stimulation in Tables 1 – 7. Additionally, we differentiated between cross-sectional, longitudinal, and experimental evidence. A first inspection of all tables revealed that most work has been done on memory and processing speed. The other five domains are under-represented in the existing literature.

Critical examination of the findings as ordered in Table 1 - 7 suggested the following major conclusions which will be discussed in turn: (1) composite scores of mental activity yield inconsistent results. There are great differences within the literature with regard to which activities are used to build composite scores which in turn leads to contradictory findings. (2) Perhaps surprisingly, there is no systematic difference in the effect on cognitive functioning between studies that use either more active or more passive composite scores studies. (3) It is the active learning and the processing of novel information that is likely to be most beneficial (in particular for episodic memory, processing speed, and working memory). The link between receptive engagement/passive information processing and cognitive functioning appears to be less distinct. (4) There is only modest domain-specificity in the effects of mental stimulation. Distinct domains of cognitive functioning appear not to benefit differentially from distinct activities. There is not enough research to draw conclusions about executive functioning, inductive reasoning, and spatial abilities. (5) There may be pre-selection effects in cross-sectional studies. Longitudinal work, however, is more conservative in that regard and reveals fewer but consistent positive effects of active learning and novel information processing.
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Composite Scores of Mental Stimulation Provide Inconsistent Results

Across all seven cognitive domains, the evidence for and against the relationship between composite score mental stimulation and cognitive functioning is contradictory. For instance, only five of 11 longitudinal studies reported positive relationships between mental stimulation and changes in memory performance (see Table 2). The other six found no association with changes in memory over 14 years (Yu, Ryan, Schaie, Willis, & Kolanowski, 2009), nor over eight (Bielak et al., 2012), six (Salthouse, 2013), three (Bosma et al., 2002), or 2.4 years (Wang et al., 2013). One study found a positive longitudinal relationship only in one of two samples (Arbuckle, Gold, Chaikelson, & Lapidus, 1994). The only experimental study in Table 2 also reported mixed results (Carlson et al., 2008). The Experience Corps project introduced adults above 60 years of age to help elementary school children with reading achievement, library support, and classroom behavior during the academic year. After eight months, it revealed trends ($p < .1$) for the effect of mental stimulation on delayed recall in a complex figure test but it found no effect for word list memory.

A similar pattern of contradictory results can be found for working memory (see Table 4), executive functioning (Table 5), inductive reasoning (Table 6), and spatial abilities (Table 7). Only with regard to processing speed and general fluid functioning, the results convey a more consistent picture. Three cross-sectional (Jonaitis, La Rue, Mueller, Koscik, Hermann, & Sager, 2013; Wilson et al., 2003; 2005) as well as four longitudinal studies (Bielak et al., 2012; Mackinnon et al., 2003; Newson & Kemps, 2005; Salthouse, 2013) report baseline correlations between composite mental stimulation and speed of processing. This finding, however, does not hold up when longitudinal data is considered.
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**Table 1.** Overview of studies that investigated the relationship between *mental stimulation* and *fluid intelligence*, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive Association/Performance Increase</strong></td>
<td><strong>Fluid Intelligence</strong> (Correlational Evidence)</td>
<td>Gribbin et al., 1980 (engagement)</td>
</tr>
<tr>
<td>Salthouse, 2013</td>
<td>Salthouse, 2013</td>
<td>Gribbin et al., 1980 (homemaker role, family dissolution, maintenance of acculturation)</td>
</tr>
<tr>
<td>Arbuckle et al., 1994</td>
<td></td>
<td>Jopp &amp; Hertzog, 2007 (crafts, games, tech use, developmental, experiential)</td>
</tr>
<tr>
<td>Christensen et al., 1996</td>
<td></td>
<td>Jopp &amp; Hertzog, 2010 (TV, experiential, religious)</td>
</tr>
<tr>
<td>Christensen &amp; Mackinnon, 1993</td>
<td></td>
<td>Wilson et al., 1999 (Reading, Radio, TV)</td>
</tr>
<tr>
<td>Gilhooly et al., 2007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schinka et al., 2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arbuckle et al., 1994 (male sample)</td>
<td>Arbuckle et al., 1994 (mixed sample)</td>
<td>Aartsen et al., 2002 (experiential, developmental)</td>
</tr>
<tr>
<td>Schooler et al., 2001</td>
<td>Gow et al., 2012</td>
<td></td>
</tr>
<tr>
<td>Wang et al., 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stine-Morrow et al., 2008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Gray highlights indicate composite scores that rely on active behavior.
IV. MENTAL STIMULATION AND COGNITIVE AGING IN REAL-LIFE

Assessing cognitive stimulation via activities such as chess and puzzles (Bosma et al., 2002), household maintenance, domestic chores, social activities, and service to others (Newson & Kemps, 2005), as well as using computer and playing bridge (Small et al., 2012), three of the six longitudinal studies reported positive associations with changes in processing speed over three, six, and 12 years. The other three studies could not support these findings (Bielak et al., 2012; Mackinnon et al., 2003; Salthouse, 2013). Similarly, seven of eight correlational studies report positive associations between composite mental stimulation and general fluid functioning. However, a look at the longitudinal work again reveals a more inconsistent picture (see Table 1).

There may be several reasons for this inconsistency. However, we believe the main problem is the often somewhat random selection of behaviors that are aggregated into a composite score of mental stimulation. In the 34 studies reviewed, there are great differences with regard to how composite scores were created. Some have tapped a broad range of behavior, spanning activities such as reading and writing, playing games or a musical instrument, volunteering, attending educational courses, or working with a computer (e.g., Salthouse et al., 2002; Schinka et al., 2005). In contrast, some have focused on a small number of very specific activities. For instance, Wilson and colleagues (2003; 2005) combined reading, writing, playing games, and attending concerts (also see Lachman et al., 2010). Others have included physical (e.g., gardening, jogging, physical activity; see Arbuckle et al., 1986; Christensen et al., 1996) and social components in their measures of mental stimulation (e.g., socializing, visiting friends, and club memberships; see Newson & Kemps, 2005; Yu et al., 2009). Furthermore, many studies do not provide a full description of which activities they merged into their composite score (but only list examples; e.g., Bosma et al., 2002). Obviously, there is great heterogeneity between these studies in the way they composed their independent variable. That is, many of the existing studies cannot be compared to each other in terms of the range of activities they cover as well as in terms of the
level of cognitive stimulation they provide. One valid conclusion to draw is, however, that heterogeneous kinds of stimulation yield heterogeneous results.

This heterogeneity may also be reflected in the psychometric qualities of those composite scores that show no association with cognitive domains (due to the level of random error contained within). That is why we scrutinized the precision of the composite scores as indexed by internal consistency reliability or coefficient of stability (test-retest). We often found quite low reliability. For instance, Gow et al. (2012), using an 11-item questionnaire, reported a Cronbach alpha of $\alpha = 0.66$. This implies, at the group level, that 34% of the observed variance is due to measurement error. Mackinnon and colleagues (Mackinnon et al., 2003) reported a similar alpha statistic of $\alpha = 0.64$ for their activity questionnaire. It is worth pointing out that the activity list employed was brief, six items, and that two of the items have been shown to correlate negatively with other cognitive activities (i.e., watching TV & resting). The modest reliability coefficient of $\alpha = 0.70$, although somewhat arbitrary, is typically cited as an acceptable minimum standard (Bland & Altman, 1997; Nunnally & Bernstein, 1994). Arbuckle et al. (1994) reported an alpha range of $\alpha = 0.52 - 0.71$ for their 22-item questionnaire. This same scale was employed by Arbuckle et al. (1992; 1998), and Gold et al. (1995), with the latter reporting reliability values observed in Arbuckle et al. (1994). Jonaitis et al. (2013) also recorded a low alpha for their activity scale ($\alpha = 0.53$). Thus, for the lowest recorded values, approximately 50% of the observed variance is due to measurement error. Wilson et al. (2003) reported good reliability metrics, with an internal consistency coefficient of $\alpha = 0.88$ and a 4-week test-retest reliability of $r = 0.79$. The average scale length over the different periods of inquire was 5 items. For such a brief instrument, given the content (i.e., complex leisure activities), these are relatively high reliability metrics (since reliability tends to improve, until a threshold is met, with additional items). We suspect that the reliability in this case may be inflated to some degree as local independence was not reported. One statistical assumption of all reliability analyses is that the items are locally
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independent, which means that all items must be reasonably independent of one another. In their ‘present’ assessment 60% of the items inquire about reading (Wilson et al. 2003). Salthouse et al. (2002) did not report on validation of reliability, however, item-level correlations were reported in which several items (based on frequency or how challenging the activity was) correlated with cognitive composites \( r = 0.26 - 0.45 \). The 22 items of this activity questionnaire (based on frequency & challenge) were summed to create a total score. However the construct validity of this summed score can be called into question as 36% of the items were negatively correlated with cognition. In Salthouse (2014) a seven-item subset of the questionnaire just mentioned was employed, with a 3-year test-retest reliability of \( r = 0.36 \). These coefficients of stability over such extended periods of time are difficult to meaningfully interpret. Yet, it may be worth pointing out, another self-report metric from this study was a brief (5-item) life satisfaction scale, which showed a 3-year test-retest of \( r = 0.71 \). Previous validation of the same life satisfaction scale showed an internal consistency reliability metric of \( \alpha = 0.87 \) (Pavot et al., 1991). Bielak et al. (2012) used the RIASEC Activity List which is a well-validated scale. However, the authors used a subset of the RIASEC which was psychometrically defined as multidimensional instrument. In spite of this, Bielak et al. (2012) merged the multidimensional scale into a single domain without further validation. Unfortunately, some studies have not reported or not assessed reliability (Wang et al., 2012; Yu et al., 2009; Bosma et al., 2002).
### Table 2.
Overview of studies that investigated the relationship between mental stimulation and memory, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Positive Association/Performance Increase</td>
</tr>
<tr>
<td>Arbuckle et al., 1986</td>
<td></td>
<td>Aartsen et al., 2002</td>
</tr>
<tr>
<td>Arbuckle et al., 1992</td>
<td>Memory (Correlational Evidence)</td>
<td>Jopp &amp; Hertzog, 2007</td>
</tr>
<tr>
<td>Arbuckle et al., 1994</td>
<td></td>
<td>Hultsch et al., 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jopp &amp; Hertzog, 2010</td>
</tr>
<tr>
<td>Bielak et al., 2012</td>
<td>Wilson et al., 2003</td>
<td>Hultsch et al., 1999</td>
</tr>
<tr>
<td>Christensen et al., 1996</td>
<td></td>
<td>(novel info processing, ‘active lifestyle’)</td>
</tr>
<tr>
<td>Lachman et al., 2010</td>
<td>Wilson et al., 2005</td>
<td>Jopp &amp; Hertzog, 2007</td>
</tr>
<tr>
<td>Mackinnon et al., 2003</td>
<td></td>
<td>(crafts, games, tech use, developmental)</td>
</tr>
<tr>
<td>Mitchell et al., 2012</td>
<td></td>
<td>Jopp &amp; Hertzog, 2010</td>
</tr>
<tr>
<td>Newson &amp; Kemps, 2005</td>
<td></td>
<td>(games, tech use, developmental)</td>
</tr>
<tr>
<td>Salthouse, 2013</td>
<td></td>
<td>Mitchell et al., 2012</td>
</tr>
<tr>
<td>Schinka et al., 2005</td>
<td></td>
<td>(novel info processing: communication, computation, conundrums)</td>
</tr>
<tr>
<td>Singh-Manoux et al., 2003</td>
<td></td>
<td>Jonaitis et al., 2013</td>
</tr>
<tr>
<td>Jonaitis et al., 2013</td>
<td></td>
<td>(games)</td>
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</tbody>
</table>
### Table 2. (continued)

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Positive Association/Performance Increase</td>
</tr>
<tr>
<td>Arbuckle et al., 1994 (only male sample)</td>
<td>Arbuckle et al., 1994 (mixed sample)</td>
<td>Change in Memory (Longitudinal Evidence)</td>
</tr>
<tr>
<td>Mackinnon et al., 2003</td>
<td>Bielak et al., 2012</td>
<td></td>
</tr>
<tr>
<td>Mitchell et al., 2012</td>
<td>Bosma et al., 2002</td>
<td></td>
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<tr>
<td>Newson &amp; Kemps, 2005</td>
<td>Salthouse, 2013</td>
<td></td>
</tr>
<tr>
<td>Small et al., 2012</td>
<td>Wang et al., 2013</td>
<td></td>
</tr>
<tr>
<td>Carlson et al., 2008</td>
<td>Change in Memory (Experimental Evidence)</td>
<td>Chan et al., 2014 (active learning: iPad)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Klusman et al., 2010 (computer training)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Park et al., 2013 (active learning: quilting &amp; photography)</td>
</tr>
</tbody>
</table>

**Note.** Gray highlights indicate composite scores that rely on active behavior.

**Inconsistencies in the Findings of Composite Score Studies Cannot be Explained by Activity Composites that Are Biased Towards Active or Passive Behavior**

In an attempt to address some of the heterogeneity in the findings of the 33 composite score studies, we highlighted all articles that used active (rather than passive) leisure time behavior to create their composite scores of mental stimulation (see Tables 1 – 7). We
highlighted studies as active (in gray) when they used a broad set of active recreational, intellectual, and occupational activities such as technology use and PC troubleshooting, handling finances, volunteering, painting, repairing, or practicing a musical instrument (Arbuckle et al., 1986; 1992; 1994; Bielak et al., 2012; Salthouse, 2013). In contrast, other studies mainly based their composite scores on passive behavior like reading and writing, listening to the radio, watching TV, visiting friends, attending cultural events, or visiting a museum (e.g., Christensen et al., 1996; Schooler & Mulatu, 2001; Wilson et al., 2003; 2005). These were categorized as passive and not highlighted. However, this classification did not help to resolve the inconsistency of results. Our hypothesis was that studies which used more active behaviors would be more often positively related to cognitive functioning whereas studies which used more passive behavior would be more often unrelated to cognitive functioning. But as can be seen in Tables 1 – 7, this is not the case. There is no systematic difference in the effect on cognitive functioning between active and passive composite scores studies.

Active Learning and Novel Information Processing as Mediators for Plasticity

It seems that active learning and novel information processing are most beneficial in terms of plasticity, at least for memory, processing speed, working memory performance, and probably reasoning. In contrast, the effect of passive information processing on cognitive performance appears to be less distinct. For instance, of the ten specific activity studies that researched memory performance, all but one provide evidence in favor of this conclusion (see Table 2). Jopp & Hertzog (2007; 2010) ran factor analyses on a broad set of mentally stimulating behavior and identified 11 independent constructs which they correlated with cognitive performance. According to their results, games (including word games, board games, card games, as well as crossword and jigsaw puzzles), technology use (e.g., using computer software, engaging in photography, playing an instrument), and developmental
activity (e.g., reading and creative writing, giving lectures, and learning foreign languages) were repeatedly associated with better memory performance, however, watching TV and experiential activity (e.g., attending movies, concerts, and plays) were not. Another group of researchers used data from the Victoria Longitudinal Study (Hultsch et al., 1993; 1999) and categorized an item pool of 70 activities into six central constructs: social participation (such as visiting friends & attending a party), self-maintenance (e.g., cooking & shopping), physical activities (e.g., jogging or walking), hobbies and home maintenance (e.g., playing a music instrument, repairing mechanical items), passive information processing (e.g., listening to the radio), and novel information processing (e.g., learning a language or playing bridge). The authors found that novel information processing as well as physical activity, social activity, and hobbies (the latter three were combined into a factor they called ‘active lifestyle’) were associated with better memory performance at baseline. However, only novel information processing was related to changes in memory over six years (whereas the factor 'active lifestyle' was not). Similar results were found over 18 years. Recently, a group of scholars around Mitchell (2012) gathered data of four large-scale longitudinal studies. Three of these used composite scores of mental stimulation. However, one study was the Victoria Longitudinal Study. The authors reported data from seven waves and exclusively used those items tapping novel information processing. When they derived subcategories of communication (e.g., giving a talk, attending lectures, learning a language), computation (e.g., arithmetic calculations, working on taxes), and engagement in conundrums (e.g., playing crossword puzzles and chess) they found that all three of them were related to changes in memory performance over 18 years. These results are in line with two experimental studies from the Synapse project (Chan et al., 2014; Park et al., 2014). The Synapse project randomized their subjects into groups of productive and receptive engagement. The productive engagement condition required active learning of novel and demanding skills such as computer training (Chan et al., 2014) or quilting and digital photography (Park et al.,
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2014). In the receptive engagement condition participants took part in social events (e.g., field trips) and engaged in activities that required passive observation (e.g., listening to classical music). Both studies found that at posttest (ten and 14 weeks later) memory was improved more effectively by active learning as compared to receptive engagement (also see Klusmann et al., 2010 for similar results). Taken together, this pattern of results further corroborates our impression from the previous section that rather than activity itself, it may be a more specific component of activity that is crucial to trigger cognitive plasticity: active learning and novel information processing.7

Apart from active learning and novel information processing, we are inclined to suggest another potential characteristic as mediating mechanism in the effect of mental stimulation: problem-solving. Although we have to admit that there is not much work to support this notion, the available evidence is consistent. Engagement in games or conundrums, for instance, was consistently correlated with higher performance in memory, speed, working memory, reasoning, and spatial abilities (Jopp & Hertzog, 2007; 2010) as well as with changes in memory, reasoning (Mitchell et al., 2012), and processing speed (Ghisletta et al., 2006). The basic process that underlies these effects could be problem-solving. However, this topic needs further research. To date, the available evidence is scarce and merely provides first (but promising) hints.

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7 The one study failing to find longitudinal relationships between specific mental stimulation and memory performance investigated the effect of experiential and developmental behavior (Aartsen, Smits, van Tilburg, Knipscheer, & Deeg, 2002). The authors used three rather passive items to assess experiential activity (making a trip to the forest or dunes, visiting a café or restaurant & visiting a cultural institution) and only one item to tap developmental activity in which only 13.1% of all subjects participated (following educational courses). The informative value of this study may therefore be limited (also see Hertzog et al., 2009).
Table 3. Overview of studies that investigated the relationship between **mental stimulation** and **processing speed**, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Processing Speed (Correlational Evidence)</td>
</tr>
<tr>
<td>Bielak et al., 2012</td>
<td>Jopp &amp; Hertzog, 2010</td>
<td>Jopp &amp; Hertzog, 2010</td>
</tr>
<tr>
<td>Wilson et al., 2003</td>
<td>Bielak et al., 2007</td>
<td>Bielak et al., 2007</td>
</tr>
<tr>
<td>Wilson et al., 2005</td>
<td>(integrative &amp; novel info processing)</td>
<td>(self-maintenance, passive info processing)</td>
</tr>
<tr>
<td>Jonaitis et al., 2013</td>
<td>Aartsen et al., 2002</td>
<td>Salthouse, Mitchell, 1990</td>
</tr>
<tr>
<td></td>
<td>(experiential, developmental)</td>
<td>(spatial visualization experience)</td>
</tr>
<tr>
<td></td>
<td>Hultsch et al., 1993</td>
<td>Hultsch et al., 1993</td>
</tr>
<tr>
<td></td>
<td>(active lifestyle)</td>
<td>(passive lifestyle)</td>
</tr>
<tr>
<td></td>
<td>Hultsch et al., 1999</td>
<td>Parslow et al., 2006</td>
</tr>
<tr>
<td></td>
<td>(novel info processing, social &amp; ‘active lifestyle’)</td>
<td>(realistic, artistic, social)</td>
</tr>
<tr>
<td></td>
<td>Jonaitis et al., 2013</td>
<td>(games)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parslow et al., 2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(conventional, investigative, enterprising)</td>
</tr>
</tbody>
</table>
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#### Table 3. (continued)

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Positive Association/Performance Increase</td>
</tr>
<tr>
<td><strong>Bosma et al., 2002</strong></td>
<td><strong>Bielak et al., 2012</strong></td>
<td><strong>Change in Processing Speed (Longitudinal Evidence)</strong></td>
</tr>
<tr>
<td><strong>Newson &amp; Kemps, 2005</strong></td>
<td>Mackinnon et al., 2003</td>
<td></td>
</tr>
<tr>
<td><strong>Small et al., 2012</strong></td>
<td><strong>Salthouse, 2013</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Stine-Morrow et al., 2008</strong></td>
<td><strong>Change in Processing Speed (Experimental Evidence)</strong></td>
<td><strong>Park et al., 2013</strong> (active learning: quilting + photography)</td>
</tr>
<tr>
<td><strong>Tesky et al., 2011</strong></td>
<td></td>
<td><strong>Chan et al., 2014</strong> (active learning: iPad training)</td>
</tr>
</tbody>
</table>

*Note.* Gray highlights indicate composite scores that rely on active behavior.
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Table 4. Overview of studies that investigated the relationship between mental stimulation and working memory, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
<th>No Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
</tr>
<tr>
<td>Arbuckle et al., 1992</td>
<td>Wilson et al., 2003</td>
<td>Working Memory (Correlational Evidence)</td>
<td>Hultsch et al., 1999 (novel info processing)</td>
</tr>
<tr>
<td>Bielak et al., 2012</td>
<td>Jonaitis et al., 2013</td>
<td>Change in Working Memory (Longitudinal Evidence)</td>
<td>Jopp &amp; Hertzog, 2010 (games, tech use)</td>
</tr>
<tr>
<td>Wilson et al., 2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stine-Morrow et al., 2008</td>
<td>Change in Working Memory (Experimental Evidence)</td>
<td>Hultsch et al., 1999 (novel info processing, 'active lifestyle')</td>
</tr>
</tbody>
</table>

Note. Gray highlights indicate composite scores that rely on active behavior.

There is Only Modest Domain-Specificity in the Effects of Mental Stimulation

Further analysis of Tables 3 and 4 reveals that processing speed and working memory performance, too, particularly respond to active learning and novel information processing. The same may hold true for inductive reasoning. There are promising results for this hypothesis. For instance, crafts, games, technology use, and developmental activity seem to be related with performance in letter set tests and Raven’s Progressive Matrices (Jopp &
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Hertzog, 2007; 2010). Similarly, novelty of information in active communication (e.g., giving a talk, attending lectures, learning a language, writing), computation (e.g., arithmetic calculations, working on taxes), and engagement in conundrums (e.g., playing crossword puzzles and chess) was not only related to higher levels of memory performance but also to baseline levels and changes in reasoning ability over 18 years (Mitchell et al., 2012). In contrast to that, the evidence for executive functioning is more inconsistent (see Chan et al., 2014 for their results on computer training and Flanker task performance). However, reasoning ability and executive functioning have received rather scant attention thus far. Within the 17 studies that researched specific activities, six addressed inductive reasoning (see Table 6) and only three were interested in executive functioning (Table 5). Although there are first interesting results (at least for reasoning), the empirical basis is too small to make any statement about these two domains.

More substantial empirical evidence may be observed with regard to spatial abilities. The two Synapse experiments may deliver first hints for domain-specific effects. They found that digital photography but not computer training and quilting yielded improvements in their measure of visuospatial processing after ten and 14 weeks (Chan et al., 2014; Park et al., 2014). This differential pattern of results may indicate that spatial abilities, in contrast to memory, working memory, and processing speed, require specific visuospatial content as well as specific challenges to the visuospatial system to be improved. Support for this hypothesis may come from two correlational studies that researched musical and spatial visualization experience. Salthouse and Mitchell (1990) found that test performance in the surface development and paper folding tests was positively related to subjective ratings of experience in visualizing travel directions from a verbal description and in imaging the view on objects from different positions. Another study investigated differences in spatial ability between professional musicians and non-musicians (Sluming, Barrick, Howard, Cezayirli, Mayes, &
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Roberts, 2002). The authors administered the judgment of line orientation test (JOL) and reported significantly higher JOL raw scores for musicians than for controls.

Table 5. Overview of studies that investigated the relationship between mental stimulation and executive functioning, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>No Association</td>
<td>Positive Association/Performance Increase</td>
</tr>
<tr>
<td>Schinka et al., 2005</td>
<td>Bosma et al., 2002</td>
<td>Executive Functioning (Correlational Evidence)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bialystok et al., 2004 (bilingualism)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jonaitis et al., 2013 (games)</td>
</tr>
<tr>
<td>Wang et al., 2013</td>
<td>Bosma et al., 2002</td>
<td>Change in Executive Functioning (Longitudinal Evidence)</td>
</tr>
<tr>
<td>Carlson et al., 2008</td>
<td></td>
<td>Change in Executive Functioning (Experimental Evidence)</td>
</tr>
<tr>
<td>Carlson et al., 2009</td>
<td></td>
<td>Chan et al., 2014 (active learning: iPad)</td>
</tr>
</tbody>
</table>

*Note.* Gray highlights indicate composite scores that rely on active behavior.
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**Table 6.** Overview of studies that investigated the relationship between mental stimulation and reasoning, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/Performance Increase</td>
<td>Reasoning (Correlational Evidence)</td>
<td>Positive Association/Performance Increase</td>
</tr>
<tr>
<td>Positive Association/Performance Increase</td>
<td>Reasoning (Correlational Evidence)</td>
<td>No Association</td>
</tr>
<tr>
<td>Singh-Manoux et al., 2003</td>
<td>Salthouse et al., 2002</td>
<td>Gribbin et al., 1980 (engagement, family dissolution)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td></td>
<td>Bialystok et al., 2004 (bilingualism)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td>Jopp &amp; Hertzog, 2007 (crafts, games, tech use, developmental, experiential)</td>
<td>Gribbin et al., 1980 (homemaker role, maintenance of acculturation)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td>Jopp &amp; Hertzog, 2010 (crafts, games, tech use, developmental, travel)</td>
<td>Jopp &amp; Hertzog, 2007 (TV)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td>Mitchell et al., 2012 (novel info processing: communication, computation, conundrums)</td>
<td>Jopp &amp; Hertzog, 2010 (TV, religious, experiential)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td>Salming &amp; Mitchell, 1990</td>
<td>Sluming et al., 2002 (musical experience)</td>
</tr>
<tr>
<td>Mitchell et al., 2012 (only 2 of 3 studies)</td>
<td>Yu et al., 2009</td>
<td>Mitchell et al., 2012 (novel info processing: communication, computation, conundrums)</td>
</tr>
<tr>
<td>Arbuckle et al., 1998</td>
<td>Change in Reasoning (Longitudinal Evidence)</td>
<td>Mitchell et al., 2012 (novel info processing: communication, computation, conundrums)</td>
</tr>
<tr>
<td>Stine-Morrow et al., 2008</td>
<td>Change in Reasoning (Experimental Evidence)</td>
<td>Mitchell et al., 2012 (novel info processing: communication, computation, conundrums)</td>
</tr>
<tr>
<td>Tranter &amp; Koutstaal, 2008</td>
<td></td>
<td>Mitchell et al., 2012 (novel info processing: communication, computation, conundrums)</td>
</tr>
</tbody>
</table>

*Note.* Gray highlights indicate composite scores that rely on active behavior.
Selection Effects in Correlational Studies, Fewer but Consistent Effects in Longitudinal Work

As can be seen, some studies report baseline correlations of mental stimulation with cognitive performance but fail to find longitudinal relationships (e.g., Bielak et al., 2012; Salthouse et al., 2013). This is why some scholars have argued that the positive link between mental stimulation and cognitive functioning is based on selection effects. According to this view, higher engagement is the consequence of higher cognitive functioning (and not vice versa; e.g., Salthouse, 2006). Our review partially confirms this hypothesis. The relationship between mental stimulation and cognitive functioning is likely to be reciprocal (e.g., Bosma et al., 2002; Schooler & Mulatu, 2001). This is not new, but it is important to consider when interpreting results. Longitudinal work, however, seems to be better guarded against such biases as it focuses on the association of change in stimulation and in cognition. For instance, of six longitudinal composite score studies that reported positive baseline correlations of mental stimulation with memory, only three found change relationships with memory (Mackinnon et al., 2003; Mitchell et al., 2012; Newson & Kemps, 2005). Only one of four longitudinal studies found associations with changes in speed (Newson & Kemps, 2005). Whereas these effects may perhaps be explained by differences in the use of composite scores, this may not be the case in research of specific behaviors. We found similar evidence in the specific activity studies as well. For instance, an ‘active lifestyle’ correlated with memory and processing but not with changes in these variables over six years (Hultsch et al., 1999). The same holds true for experiential and developmental activities (Aartsen et al., 2002). Only one effect seemed robust enough to survive longitudinal study designs. Novel information processing was related to changes in memory and working memory (Hultsch et al., 1999; Mitchell et al., 2012) as well as to changes in processing speed (Bielak et al., 2007). The evidence concerning problem-solving is, as stated above, scarce but promising.
Table 7. Overview of studies that investigated the relationship between mental stimulation and spatial abilities, separated for composite versus specific mental stimulation as well as correlational, longitudinal, and experimental evidence.

<table>
<thead>
<tr>
<th>Composite Mental Stimulation</th>
<th>Domain of Cognitive Functioning</th>
<th>Specific Mental Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Association/No Association</td>
<td>Positive Association/Performance Increase</td>
<td>Jopp &amp; Hertzog, 2007</td>
</tr>
<tr>
<td>Wilson et al., 2003</td>
<td>Salthouse et al., 2002</td>
<td>Crafts, tech use, developmental</td>
</tr>
<tr>
<td>Wilson et al., 2005</td>
<td>Salthouse, Mitchell, 1990 (spatial visualization experience)</td>
<td>Sluming et al., 2002 (musical experience)</td>
</tr>
<tr>
<td>Jonaitis et al., 2013</td>
<td>Change in Spatial Abilities (Experimental Evidence)</td>
<td>Jonaitis et al., 2013 (games)</td>
</tr>
<tr>
<td>Arbuckle et al., 1998</td>
<td>Stine-Morrow et al., 2008</td>
<td>Park et al., 2013 (active learning: professional photography)</td>
</tr>
<tr>
<td>Tranter &amp; Koutstaal, 2008</td>
<td>Change in Spatial Abilities (Longitudinal Evidence)</td>
<td>Chan et al., 2014 (active learning: iPad)</td>
</tr>
<tr>
<td>Tranter &amp; Koutstaal, 2008</td>
<td>Change in Spatial Abilities (Experimental Evidence)</td>
<td>Park et al., 2013 (active learning: quilting, receptive engagement)</td>
</tr>
</tbody>
</table>

Note. Gray highlights indicate composite scores that rely on active behavior.

Conclusion I – Learning and Novelty as Facilitators of Cognitive Plasticity

Our findings may have several implications: (a) since the use of composite scores of mental stimulation yields inconsistent results, future work may benefit from abandoning such composite scores and focus on more specific characteristics of mentally stimulating behavior;
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(b) the level of activity in mentally stimulating behavior may be less critical for cognitive plasticity to manifest than (c) active learning and novelty; and (d) mental stimulation does not seem to provide domain-specific effects, most cognitive abilities benefit from mental stimulation in a similar way. Apart from these observations, however, many questions have yet to be answered in future research.

Our analysis suggests that the use of composite scores with varying combinations of leisure time behavior may have yielded inconsistent results. Leisure time researchers have often been satisfied with combining varying sets of behavior which they assumed as mentally stimulating. However, only rarely did they give an operational definition of mental stimulation and test their a priori assumptions empirically. This rather careless approach may account for the existing inconsistencies. This interpretation is further corroborated by the fact that those composite scores which show no association with cognitive functioning often display low reliability estimates. Moreover, mere investigation of heterogeneous activities will not deepen our understanding of the mechanisms that facilitate real-life cognitive plasticity. Future work may therefore abandon composite scores and focus on more specific characteristics of mentally stimulating behavior such as active learning and novel information processing. With this, we hope to spark a shift in the ongoing debate from ‘whether or not mental stimulation fosters cognitive functioning’ to ‘what specific characteristics have the potential to do so’. If interested in specific activities, we advise to employ precise operational definitions (instead of a priori assumptions) of mental stimulation and assess the level of stimulation that is conveyed by the behavior in question. Otherwise, we will not know whether an activity is truly ‘mental’ or not.

According to our literature analysis, there is no systematic difference between more active and more passive leisure time behavior in the effect on cognitive functioning. Our hope was that composite score studies which used more active rather than passive behavior to create composite scores of mental stimulation would be more often positively related to
cognitive functioning. However, there were no signs for such differences in the literature. Abandoning composite scores and focusing on more specific characteristics of leisure time behavior corroborated these results. This is reflected in the fact that an ‘active lifestyle’ (Hultsch et al., 1999) or, for instance, manual work (Ghisletta et al., 2006) and travelling (Bielak et al., 2007) were not related to longitudinal changes in memory and processing speed.

Our interpretation is that instead of activity itself it may be a more specific type of activity that is needed for cognitive plasticity to manifest: active learning and novel information processing are most likely essential mediators in the relationship between mental stimulation and cognitive functioning. This could imply that highly challenging activities such as learning a foreign language or playing a musical instrument may be less stimulating as soon as one has reached a certain level of proficiency and routine. This is in line with the very interesting finding that greater variety of participation in cognitively stimulating activities was associated with a ~10% lower risk of cognitive impairment (regardless of how challenging these tasks were; Carlson et al., 2012). In addition to that, routinization has been shown to be negatively associated with cognitive flexibility (Tournier et al, 2012). Similarly, preferences for routine were positively correlated with cognitive decline over three years (Bergua, Fabrigoule, Barberger-Gateau, Dartigues, Swendsen, & Bouisson, 2006). That is, the degree of cognitive variety and novelty in information processing may be more important than higher levels of cognitive challenge in terms of mental stimulation in case the cognitive challenge has become a 'non-adaptive' routine. This also implies that cognitive variety and cognitive novelty could serve as better indicators of mental stimulation than frequency of participation or the level of cognitive challenge. There may be more such indicators. Engagement in games or conundrums was associated with changes in memory, reasoning (Mitchell et al., 2012), and processing speed (Ghisletta et al., 2006). Problem-solving may therefore be a valuable avenue
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for future research. To date, however, the available evidence is scarce and merely provides first (but promising) hints.

With regard to the outcome of mental stimulation, we found no domain-specific effects. Most cognitive abilities (memory, processing speed, working memory, and probably reasoning) seem to benefit from mental stimulation in a similar way. Spatial abilities may be an exception to this rule. In contrast to memory, working memory, and processing speed, spatial abilities could require specific visuospatial content as well as specific challenges to the visuospatial system to be improved. However, much more research is needed to verify this impression. This will be an interesting avenue for future research.

Although we are convinced to have answered important questions in the field, some questions remain unanswered. One such question concerns, for instance, the temporal ordering of the relationship between cognitive activity and mental stimulation. Several different paradigms can be identified in the available literature (Small et al., 2012), provided that dynamic 'lead' and 'lag' models were employed. First, a cognitive-first hypothesis in which cognition is a 'leading indicator' of change in activity. Such a finding would be supported by the premise that high cognitive ability is a determinant of lifestyle choices including leisure activity (Gow et al., 2012b). In terms of cognitive aging, prior cognitive ability is a major confounder, given the high rank-order stability of cognitive ability across the life-course (Deary et al., 2000); second, the concurrent change hypothesis would reveal that both constructs present with leading and lagging characteristics, that is, changes in both constructs impact changes in the other; the final pattern to observe would be that activity is a leading indicator of change in cognition. This last pattern appears to be the least common finding. For instance, Mitchell and colleagues (2012) observed a consistent positive association between change in activity and within person variability in cognition in nearly every cognitive outcome across all four studies. The implication here is that people who expand their level of cognitive leisure activities are likely to see changes in cognitive ability.
However, it is worth pointing out that Mitchell and colleagues did observe one instance in which activities appeared to be a leading indicator of change in cognition. This latter pattern has been confirmed elsewhere: Lövdén et al. (2005), Ghisletta et al. (2006), and select evidence from Brown et al (2012). These findings seem to support the more traditional view that the protective effects of an engaged lifestyle at a previous time point offer protective effects later in life. However, the available evidence on this topic is far from conclusive and does not allow for any conclusion.

Another open question is whether mental stimulation has personalized effects. It is possible that, depending on specific personality or demographic variables, some people respond to certain kinds of stimulation whereas others do not. Some evidence seems to exist for the moderating effects of age, education, and gender (e.g., Bielak, 2010). Especially age-specific effects have been discussed repeatedly (also see Salthouse, 2006). And there are good reasons for that. It seems all too likely that mental stimulation unfolds its strongest impact only later in life, when cognitive decline gains in severity. However, this assumption is hard to verify. Longitudinal research designs with measurement points throughout the entire lifespan would be needed in order to compare the many stages in life. To date, we are not aware of any such study. Other variables have largely been neglected. For example, it would be interesting to investigate the role of personality-related variables such as openness to experience or control beliefs. This is an interesting avenue for future research. A third question we did not answer may relate to whether lagged or concurrent effects of mental stimulation take greater effect on cognitive functioning. There is some evidence suggesting that current mental stimulation is more important in predicting current levels of cognitive functioning than past stimulation. When Wilson and colleagues (2005) regressed late life cognitive function (mean age = 80.2 years) on current and past mental stimulation (i.e., in childhood and at ages 18 and 40), they found that current stimulation was a stronger predictor than past behavior in semantic memory, working memory, processing speed, and visuospatial
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abilities. Other studies seem to corroborate these findings (see Bielak, 2010). But again, more research is needed to verify these results.

A last question that we have not touched upon but which is important refers to the neurophysiological mechanisms that accompany the effects of mental stimulation. Fortunately, there is a growing group of researchers that turns towards this topic. Thus far, most studies depicted short-term gains in gray and white matter density in response to mental stimulation. For instance, learning a second language (Stein et al., 2012) and learning to decipher Morse code (Schmidt-Wilcke, Rosengarth, Luerding, Bogdahn, & Greenlee, 2010) were associated with gray matter gains in frontal and parietal regions. Other studies observed functional changes and found, for instance, enhanced neural activity in the anterior hippocampus after ear training in musical students (Herdener et al., 2010; also see Sluming et al., 2002). However, much of this research is conducted with rather young samples. The mean age in these studies often revolves around 30 years (Schmidt-Wilcke et al., 2010) or less (Herdener et al., 2010; Stein et al., 2012). Notable exceptions which are based on elderly or lifespan samples are only just emerging (e.g., Park et al., 2013).

Review II –Mental Stimulation at Work and Cognitive Functioning

Since work represents an important part of everyday life, studies on mental stimulation at work represent an important part of 'in vivo' research. However, the investigation of mental stimulation in leisure time and of mental stimulation at work is embedded in rather different research traditions. Moreover, the field does not lend itself to exactly the same schema of composite versus specific mental stimulation. The existing literature is too small and the available concepts are too heterogeneous to broadly classify them as composite or specific measure of mental stimulation at work. Therefore, we decided to approach this strand of research separately and rather un-prepossessed, without reference to the classification system as we have introduced it in the preceding chapter.
Sixteen studies investigated the relationship between mentally stimulating work environments and cognitive functioning as measured by a general factor of fluid intelligence or specific tests of episodic memory, processing speed, working memory, executive functioning, inductive reasoning, and spatial abilities. Of these, 13 studies researched distinct concepts such as job complexity, mental workload, or intellectual challenge. We identified another four articles that researched specific job types and their effect on cognitive functioning (one study did both; Avolio & Waldman, 1990). Examination of these 16 studies led us to suggest two primary conclusions: (1) the empirical basis for a positive effect of mental stimulation at work is quite consistent. Of the 13 studies, all but one indicated that mental stimulation at work is positively related to better cognitive functioning. (2) The available evidence on mental stimulation in specific job types is too scarce and too heterogeneous to derive any systematic conclusion. Job types are hard to compare without a more detailed description of their typical level of mental stimulation.

**Mental Stimulation at Work is Consistently Associated with Higher Cognitive Functioning**

Of the 13 studies that researched the effect of mental stimulation through work, 12 found positive associations with cognitive functioning. Only one study (Gow et al., 2014) could not establish this link.

Using a prospective study design which spanned a time frame of 30 years and controlling for a multitude of socioeconomic and demographic variables, Schooler and colleagues (1999; 2004), reported a reciprocal relationship between job complexity and cognitive functioning (for their definition of job complexity, see above). The authors used the *Dictionary of Occupational Titles* (DOT; Roos & Treiman, 1980) as an orientation for their appraisals of complexity and found that although individuals with higher baseline cognitive functioning were more likely to be given high complexity jobs, the reciprocal effect of
complexity on general cognitive functioning was still present and even somewhat stronger. A recent study corroborated these results and reported positive effects of job complexity on episodic memory (e.g., Fisher, Stachowski, Inurna, Faul, Grosch, & Tetrick, 2014). One correlational study found positive effects of complexity on processing speed and visuospatial abilities but failed to find positive associations with word list recall, working memory, and executive functioning (Jonaitis, La Rue, Mueller, Koscik, Hermann, & Sager, 2013).

Extending the research on job complexity, Finkel and colleagues (2009) used DOT rankings to take a more specific look at complexity with data, people and things on memory, processing speed, and visuospatial abilities in twins. Controlling for educational background and using prospective data over 16 years, it depicted that complexity with people was related to changes in speed and visuospatial ability but not to changes in memory. In addition, complexity with data was found to be associated with changes in spatial ability (but not memory and speed). Complexity with things was not related to any cognitive domain.

Next to job complexity, researchers have used other concepts to operationalize mental stimulation at work. One study reported that time pressure was positively associated with general fluid functioning whereas closeness of supervision, routinization, and dirtiness of work were not (Kohn & Schooler, 1973). Two longitudinal French studies assessed training participation and opportunities to increase (or learn new) skills as well as task variation and intellectual job demands on memory and multi-tasking over ten years (Ansiau, Marquie, Soubelet, & Ramos, 2005; Marquie et al., 2010). The authors indicated positive effects on general fluid functioning, episodic memory, and processing speed. Similar effects have been revealed by a Dutch study that investigated a composite measure of strong concentration, great precision, and high time pressure over three years (Bosma et al., 2003). Only one study failed to provide evidence for a positive link between mental work stimulation and cognitive performance. Gow and colleagues (2014) used dichotomous items to describe intellectual challenge. They asked their participants whether their last occupation was varied (yes/no),
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routine (yes/no), and intellectual or manual work. The authors reported no association with general fluid functioning.

One German study investigated the effect of assembly line work of old and young car manufacturers versus individuals in more self-directed jobs such as quality management, maintenance, and service (Gajewski, Wild-Wall, Schapkin, Erdmann, Freude, & Falkenstein, 2010). Controlling for age and education, it reported age-dependent performance differences between assembly line workers and individuals in more self-directed jobs in task switching. The authors also recorded EEG data and found electrophysiological patterns in the old sample with repetitive job demands which they interpreted as indication of reduced working memory capacity and deficits in error monitoring.

Job Types – The Available Evidence is too Scarce and too Heterogeneous

We identified four studies that researched the effect of specific job types. In order to appraise the level of cognitive stimulation that underlies each job type, we attempted to classify them according to the DOT (Roos & Treiman, 1980). However, in three of four cases, this was not possible. For instance, one study compared blue-collar workers with academics that worked in the fields of humanities, social science, and science (Christensen et al., 1997). Obviously, there is a great range of possible occupations within both the fields of blue-collar work and academia. Specifying a certain job code was not possible. Similarly, Avolio and Waldman (1990) provided evidence that clerks as compared to, for instance, health care workers show less pronounced age effects in measures of general fluid functioning. Again, the range of possible occupations within the fields of clerical or health care work was too wide to find a particular job code that represents the sample appropriately. Only one study allowed us to find a job code. Van der Elst, van Boxtel, and Jolles (2012) compared primary and secondary school teachers with non-teachers and found that teachers depicted higher levels of working memory performance as compared to non-teachers (a randomly selected subsample
of participants in the Maastricht Aging Study that was matched on age, gender, occupational achievement, and educational background). According to the ranking of the DOT, primary and secondary school teachers score relatively high on complexity with data and people and low on complexity with things. These results would extend the work of Finkel and colleagues on complexity with people (see above). However, group differences could not be observed for memory, processing speed, and executive functioning (which could also be a consequence of high average levels of job complexity in non-teachers; we were not able to classify non-teachers according to the DOT).

Taken together, the literature is too small and too heterogeneous to derive any systematic conclusion. The work on job types is an interesting strand of research. However, the existing studies do not allow inferences on the level of mental stimulation that is conveyed by a specific job. Future work should therefore be more precise in the description of their samples and, for instance, assess the average level of complexity with data, people and things.

**Conclusion II – Consistent Results for the Relationship Between Mental Stimulation at Work and Cognitive Functioning**

On the basis of our literature review we suggest the following main inferences: (a) the results concerning the effect of mental stimulation at work on cognitive functioning are surprisingly consistent; (b) these differences may be based on fundamental differences in the assessment of mentally stimulating behavior; (c) whereas high job complexity is beneficial in terms of cognitive functioning, there is evidence that low job complexity has detrimental effects; and (d) the literature on specific job types is too scarce and too heterogeneous and requires more direct assessments of the level of mental stimulation.

In contrast to mental stimulation in leisure time, the results concerning mental stimulation at work are surprisingly consistent. This is an interesting and important observation. One possible explanation may be rooted in the fact that high mental work
demands are likely to be confounded with high cognitive functioning. As Schooler and colleagues (1999) pointed out, the relationship between job complexity and cognitive functioning is reciprocal. High ability individuals are more likely to be selected into complex and challenging work environments. As a consequence, results may be biased. Another reason may be that mental stimulation at work and mental stimulation in leisure time are usually approached very differently. Leisure time researchers have often been satisfied with combining varying sets of behavior which they assumed as mentally stimulating. However, only rarely did they give an operational definition of mental stimulation and test their a priori assumptions empirically. This is different in the literature on mental stimulation at work. Scholars in this field usually define the construct they are interested in, be it job complexity (e.g., Schooler et al., 1999), mental workload (Bosma et al., 2003), or mental job demands (Marquie et al., 2010), and use this definition to directly assess the level of mental stimulation that is conveyed by the work characteristics in question. These two approaches differ fundamentally. And this difference may account for the inconsistencies with regard to leisure time behavior.

Mental stimulation at work has beneficial effects on cognitive functioning. In particular, high job complexity is a very prominent construct within this literature which has received sound support in our review (Finkel et al., 2009; Fisher et al., 2014; Schooler et al., 1999; 2004). High job complexity has repeatedly been linked to better cognitive functioning. Conversely, low job complexity seems to have detrimental effects as indicated by the interesting results regarding repetitive versus more self-directed work (Gajewski et al., 2010). The available literature on job types, in contrast, is insufficient and too heterogeneous to derive any conclusion. Moreover, many studies do not allow inferences on the level of mental stimulation. Future job type studies should therefore assess average levels of, for instance, complexity with data, people, and things.
Another important topic for future research may be the interaction between leisure time and work life. The interplay of mental stimulation at work and mental stimulation in leisure time is not yet understood. Only recently, one study started to provide answers to this interesting question (Andel, Silverstein, & Kåreholt, 2015). Controlling for childhood, midlife, and late-life covariates, it found that mental stimulation at work and mental stimulation in leisure time were both associated with better late-life cognitive functioning (independently of one another). In addition to that, the authors reported a compensatory interactive effect. That is, with greater engagement in one of the two spheres of life, the importance of the other sphere of life as a source of mental stimulation declined (Andel et al., 2015). This is an interesting finding and a valuable avenue for future research.

Summary

This review set out to resolve some of the inconsistencies that pervade the debate in current research of mental stimulation. Our literature analysis suggested four fundamental insights. First, one reason for inconsistent results may be based on the rather common use of composite scores that combine varying sets of presumably stimulating behavior. The degree of mental stimulation, however, is only rarely evaluated in a sufficient manner. Future research may therefore benefit from abandoning composite scores and focus on more specific characteristics of mental stimulation. Second, the level of activity in mentally stimulating behavior may be less critical for cognitive plasticity to manifest than active learning and recurrent novelty and variety. Our literature review revealed novel information processing and active learning (but not activity versus inactivity) as important facilitators of mental stimulation. There is promising evidence for problem-solving as well but more research is needed to verify this impression. Third, apart from spatial abilities, there are most likely no domain-specific effects. Memory, processing speed, and working memory show similar response patterns to mental stimulation. Fourth, in contrast to mental stimulation in leisure
time, the results concerning mental stimulation at work are surprisingly consistent. In particular, there is sound evidence that job complexity is positively linked to cognitive performance. Our interpretation is that the two fields are usually approached very differently: whereas leisure time researchers often combine varying sets of behavior without reference to any level of mental stimulation, work-environmental researchers directly assess the level of mental stimulation that is conveyed by the work characteristics in question.

Taken together, our literature review provided evidence to discuss at least two characteristics of mentally stimulating behavior that seem to be critical for cognitive plasticity to manifest: the complexity of a task or situation on the one hand as well as its novelty on the other hand. With these results, we hope to spark a shift in the ongoing debate from ‘whether or not mental stimulation fosters cognitive functioning’ to ‘what specific characteristics have the potential to do so’.
V. TRANSITION BETWEEN STUDY 1 AND 2

Study 1 revealed that at least two characteristics of mentally stimulating behavior seem to be critical in terms of cognitive plasticity: the complexity as well as the novelty of a given task or situation. Recent theoretical discussions of plasticity share this view and proposed that it could particularly be "the encountering of novel situations (at different levels of complexity)—at work and in general—that supports the maintenance of fluid abilities across adulthood" (Bowen, Noack, & Staudinger, 2011, p. 265; also see Park & Bischoff, 2013). In line with this, recent evidence suggested that variety in mental stimulation could be more important for plasticity than the frequency of participation in mentally stimulating activities (Carlson et al., 2012).

In the following, study 2 sets out to further deepen the understanding of the role of novelty in cognitive plasticity. It takes the idea that recurrent exposure to novelty is conducive to cognitive functioning and applies it to the work context of monotonous industrial production work. Due to highly standardized work routines and constraint decision latitude, industrial production work is characterized by low levels of mental stimulation (i.e., low job complexity). Investigating such low complexity occupations is interesting at least for two reasons. First, it may help to un-confound the amount of cumulative cognitive challenge through repeated novelty at work and the amount of cognitive challenge through high job complexity. And second, low job complexity has been linked with negative effects on cognitive functioning (Gajewski et al., 2010; Schooler et al., 1999; Tournier et al., 2012) and seems to be associated with a higher risk of cognitive impairment (Bosma et al., 2003) and dementia (Andel et al., 2005; Potter et al., 2007). In addition to that, a recent 10-year longitudinal study revealed that prolonged exposure to rotating shift work (a standard in industrial production work) seems to aggravate these effects (Marquie et al., 2014).

On the basis of the findings in Study 1, Study 2 aims at investigating work-task
changes as facilitators of cognitive performance in the context of long-term industrial production work. Work-task changes (WTC) refer to changes in work function in which each change implies to learn new skills or to deal with new materials. Work biographies that are shaped by multiple WTC indicate the degree to which a production worker is recurrently confronted with novel work situations, new skill learning, and unfamiliar work tasks over a prolonged period of time throughout his or her career. WTC may thus help to counteract non-adaptive routinization and provide the cognitive variety that seems vital to cognitive plasticity (Carlson et al., 2012; Tournier et al., 2012). This may yield cumulative positive effects on the level of cognitive performance.
VI. STUDY 2

Cognitive Plasticity Studied in the Wild -
Cumulative Effects of Work-Task Changes in Midlife

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Abstract

Based on the assumption that cognitive plasticity is strongly linked with learning processes resulting from recurrent exposure to unfamiliar tasks, we analyzed the influence of multiple changes of the work task (Work-Task Changes; WTC) on processing speed and working memory in production workers of one company. To test this hypothesis we employed a case-control quasi-experimental research design covering a treatment window of 17 years with matched samples ($N = 38$) and controlling for the influence of cognitively stimulating leisure time activity. Results showed that middle-aged production workers ($M_{age} = 47$ years; range = 38-54 years) with multiple as opposed to zero or only one WTC in 17 years had higher levels of cognitive performance in an identical pictures and N-back test. These results may indicate the beneficial effects of WTC and extend our knowledge on the mechanisms that seem to underlie cognitive plasticity.

*Keywords:* work-task changes, cognitive functioning, plasticity, processing speed, working memory
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Plasticity denotes an individual's potential for modifications in his or her developmental trajectory throughout the lifespan; cognitive plasticity, thus, refers to the modifiability of the cognitive aging process resulting in very individual performance levels (Baltes, 1987; Baltes, Lindenberger, & Staudinger, 2006). The degree of plasticity is contingent on the sum of developmental resources available. Resources can be rooted within an individual (physiological, psychological) or of external nature (Staudinger, Marsiske, & Baltes, 1995).

Schooler and colleagues (Kohn & Schooler, 1978) were among the first to leave the lab and study the cumulative effects of real life contexts such as work settings. Using a longitudinal approach, the authors established a reciprocal relationship between job complexity (work that requires thought and independent judgment) and cognitive functioning (Schooler, Mulatu, & Oates, 1999; 2004). Although individuals with high levels of functioning at baseline were more likely to be selected into cognitively stimulating job environments, the reciprocal effect was slightly stronger. Exposure to complex work tasks over a period of 30 years entailed better cognitive functioning, irrespective of age and level of education. Following Schooler’s example, subsequent studies (mostly epidemiological) corroborated these results and, for instance, discovered that higher job complexity was associated with a lower risk of cognitive impairment (Bosma, van Boxtel, Ponds, Houx, Burdorf, & Jolles, 2003) as well as of dementia and Alzheimer’s Disease (Andel et al., 2005; Potter, Helms, Burke, Steffens, & Plassman, 2007).

Still, important questions in the relationship between job complexity and cognitive functioning remain unanswered. In the current article, we aim to tackle two of them. First, it is not yet well understood which characteristics of mental stimulation are crucial to activate plasticity (e.g., Salthouse, 2006; Stine-Morrow et al., 2008). There is reason to assume that recurrent learning processes (i.e., that something is new and has to be learned) play an important role in optimally exploiting plastic potentials. And second, note that highly
complex jobs are necessarily linked with higher baseline levels of cognitive functioning (see above; Schooler et al., 1999). But what can be done for individuals without access to these jobs? Thus far, only one study has taken into account cognitive plasticity in occupations with low complexity. It compared assembly-line workers with more self-directed occupations and found positive associations with task-switching performance (Gajewski, Wild-Wall, Schapkin, Erdmann, Freude, & Falkenstein, 2010).

The mental stimulation hypothesis assumes that prolonged engagement in mentally stimulating activities slows down the pace of cognitive aging (Hultsch, Hertzog, Small, & Dixon, 1999; Salthouse, 2006; also see Denney, 1984). Cross-sectional (Arbuckle, Gold, & Andres, 1986; Hultsch, Hammer, & Small, 1993), longitudinal (Arbuckle, Gold, Chaikelson, & Lapidus, 1994), and experimental work (Stine-Morrow, Parisi, Morrow, & Park, 2008; Tranter & Koutstaal, 2008) suggests that greater participation in cognitive activities is related to higher levels of cognitive functioning. However, the classic understanding of the mental stimulation hypothesis did not distinguish between the need to practice mental abilities in the sense of repetition and the need to be confronted with new, yet unknown situations and cognitive problems (Bowen, Noack, & Staudinger, 2011). Manifestations of positive plasticity may occur only to the extent that an individual is confronted with a mismatch between the functional supply of his or her cognitive system and challenging environmental demands (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010; Piaget, 1950). It seems to be the novelty that is critical to cognitive plasticity, be it in terms of maintenance or improvement of performance levels across time (Staudinger, Marsiske, & Baltes, 1995). First experimental work provides evidence for this notion (Park et al., 2014). In line with this, recent evidence suggests that greater variety of participation in cognitively stimulating activities was associated with a lower risk of cognitive impairment (regardless of how challenging these tasks were; Carlson et al., 2012). In addition to that, routinization seems negatively related to cognitive flexibility (Tournier, Mathey, & Postal, 2012), and preferences
for routine correlate positively with cognitive decline over three years (Bergua, Fabrigoule, Barberger-Gateau, Dartigues, Swendsen, & Bouisson, 2006).

With the present work, we attempt to further scrutinize the idea that novelty is critical for cognitive plasticity to unfold. We focus on one distinct job characteristic, that is, the degree to which a person is recurrently confronted with novel work situations and unfamiliar tasks to be completed. To do so, we compared workers with regard to their cumulative number of work-task changes (WTC). Our hope is that WTC allow disentangling the effect of repetition from the effect of novelty. Secondly, we focus on jobs with low complexity by researching assembly-line work or similar monotonous workplaces in order to un-confound the level of cognitive challenge through novelty from the effect of cognitive challenge through complexity.

Sources of Cognitive Plasticity in the Wild: Beyond Work

Obviously, cognitive challenges not only occur in the workplace but also in private life. Workers may train their brain outside the usual business hours, for example, by leisure time computer programming or engagement in sport clubs. That is, leisure time activities need to be taken into account when interested in the specific effects of multiple WTC.

In addition to being an important control variable, it seems useful to test whether work-related activity changes tap into different or the same aspects of cognitive plasticity than cognitive challenges embedded in leisure time activities. Unfortunately, the literature on this topic is scarce. A recent study reported a compensatory relationship between leisure time activity and work complexity (Andel, Silverstein, & Kåreholt, 2015). Apart from the fact that mental stimulation at work and mental stimulation in leisure time were both associated with better late-life cognitive functioning (independently of one another), the authors reported a compensatory interactive effect. Greater engagement in one of the two spheres of life deemed the importance of the other sphere of life as a source of mental stimulation more unimportant.
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(Andel et al., 2015). Thus, there may be reason to assume a similar relationship between leisure time activity and multiple WTC on cognitive functioning. Accordingly, we expected leisure time activities to compensate for low WTC and vice versa, although it must be noted that this hypothesis is rather exploratory since there is only one study up to now that supports this reasoning.

Defining Work-Task Changes

WTC need to be distinguished from both job mobility (Louis, 1980; Ng, Sorensen, Eby, & Feldman, 2007) and job rotation (e.g., Ortega, 2001). Twelve types of job mobility based on three dimensions of change have been suggested (Nicholson & West, 1988): status (upwards, downwards, lateral), function (same/changed), and employer (internal/external). WTC refer to changes in work function, that is, changes of the work-task within one company (internal), excluding promotion and demotion, each of which implies to learn new skills or dealing with new materials. This definition of WTC avoids confounding the amount of cumulative cognitive challenge through novelty with the influence of job complexity (upward/downward mobility) and of changes in social environment as is the case when changing employers (e.g., see Lövdén, Ghisletta, & Lindenberger, 2005).

Another distinction to be made is that between WTC and job rotation. Indeed, these two constructs bear resemblance to each other (for a definition of job rotation, see Campion, Cheraskin, & Stevens, 1994). However, WTC imply the cumulation of novel situations and the learning of how to deal with new materials whereas job rotation refers to switching between two or more known tasks in a fixed temporal sequence (which amounts to repetition).
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Processing Speed and Working Memory Performance as Leading Indicators of WTC and Cognitive Aging

Work biographies which are shaped by multiple WTC provide repeated confrontation with new, yet unknown problems and routines which in turn may activate cognitive plasticity (Bowen et al., 2011; Lövdén et al., 2010). According to Ackerman (1988), skill acquisition places high demands on working memory and processing speed. During skill acquisition, individuals have to understand and reproduce skill characteristics and operational sequences which is associated with the ability to temporarily store and update new information in working memory. In addition, skill procedures need to be automatized and streamlined in order to improve performance speed and accuracy. This has been related to speed of processing (also see Ackerman, 1992). Thus, we used measures of speed of information processing and working memory capacity to test whether multiple WTC affect the level of cognitive functioning. We hypothesized that multiple as opposed to zero or only one WTC are associated with higher levels of performance in processing speed and working memory tasks.

Testing the Effects of Mental Stimulation in Real Life – the Mobilis Project

Our study was part of the interdisciplinary 'Mobilis' project which allowed us to cooperate with a globally acting production company in the northwest of Germany and to analyze the effect of work biographies of industrial production workers within a treatment window of 17 years. We used a highly controlled quasi-experimental field study to test our hypotheses. This approach has high external validity but challenges to master on the side of internal validity since randomization is not applicable and causality testing in a strict sense is impaired (also see Salthouse, 2006; Stine-Morrow et al., 2008; Winhsip, & Morgan, 1999). In order to restore an acceptable balance between external and internal validity, we attempted to ascertain as many of the relevant confounding covariates as possible (Campbell, 1957).
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Previous work has shown that causal inference in quasi-experimental research can be approximated with an accurate matching on all baseline variables thought to affect the outcome measure (Holland & Rubin, 1988; Rubin, 1974). We did have the big advantage that all participants were workers at the same plant and had all been working there for at least 17 years. This takes care of influences of the work environment (e.g., company culture, working rules etc.). Obvious socio-demographic matching variables were age and job level. Given that we wanted to test the effect of multiple work-task changes on cognitive functioning, we had to ascertain a measure of baseline cognitive ability. Furthermore, seeking out or accepting task changes may be related to personality as indexed by openness to new experiences (hereafter: openness). Openness goes hand in hand with behavioral flexibility and intellectual curiosity (McCrae, 1996). As such, it has been related to cognitive functioning (e.g., Gignac, 2005; Hogan, Staff, Bunting, Deary, & Whalley, 2012). To control for the influence of this personality dimension, we had to reconstruct a baseline measure of openness. Finally, leisure time activities at baseline need to be taken into account in the same way as leisure activities at posttest were investigated with regard to their mediating and moderating effects. Based on all these variables, closely matched pairs of participants were identified and subsequently tested in processing speed and working memory performance as indicators of cognitive functioning. In doing so, our matching procedure may help to minimize and compensate for potential selection biases.

Method

Participants and Matching

All participants were production workers from one German company who had worked for this company at the assembly line or similar monotonous workplaces at least between 1996 and 2013 (i.e., for 17 years). The 17 years treatment window was chosen because at that time, in 1996, major changes in the work organization were implemented in that company.
With consent of the works council, the Human Resource Department selected 3,500 workers based on the following criteria: continuous low level of job complexity (no promotion or demotion) and full-time employment during the treatment phase of 17 years. Afterwards, the company distributed our screening questionnaire.

Ten female and 166 male workers returned the screening questionnaire which assessed the relevant matching variables and also indicated that they would be willing to undergo further testing at our laboratory (see below). On the basis of this information, respondents were organized into subgroups of gender (female/male), job level (skilled/unskilled production work), and age (30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and more than 60 years of age). We called all potential participants and led semi-structured telephone interviews in order to retrieve individual work biographies and determine their respective number of WTC between 1996 and 2013. Afterwards, participants with ‘multiple’ versus ‘zero or one’ WTC between 1996 and 2013 were matched on academic performance as well as engagement in mentally stimulating leisure activities and openness at baseline (within the subgroups of gender, job level, and age). In order to identify matched pairs, differences of half a standard deviation were used as a range of tolerance.

On the basis of this complex and controlled matching procedure we found 19 pairs of participants with ‘multiple’ versus ‘zero or one’ WTC between 1996 and 2013 ($N = 38$). Table 8 shows the similarity between the two quasi-experimental groups (except for the amount of WTC). It is important to note that due to a very small number of female workers that satisfied our original selection criteria, our study sample included only male participants. The study sample of 38 participants did not differ significantly from the initial 166 male workers who responded to the screening questionnaire with regard to age, years of education,
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academic achievement, health status, work ability, job level, leisure time activity, and openness in young adulthood.⁸

Table 8. Sample characteristics of the Mobilis study sample as a result of the matching process

<table>
<thead>
<tr>
<th>Matching variables</th>
<th>Work-task changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 or 1 (N = 19)</td>
</tr>
<tr>
<td>Age</td>
<td>46.95 (4.38)</td>
</tr>
<tr>
<td>Years of education</td>
<td>12.60 (0.82)</td>
</tr>
<tr>
<td>Gender (No. of male participants)</td>
<td>19</td>
</tr>
<tr>
<td>Job complexity (% of unskilled work)</td>
<td>74%</td>
</tr>
<tr>
<td>Grade point average (High school)</td>
<td>2.99 (0.40)</td>
</tr>
<tr>
<td>LEQ score (Young adulthood, reconstructed)</td>
<td>9.37 (2.99)</td>
</tr>
<tr>
<td>Openness to new experiences (Young adulthood, reconstructed)</td>
<td>3.32 (0.49)</td>
</tr>
<tr>
<td>Task changes</td>
<td>0.74 (0.45)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses. LEQ = Lifetime Experience Questionnaire. Significant group differences are in italics.

Measures

Screening questionnaire. The screening questionnaire was distributed via internal mail of the co-operating company and filled in at home prior to the matching process. It consisted of four parts. Part one gathered information on demographic variables (age, gender, educational attainment, years of education, family status, and number of children). Afterwards, a description of each position since 1996 was requested. Participants were asked for job title, content, average working hours per week, team size, and employment status. Part three of the screening questionnaire was used to assess engagement in mentally stimulating

⁸ A multivariate ANOVA with age, years of education, academic achievement, health status, work ability, job level, leisure time activity, and openness in young adulthood as dependent variables revealed no group differences between the study sample (N = 38) and the 166 workers who returned the screening questionnaire, $F(10,155) = 0.92, p = 0.50, \eta^2 = 0.05.$
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activities and openness in young adulthood. The fourth and last part captured the high school grade point average as marker for baseline cognitive functioning.

(i) Approximating leisure time activity in young adulthood. In order to assess leisure time activity in young adulthood, we used a translated version of the Lifetime of Experiences Questionnaire (LEQ; Valenzuela & Sachdev, 2007). The LEQ determines a person’s mental stimulation through education, complex occupations, and cognitively stimulating leisure activities across the lifespan. It comprises 42 items and is subdivided into age-specific and non-specific parts. Since we already had the information about education and occupational history, we excluded these items but used the remaining questions to assess former (in young adulthood) and current participation in a broad range of stimulating leisure time activities (e.g., reading, writing, giving lectures, playing a musical instrument, learning a second language, or being engaged in physical activity). The LEQ is a highly reliable instrument (test-retest reliability: $r = 0.98$) which was shown to be a valid predictor of longitudinal cognitive change as well as brain atrophy (Valenzuela & Sachdev, 2007; Valenzuela, Sachdev, Wen, Chen, & Brodaty, 2008).

(ii) Approximating openness in young adulthood. To approximate baseline openness, nine items were created on the basis of the German version of the Big Five Inventory (BFI; Rammstedt & John, 2005). In order to minimize recall errors and avoid ‘telescoping effects’ (Rubin & Baddeley, 1989) we created items that asked to recall behaviors linked with salient and noteworthy life-events (e.g., Belli, 1998; Coughlin, 1990). To further improve retrieval we used the item introduction to ask for specific living conditions and significant incidents during that period of their life (to set landmarks and create a temporal reference system; Friedenreich, 1994). A 5-point Likert scale (ranging from 1, completely disagree to 5, completely agree) was used to assess agreement with statements like “When I was 16 to 25 years old, I attended many different music events” or “When I was 16 to 25 years old, I traveled a lot”. The average of these nine items constituted a scale for (reconstructed)
openness in young adulthood ($\alpha = 0.68$). The bivariate correlation of this baseline openness measure with the openness scale of the German BFI version was very satisfactory ($r = 0.64$). It also correlated moderately high with scales of behavioral rigidity ($r = -0.23$; Krampen, 1977) and flexible goal adjustment ($r = 0.44$; Brandstädter & Renner, 1990) as well as the LEQ scale for mental activity in young adulthood ($r = 0.26$).

(iii) Approximating cognitive performance in young adulthood. Although meta-analyses have repeatedly shown that there is no relationship between cognitive ability and job mobility (Cotton & Tuttle, 1986; Griffeth, Hom, & Gaertner, 2000), we wanted to control for this possibility and used academic achievement as retrospective proxy variable for baseline intellect. It is widely accepted that cognitive ability is associated with academic achievement (Chamorro-Premuzic & Furnham, 2008). Ample research has established correlations of about 0.4 - 0.7 between IQ scores and school performance (Deary, Strand, Smith, & Fernandes, 2007). Indeed, measures of intelligence have originally been created to predict school preparedness (Binet & Henri, 1895). In addition to that, a recent meta-analysis found that out of 112 studies that were used to assess the relationship between personality traits and intellect, 86 utilized academic achievement as proxy variable of intellect. Next to intelligence tests, it was the most often employed indicator of cognitive functioning (von Stumm & Ackerman, 2013). Therefore, grade point averages were used as marker for baseline cognitive functioning. It was calculated as a mean of six grades retrieved from the graduation certificates of each participant: German, English, mathematics, physics (if not available: chemistry), history (if not available: geography), and arts. Bivariate correlations of these averages with the cognitive performance measures used below were again satisfactory ($r = 0.29 - 0.42$) and comparable to long-term correlations between grades and cognitive performance reported in the literature (Deary et al., 2007; Mackintosh, 1998).

(iv) Reconstruction of work biographies. Individual work biographies were retrieved via telephone. Four trained interviewers led semi-structured biographical interviews. Each
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interview started with the question “Which tasks and duties does your current position include? Please give a detailed description.” Afterwards, participants were asked “Were there ever any changes in your tasks and duties since 1996? If yes, when?” Subsequently, the interviewer went through the work biography in reverse. Each interviewee gave a detailed description of all tasks since 1996 (e.g., screw, weld, paint). Task changes were noted thoroughly. Afterwards, the number of WTC was determined for each participant in consensus meetings that involved all four interviewers as well as the Mobilis project members. In order to control for the potential influence of voluntariness in WTC, we additionally assessed voluntariness in each WTC over the 17-year period. For each WTC, participants were asked “Was this a voluntary work-task change?” A 5-point Likert scale (ranging from 1, absolutely voluntary to 5, absolutely not voluntary) was employed to indicate voluntariness.

Cognitive tests. All cognitive tests were administered as computer tasks on a black screen in a controlled laboratory setting. The order of the tasks was randomized for each participant.

(i) Processing speed was measured via two tasks: the visual search task (Hommel, Li, & Li, 2004) and the identical pictures test (Ghisletta, McArdle, & Lindenberger, 2006). The visual search task was similar to that used by Voelcker-Rehage and colleagues (2011), apart from the fact that we exclusively used conjunction searches with a set size of 14 stimuli. Participants had to search a target (filled white circle) among 14 unfilled circles and filled white squares and were instructed to press a left button with their left index finger if they found the target and press a right button with their right index finger in case they did not find it. It was emphasized to respond as quickly and as accurately as possible. In total, participants had to work on five experimental blocks with 80 trials each (50% target present trials). They were not given any practice run but received a standardized theoretical instruction and
illustrated examples. z-scores of the median reaction times and the response accuracy were used to create a composite z-score of the visual search task as outcome variable.

The identical pictures test is an adapted version of a test originally designed by Ekstrom and colleagues (Ekstrom, French, Harman, & Derman, 1976). It presents a target figure in the upper half and five response alternatives in the lower half of a computer screen. Subjects were instructed to identify as fast and as accurately as possible the one figure among the five response alternatives that equals the target figure and click on it (Ghisletta et al., 2006). Each trial ended at first response and was then followed by the next. In total, 46 trials were available. However, the test ended automatically after 80 seconds. According to the standard (see Ekstrom et al., 1976), the identical pictures test resorts to the number of correctly solved trials within this time frame to assess processing speed. Therefore, z-scores of the number of correctly solved trials within 80 seconds were used in the statistical analyses.9

(ii) Working memory performance was assessed with an N-back task (Dobbs & Rule, 1989; Jaeggi, Buschkuehl, Perrig, & Meier, 2010). Participants had to remember a span of separately presented letters and compare the current item with the one N items before. The task was administered at two levels of difficulty, as 1-back and 2-back task. In the 1-back task, participants were told to press a left button with their left index finger whenever the current letter equaled the one presented immediately before. If the current letter was different, they were instructed to press a right button with their right index finger (Voelecker-Rehage et al., 2011). Similarly, in the 2-back task, they had to press the left button if the current letter

9 It was important to us to find processing speed tasks with high external validity. We expected the two search tasks (visual search task & identical pictures test) to be more consistent with the reality of industrial production work than other processing speed measures. We combined these two measures because they imply differential levels of difficulty. Whereas in the visual search task participants have to compare simple geometric shapes, the identical pictures test uses more sophisticated figures. It forces participants much more than the visual search task to pay attention to details. In line with this rationale, visual search theory suggests that greater difficulty is more sensitive in carving out existing dissimilarities in cognitive functioning (Wolfe, 1997; 2007). That is, differential levels of difficulty in the visual search and identical pictures test may aggravate or mitigate existing dissimilarities in cognitive functioning between participants with multiple versus zero or one WTC.
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was equal to the one presented two items earlier, and press the right button if this was not the case. All subjects started with the 1-back task and were shown a randomized sequence of 80 letters at both levels of difficulty (37.5% match trials). Each letter was presented for approximately 1500 ms and was then followed by a fixation cross (exposure time = 300 ms). As in the visual search task, participants were not given practice trials. They received a standardized theoretical instruction and digitally illustrated examples in which it was emphasized to respond as accurately as possible. Response accuracy was used as outcome variable.

Results

Due to the rather small sample size, hypotheses were tested via one Multivariate Analysis of Covariance (MANCOVA)—rather than using multilevel modeling—with (a) a composite score for the visual search task which included z-scores of the median reaction time per trial as well as z-scores of the accuracy in the visual search task, (b) z-scores of the number of trials reached within 80 seconds in the identical pictures test, and (c) a composite z-score of the accuracies in the 1- and 2-back task as dependent variables. WTC (multiple versus zero or one) were included as independent variable. A composite LEQ score (Valenzuela & Sachdev, 2007) and its interaction with WTC served as covariates. The results for the main effects of WTC after controlling for leisure time activity can be found in Table 9.

Using Pillai’s trace, the multivariate statistics revealed a main effect of WTC on cognitive functioning, $F(3,32) = 2.81, p = 0.05, \eta^2 = 0.20$, as well as a marginally significant main effect of leisure time activity, $F(3,32) = 2.28, p = 0.09, \eta^2 = 0.17$, and a marginally significant interactive effect, $F(3,32) = 2.28, p = 0.09, \eta^2 = 0.17$. In order to control for the potential influence of voluntariness in WTC, we ran the same multivariate analysis additionally controlling for voluntariness of WTC over the 17-year period. Using Pillai’s trace, the main effect of WTC remained significant, $F(3,26) = 3.21, p = 0.03, \eta^2 = 0.27$. We
decided to accept this pattern of results as indication of a potential main effect of WTC and inspected the univariate statistics for processing speed and working memory performance.

Table 9. Cognitive performance by work-task changes (adjusted for leisure time activity)

<table>
<thead>
<tr>
<th>Indicators of cognitive performance</th>
<th>0 or 1 (N = 19)</th>
<th>Multiple (N = 19)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual search</td>
<td>-.64 (.66)</td>
<td>.67 (.66)</td>
<td>1.01</td>
<td>0.32</td>
</tr>
<tr>
<td>Identical pictures</td>
<td>-1.75 (.78)</td>
<td>1.75 (.78)</td>
<td>5.15</td>
<td>0.03</td>
</tr>
<tr>
<td>N-back</td>
<td>-1.23 (.54)</td>
<td>1.29 (.54)</td>
<td>5.59</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note. Indicators of cognitive performance are presented in composite z-scores. Standard errors are given in parentheses.

Processing speed. Univariate statistics depicted a significant main effect of WTC on the identical pictures test, $F(1,34) = 5.15, p = 0.03$, partial $\eta^2 = 0.13$ (see Table 9). Participants with multiple WTC reached higher performance in the identical pictures test ($M_{\text{multiple}} = 1.75, SE = .78$) than participants with zero or one WTC ($M_{0 \text{ or } 1} = -1.75, SE = .78$). Figure 3 illustrates these results. For ease of understanding, and independent of our statistical analyses, we took a direct look at the number of correct trials in the identical pictures test and plotted the results in Figure 4. These results illustrate that on a descriptive level, participants with multiple WTC processed more than 40% more correct trials within 80 seconds ($M_{\text{multiple}} = 41.69, SE = 4.03$) than participants with zero or one WTC ($M_{0 \text{ or } 1} = 24.44, SE = 3.83$).

The univariate statistics revealed no main effect of WTC on performance in the visual search task, $F(1,34) = 1.01, p = 0.32$, partial $\eta^2 = 0.02$. In order to get a better understanding of the visual search results, we split up the visual search composite score and analyzed reaction times and accuracy rates separately (adjusted for leisure time activity). On a
descriptive level, participants with multiple WTC displayed faster reaction times WTC ($M_{\text{multiple}} = 654.87$, $SE = 52.49$ versus $M_{0 \text{ or } 1} = 696.33$, $SE = 52.49$) and higher accuracy rates than participants with zero or only one WTC in 17 years ($M_{\text{multiple}} = 97.4$, $SE = 3.4$ versus $M_{0 \text{ or } 1} = 87.7$, $SE = 3.4$). The average reaction time and accuracy rate across all participants and conditions of the visual search task amounted to $M_{\text{all}} = 675.6$, $SE = 10.5$ and $M_{\text{all}} = 92.7$, $SE = 0.7$.

Figure 3. Identical pictures test and N-back performance by multiple versus zero or one WTC (adjusted for leisure time activity). (A) Estimated $z$-scores of the identical pictures test, (B) and N-back task by multiple versus zero or one WTC in 17 years, adjusted for engagement in mentally stimulating leisure time activities.
VI. COGNITIVE PLASTICITY STUDIED IN THE WILD

**Working memory.** We found a significant univariate effect of WTC on the N-back task, $F(1,34) = 5.59, p = 0.02$, partial $\eta^2 = 0.141$ (see Table 9 & Figure 3). Multiple WTC led to higher composite z-scores in the N-back task than zero or one WTC ($M_{\text{multiple}} = 1.29$, $SE = .54$ vs. $M_{0 \text{ or } 1} = -1.23$, $SE = .54$). Again, a more direct look at the accuracy rates of the 1- and 2-back task on a descriptive level revealed that participants with multiple WTC reached higher accuracy rates than participants with zero or one WTC in both the 1-back task ($M_{\text{multiple}} = 94.93$, $SE = 11.2$ vs. $M_{0 \text{ or } 1} = 70.57$, $SE = 10.6$) and the 2-back task ($M_{\text{multiple}} = 93.76$, $SE = 18.9$ vs. $M_{0 \text{ or } 1} = 37.28$, $SE = 18.0$). See Figure 4.

**Interaction analyses.** With regard to the interaction of WTC and leisure time activity, the univariate statistics yielded significant and marginally significant effects and reasonable effect sizes for performance in the identical pictures test and the N-back task, $F(1,34) = 4.33$, $p = 0.03$, $\eta^2 = 0.12$, and, $F(1,34) = 1.80$, $p = 0.05$, $\eta^2 = 0.10$. In terms of the identical pictures test, it seems that participants with the combination of zero or one WTC and leisure time inactivity depicted the lowest level of performance whereas those participants with multiple WTC and leisure time inactivity indicated the best performance. In the N-back task, participants with the combination of zero or one WTC and leisure time inactivity displayed the lowest accuracy rates, whereas participants with the combination of multiple WTC and high leisure time activity reached the highest accuracy rates. See Figure 5 for further information. However, a post-hoc analysis of the planned contrasts between all four factor combinations (zero or one WTC/inactive, zero or one WTC/active, multiple WTC/inactive & multiple WTC/active) did not corroborate these observations. There was no significant difference between any of the four factor combinations, neither in the identical pictures test

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Note that these values are logit-transformed. Since the original means were adjusted for the constant influence of leisure time activity they reached values above 100% accuracy (as a consequence of the statistical estimation procedure). For ease of presentation, we logit-transformed the raw n-back scores [$\ln(p/(1-p))$] and re-transformed the estimated values [$p=(e^{\text{logit}}/(1+e^{\text{logit}}))$] to obtain estimated n-back means between 0 and 1. The results of the MANCOVA and the univariate statistics are, however, reported on the basis of composite z-scores.
nor in N-back task. This inconsistent and somewhat weak pattern of results does not allow for a reliable conclusion.

**Discussion**

Based on the idea that recurrent confrontation with novel situations and unfamiliar problems is conducive to cognitive functioning, the present study analyzed the influence of multiple work-task changes (WTC) on two key indicators of intellectual performance—namely, processing speed and working memory. By employing a quasi-experimental study design with matched samples and controlling for the influence of mentally stimulating leisure time behavior, it was explored whether industrial production workers with multiple as opposed to zero or only one WTC in 17 years disclose higher levels of cognitive performance.

All in all, our results support the central hypothesis. Multiple WTC seem to facilitate cognitive functioning at low levels of job complexity.

After controlling for leisure time activity, we found a significant main effect of multiple WTC on both processing speed and working memory performance. Consistent with our hypotheses, participants with multiple WTC reached higher levels of performance in the identical pictures test and the N-back task than participants with zero or only one WTC. On a descriptive level, multiple WTC subjects processed more correct trials (and hence displayed faster reaction times) in the identical pictures test and reached higher levels of accuracy in the 1- and 2-back task than their counterparts. In both tasks, multiple WTC were associated with better cognitive performance.
Figure 4. Processing speed and working memory performance by multiple versus zero or one WTC (adjusted for leisure time activity). (A) The estimated average number of correct trials in the identical pictures test by multiple versus zero or one work-task changes. (B) The estimated average percentage of correct trials in the 1-back and (C) 2-back task by multiple versus zero or one work-task changes. All means are adjusted for engagement in mentally stimulating leisure time activities.
Our results revealed no main effect of multiple WTC on performance in the visual search task. We interpret this finding as a potential ceiling effect as a consequence of lower cognitive load in comparison to the identical pictures test. The average reaction time across all participants and conditions of the visual search task ($M_{all} = 675.6$ ms) was more than 200 ms lower than in a comparable subsample of the lifespan study by Hommel and colleagues (Hommel et al., 2004; $M_{Hommel, 45-55 \text{ years}} = 876$ ms). In addition, the standard deviation was only a fourth of that presented in Hommel's work ($SD_{all} = 65.1$ ms versus $SD_{Hommel, 45-55 \text{ years}} = 253$ ms). One explanation for the inconsistencies between the visual search task and the identical pictures test may be rooted in their differential level of difficulty. Whereas in the visual search task participants had to compare rather simple geometric shapes (find a filled white circle among black and white distractors), the identical pictures test uses more sophisticated figures. Further descriptive analysis of the visual search results disclosed that there were only marginal differences in median reaction times ($M_{\text{multiple}} = 654.8$ ms versus $M_{0 \text{ or } 1} = 696.3$ ms) but more distinct differences in accuracy rates ($M_{\text{multiple}} = 97.4\%$ versus $M_{0 \text{ or } 1} = 87.7\%$) between participants with multiple as opposed to zero or one WTC. These differences in accuracy rates cautiously corroborate the effect direction we found in the identical pictures test and the N-back task. There may be reason to assume that the ceiling effect of the visual search task is primarily represented in the reaction times (which were exceptionally low; cf. Hommel et al., 2004).

Given the compensating effect of mental stimulation during leisure time activities, we were also interested in the interactive effect of WTC and leisure time behavior. The results of the interaction analyses, however, were inconclusive. Although they revealed significant and marginally significant interactive effects on the identical pictures test and the N-back task, post-hoc analyses of the planned contrasts between the four factor combinations did not entail significant differences. This pattern of results does not allow for any reliable conclusion. Whether or not (and how) multiple WTC and leisure time behavior interact to foster or hinder
cognitive functioning, we cannot definitely say. One explanation may lie in our rather small sample size. With 38 participants in total and only eight to ten participants in each of the four factor combinations, the statistical power of our interaction analyses was low. However, it is speculation to assume that we would have been able to find clearer results with a greater sample size. And unfortunately, the literature on this topic is scarce. Recently, Andel, Silverstein, and Kåreholt (2015) were the first to investigate the interplay of work and leisure time. They suggested a compensatory relationship. It is worth to further examine particularly this issue.

Implications, Limitations and Future Directions

Why and how multiple WTC affect cognitive performance is an open question. We interpret our findings in such a way that multiple as opposed to zero or only one WTC in 17 years represent a work context that is characterized by repeated confrontation with new, yet unknown situations and cognitive challenges. And it is especially the recurrent confrontation with novelty that is essential to maintain (or spark positive changes in) adult cognitive functioning. To this respect, our findings extend our knowledge on the critical contextual features that foster cognitive plasticity: besides the complexity of a given task or situation (Schooler et al., 1999), we provided empirical evidence that recurrent exposure to novelty (at work or in general) may be another crucial component for positive plasticity to manifest (Bowen et al., 2011; Lövdén et al., 2010; Park et al., 2014).
Figure 5. Interactive effect of WTC and leisure time activity on processing speed and working memory performance. (A) $z$-scores of the identical pictures test by WTC (zero or one versus multiple) and leisure time activity (inactive versus active). (B) $z$-scores of the N-back task by WTC (zero or one versus multiple) and leisure time activity (inactive versus active).

Although this study uncovered some interesting results, it does have limitations. The first relates to the sample size. With 38 participants in total and 19 participants in each of the two experimental groups (multiple versus zero or one WTC), the statistical power of the analyses was low. Some effects may have failed to reach conventional levels of significance. Specifically, the multivariate results could have been clearer with a larger sample size. They
were now significant at a \( p \)-level of 0.05. Moreover, the results regarding the interaction analyses could have been stronger (see above). However, although our sample was rather small, it did not differ from the initial group of 166 male workers that returned the screening questionnaire on all relevant covariates. We interpret this fact as indication for the representativeness of our results.

Another limitation relates to the quasi-experimental research design. We were not able to randomize the study samples and manipulate WTC experimentally. We cannot entirely rule out the possibility that our effects are a consequence of selection biases. We tried to address this problem with an accurate matching of the two WTC groups (multiple versus zero or one) on all relevant covariates (Holland & Rubin, 1988). However, some of these covariates were assessed in retrospect. Although we are convinced that our approach minimized the likelihood of selection biases, we cannot guarantee their reliability. Within these limitations, however, our study can serve as first cautious hint that WTC could indeed be conducive to cognitive functioning and that it may be worthwhile to further investigate this concept in future work. Subsequent studies should then aim for longitudinal designs with pre- and post-assessment of all relevant covariates and measures of intellectual ability.

**Outlook and Conclusion**

Finally, two more topics should be addressed in future work. First, it will be interesting to study the effect of WTC on other indicators of cognitive functioning than processing speed and working memory. For instance, there could be effects of multiple WTC on inductive reasoning or episodic memory. Our rationale was that processing speed and working memory as fundamental cognitive processes and crucial limiting factors in any cognitive operation (Finkel et al., 2007; Salthouse, 1996) are rather sensitive in detecting possible effects (unlike higher order fluid abilities). A second avenue for the studies to come is the long-term effect of WTC. In the present work, we studied middle-aged workers (\( M_{age} = \))
47 years) in a treatment window of 17 years. It is an open question whether the small effects we found with this comparatively young sample would be more pronounced in an older population. There is reason, however, to assume that a career of multiple versus zero or only one WTC could unfold greater influence later in life. For instance, job complexity took greater effect in older than in younger workers (Schooler et al., 1999). Whether the same holds true for WTC is an interesting question that should be dealt with in future work.

In summary, the present study was the first to provide evidence that multiple WTC can have beneficial effects on adult cognitive functioning. By providing mental stimulation through repeated lateral and intra-organizational changes of the work task, multiple WTC offer a way to foster cognitive functioning at work not only in high but also in low complexity occupations. Moreover, our findings may extend the existing knowledge on the critical contextual features that foster cognitive plasticity: besides the complexity of a task or situation, recurrent exposure to novelty may be another crucial component for positive plasticity to manifest.
VII. TRANSITION BETWEEN STUDY 2 AND 3

Controlling for the influence of age, job level, and educational attainment, as well as leisure time activity and openness to experience at baseline, the behavioral experiments in Study 2 provided first evidence that industrial production workers who underwent multiple (i.e., two or more) WTC over 17 years depict higher levels of processing speed and working memory performance as compared to a matched control group of workers with zero or one WTC. There is thus justified reason to assume that recurrent exposure to novelty at work (indicated by multiple WTC in 17 years) can have the potential to diminish the negative impact of non-adaptive working conditions in long-term industrial production work (i.e., monotonous work, routinization, low job complexity) on cognitive functioning. It is an open question, however, how these effects are mediated on a neurophysiological level. It is likely that the differences in cognitive performance that were observed in Study 2 between workers with multiple versus zero or only one WTC are associated with differences on a neurophysiological level.

In the following, Study 3 will therefore explore whether multiple WTC have the potential to influence not only cognitive but also brain development. In particular, it investigates differences in gray matter (GM) volume between industrial production workers as a function of multiple versus zero or only one WTC in 17 years. Neuroscientists have repeatedly demonstrated regional GM volume gains in response to novel experience and skill acquisition. For instance, completing a golf license over several weeks, learning to decipher Morse code over four months, and musical training over seven months were shown to yield considerable gains in GM volume in regions associated with these activities (Bezzola, Merillat, Gaser, & Jäncke, 2011; Herdener et al., 2010; Schmidt-Wilcke, Rosengarth, Luerding, Bogdahn, & Greenlee, 2010). It is important to note, however, that such volume gains vary by region and are highly content-specific. Experienced string players, for instance,
VII. TRANSITION BETWEEN STUDY 2 AND 3

depicted particularly enlarged cortical hand representations (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). Similarly, London taxi drivers showed focal expansions of the posterior hippocampus as a consequence of the time they spent navigating the cab (Maguire, Woollett, & Spiers, 2006). Multiple as opposed to zero or only one WTC in 17 years represent a work context which may be characterized by recurrent skill acquisition and automation of new work routines. On a neurophysiological level, skill acquisition is mediated by a network of striatal, frontal, and motor cortical regions (Doyon & Benali, 2005). In addition to that, longitudinal studies of healthy aging have shown that with the exception of the hippocampal area, the greatest early decline in GM was investigated in striatal and frontal regions (Park & Reuter-Lorenz, 2009; Raz et al., 2005). That is why we expected multiple WTC to particularly affect gray matter volume in frontal and striatal regions.
VIII. STUDY 3

Don’t Lose Your Brain at Work – Work-Task Changes Are Associated With Greater Brain Volume in Striatal, Frontal, and Insular Regions

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Abstract

Despite considerable age-related changes, the brain retains a potential for plasticity, that is, for structural modifications in response to environmental demands. Full-time employees expose themselves to the demands of work for a large percentage of their waking hours. We therefore hypothesize that work demands influence the aging process of the brain. To date, however, the relationship between working conditions and brain structure has received only scant attention. Behavioral evidence suggests that high job complexity is conducive to cognitive functioning and even is associated with a lower risk of cognitive impairment and dementia. Based on the idea that neural plasticity is linked with recurrent learning and skill acquisition, we investigated the effect of multiple changes in work tasks (work-task changes; WTC) on gray matter volume in middle-aged production workers ($M_{age} = 47$ years; range = 38-54 years). In a case-control study design with matched samples ($N = 20$) and controlling for cognitively stimulating leisure-time activities, voxel-based morphometry (VBM) revealed that multiple WTC within 17 years were associated with more gray matter volume in striatal, frontal, and insular regions; regions that have been associated with learning and skill acquisition and that show pronounced age-related decline.
‘Cognitive aging’ circumscribes the fact that the cognitive system changes with age. On a neurophysiological level, cognitive aging denotes fundamental transformations in the structure of the brain. Amongst others, it brings about gray matter volume loss through cell shrinkage, synapse loss, and dendritic regression (e.g., Grady, 2012; Raz et al., 2005). Notwithstanding these age-related changes, the human brain depicts an enormous potential for plasticity, that is, for structural modifications in response to cognitive challenges and environmental demands (e.g., Draganski & May, 2008; Greenwood, 2007). Ample research provided evidence that, for example, a cognitively stimulating lifestyle (e.g., playing a musical instrument, learning a second language, being physically active) is associated with greater maintenance of gray matter volume in frontal, parietal and temporal regions (Bartrés-Faz et al., 2009; Valenzuela et al., 2008; Voelcker-Rehage & Niemann, 2013).

For full-time employees, work takes up a large percentage of their waking hours. Therefore, we claim that work demands have a strong influence on cognitive and brain aging. However, the literature to assess the relationship between working conditions and brain structure is scarce. Epidemiological and behavioral studies provided evidence that cumulative exposure to high job complexity (work that requires thought and independent judgment) is associated with better cognitive performance and a lower risk of cognitive impairment and dementia later in life (Bosma et al., 2003; Potter et al., 2007; Schooler et al., 1999). Recent neurophysiological work has suggested that extended phases of high job complexity (supervisory experience) in midlife are associated with reduced hippocampal gray matter loss in old age (Suo et al., 2012). Conversely, low levels of job complexity seem to have detrimental effects on brain and cognition. For instance, old assembly-line workers displayed lower performance and reduced electrophysiological brain activity in task switching than a matched control group in more complex work settings (Gajewski et al., 2010; Marquie et al., 2014). Jobs with low complexity, however, are making up a big share of the labor market (ILO Department of Statistics, 2015) and since population aging is influencing labor force
composition (Staudinger & Kocka, 2010), it seems more than timely to investigate ways to counteract these detrimental effects. This has been one of the purposes of the present study.

Laboratory and training studies suggest that it may specifically be novel experience and the learning of new skills as in learning to juggle (Boyke et al., 2008) or in learning to decipher Morse code (Schmidt-Wilcke et al., 2010) that activates positive changes in gray matter volume (also see Bezzola et al., 2011). In a controlled field study, we investigated whether the degree of exposure to novelty at work, at low levels of complexity, was associated with the degree of brain aging in full-time production workers within a time window of 17 years. In particular, we focused on one distinct job characteristic, and that is the degree to which (or the lack thereof) a worker had been recurrently confronted with novelty at work, in the sense that new tasks needed to be mastered. Specifically, we compared industrial production workers with either multiple (i.e., two or more) versus only one or zero cumulative work-task changes (WTC) within 17 years in terms of their gray matter volume. WTC refer to changes in work function, that is, intra-organizational changes of the work task, excluding promotion and demotion, in which each change implies to learn new skills or dealing with new materials. WTC un-confound the amount of cumulative cognitive challenge through novelty and changes in job complexity through upward/downward mobility. That is, WTC focus on novelty and keep complexity constant.

We expected multiple WTC in 17 years to be positively associated with greater maintenance of gray matter volume in production workers when compared to matched controls with only one or zero WTC. To our knowledge, this has never been tested. Thus, the present study was rather exploratory. From a theoretical point of view, several regions could benefit from multiple WTC. Repeated skill acquisition requires individuals to understand and reproduce skill characteristics and operational sequences. This is associated with the ability to temporarily store and update new information in working memory. In addition, procedures need to be automatized and streamlined in order to improve performance speed and accuracy.
VIII. DON’T LOSE YOUR BRAIN AT WORK

On a neurophysiological level, skill acquisition is mediated by the ‘cortico-striatal system’, a network of striatal, frontal, and motor cortical regions (Doyon & Benali, 2005). In line with this theory, frontal and bilateral striatal activation was found in the early stage of a kinematic motor adaption task along with activation in the pre-motor and supplementary motor cortex (Seidler, 2010). In addition to that, longitudinal studies of healthy aging have shown that with the exception of the hippocampal area, gray matter begins to shrink already in young adulthood (Greenwood, 2007). The greatest early decline was investigated in striatal and frontal regions (Park & Reuter-Lorenz, 2009; Raz et al., 2005). On the basis of these findings, we expected multiple WTC to particularly affect gray matter volume in frontal and striatal regions.

Materials and Methods

Study design and participants. As part of the interdisciplinary 'Mobilis' project our study was conducted with employees of a globally acting production company in Northern Germany. We used a case-control study design to investigate the effect of multiple WTC on production workers within a time window of 17 years. In order to control for selection biases, we applied a diligent matching procedure on a large number of baseline variables thought to affect the outcome measure (Holland & Rubin, 1988; Rubin, 1974). First, to avoid confounding influences of changes in job complexity (e.g., see Schooler, et al., 1999) or the work environment (e.g., company culture, working rules, etc.), all participants were production workers who had worked for the company at the assembly line or similar monotonous workplaces without interruption at least between 1996 and 2013. The 17 years treatment window was chosen because in 1996 the company undertook major changes in work organization. Next, we identified the following variables as important matching variables: age, job level (skilled versus unskilled production work), baseline cognitive functioning, leisure time activities (current and at baseline), and openness to experience (at
baseline). Current/baseline leisure time activities need to be taken into account in order to control for mental stimulation beyond work (e.g., playing a musical instrument, learning a second language, being physically active). Furthermore, seeking out or accepting task changes may be related to personality as indexed by openness to new experiences (as one of the so-called big five personality traits; McCrae, 1996). Openness to new experiences (hereafter: openness) goes hand in hand with behavioral flexibility and has been related to cognitive functioning (e.g., Gignac, 2005; Hogan et al., 2012). To control for the influence of these variables, closely matched pairs of participants were identified according to the following procedure.

With consent of the works council, the Human Resource Department of the company selected 3,500 production workers that were continuously full-time employed in low levels of job complexity (no promotion or demotion) during the treatment phase of 17 years. Afterwards, the company distributed a screening questionnaire that was used to assess all relevant matching variables. Ten female and 166 male workers returned the screening questionnaire. On the basis of this information, respondents were organized into subgroups of gender (female/male), job level (skilled/unskilled production work), and age (30-34, 35-39, 40-44, 45-49, 50-54, 55-59, and more than 60 years of age). We called all potential participants and led semi-structured telephone interviews in order to retrieve individual work biographies and determine their respective number of WTC between 1996 and 2013. Afterwards, participants with ‘multiple’ versus ‘zero or one’ WTC between 1996 and 2013 were matched on academic performance as well as engagement in mentally stimulating leisure activities and openness at baseline (within the subgroups of gender, job level, and age). In order to identify matched pairs, differences of half a standard deviation were used as a range of tolerance. On the basis of this matching procedure we found ten pairs of 'multiple' versus 'zero or one' WTC participants (N = 20). These 20 participants were then invited to take part in the Mobilis study. Table 10 shows the similarity between the two quasi-
experimental groups except for the level of WTC. Note that due to a very small number of female workers that satisfied our original selection criteria, our study sample included only male participants. The study sample of 20 participants did not differ significantly from the initial 166 male workers who responded to the screening questionnaire with regard to age, years of education, academic achievement, health status, work ability, job level, leisure time activity, and openness in young adulthood.11

Table 10. Sample characteristics of the Mobilis study sample for the neurophysiological experiments.

<table>
<thead>
<tr>
<th>Matching variables</th>
<th>Work-task changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 or 1 (N = 10)</td>
</tr>
<tr>
<td>Age</td>
<td>46.90 (4.22)</td>
</tr>
<tr>
<td>Years of education</td>
<td>13.00 (0.53)</td>
</tr>
<tr>
<td>Gender (No. of male participants)</td>
<td>10</td>
</tr>
<tr>
<td>Job complexity (% of unskilled work)</td>
<td>70%</td>
</tr>
<tr>
<td>Grade point average (High school)</td>
<td>3.01 (0.49)</td>
</tr>
<tr>
<td>LEQ score (Young adulthood, reconstructed)</td>
<td>9.50 (2.84)</td>
</tr>
<tr>
<td>Openness score (Young adulthood, reconstructed)</td>
<td>3.27 (0.54)</td>
</tr>
<tr>
<td>Task changes</td>
<td>0.80 (0.42)</td>
</tr>
</tbody>
</table>

Note. MRI = Magnetic resonance imaging. Standard deviations are in parentheses. LEQ = Lifetime Experience Questionnaire. Significant group differences are in italics.

Screening questionnaire. The screening questionnaire was filled in at home prior to the matching process. It gathered information on demographic variables (age, gender, educational attainment, years of education, family status, and number of children) and requested a description of each position since 1996 (job title, content, average working hours

11 A multivariate ANOVA with age, years of education, academic achievement, health status, work ability, job level, leisure time activity, and openness in young adulthood as dependent variables revealed no group differences between the study sample (N = 20) and the 166 workers who returned the screening questionnaire, $F(10,155) = 0.72, p = 0.70, \eta^2 = 0.04$. 

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per week, team size, and employment status). Additionally, it captured the high school grade point average as marker for baseline cognitive functioning and assessed engagement in cognitively stimulating activities and openness in young adulthood.

*Approximating cognitive performance in young adulthood.* Meta-analyses have repeatedly shown that cognitive ability and job mobility are not related (Cotton & Tuttle, 1986; Griffeth et al., 2000). Nevertheless, we wanted to rule out this possibility and used academic achievement as retrospective proxy variable for baseline cognitive functioning. Academic achievement is undoubtedly linked to cognitive ability (Chamorro-Premuzic & Furnham, 2008; Deary et al., 2007). In addition to that, a recent meta-analysis reported that next to intelligence tests, academic achievement is the most often employed indicator of cognitive functioning (von Stumm & Ackerman, 2013). Therefore, we used high school grade point averages as marker for baseline cognitive functioning. It was calculated as a mean of six grades retrieved from the graduation certificates of each participant: German, English, mathematics, physics (if not available: chemistry), history (if not available: geography), and arts. Bivariate correlations of these averages with the cognitive performance measures used below were satisfactory \( r = 0.29 - 0.42 \) and comparable to long-term correlations between grades and cognitive performance reported in the literature (Deary et al., 2007; Mackintosh, 1998).

*Approximating leisure time activity in young adulthood.* We employed a translated version of the Lifetime of Experiences Questionnaire (LEQ; Valenzuela & Sachdev, 2007) to capture leisure time activity in young adulthood. The LEQ determines a person’s mental stimulation through education, complex occupations, and cognitively stimulating leisure activities across the lifespan. We used it to assess former (in young adulthood) and current participation in stimulating leisure time activities (e.g., reading, writing, giving lectures, playing a musical instrument, learning a second language, or being engaged in physical activity). Whereas we employed leisure time activity in young adulthood as a matching
VIII. DON’T LOSE YOUR BRAIN AT WORK

variable, we used current leisure time activity as covariate in our general linear model (GLM). The LEQ is a highly reliable instrument (test-retest reliability: $r = 0.98$) which was shown to be a valid predictor of longitudinal cognitive change as well as of hippocampal atrophy (Valenzuela et al., 2008).

Approximating openness in young adulthood. To approximate baseline openness, we created nine items on the basis of the German version of the Big Five Inventory (BFI; Rammstedt & John, 2005). In order to minimize recall errors and avoid ‘telescoping effects’ (Rubin & Baddeley, 1989) participants were asked to recall behaviors linked with salient and noteworthy life-events (e.g., Belli, 1998; Coughlin, 1990). Additionally, the item introduction asked for specific living conditions and significant incidents in young adulthood (to further improve retrieval by setting landmarks and creating a temporal reference system; Friedenreich, 1994). A 5-point Likert scale (ranging from 1, completely disagree to 5, completely agree) assessed agreement with statements like “When I was 16 to 25 years old, I attended many different music events” or “When I was 16 to 25 years old, I traveled a lot”. The average of these nine items constituted a scale for (reconstructed) openness in young adulthood ($\alpha = 0.68$). The bivariate correlation of this baseline openness measure with the openness scale of the German BFI version was very satisfactory ($r = 0.64$). It also correlated moderately high with scales of behavioral rigidity ($r = -0.23$; Krampen, 1977) and flexible goal adjustment ($r = 0.44$; Brandstädter & Renner, 1990) as well as with our LEQ scale for cognitively stimulating activity in young adulthood ($r = 0.26$).

Reconstruction of work biographies. Individual work biographies had to be retrieved via telephone. Therefore, four trained interviewers led semi-structured biographical interviews, starting each interview with the open question “Which tasks and duties does your current position include? Please give a detailed description.” Subsequently, participants had to indicate whether there were any changes in these tasks and duties since 1996 and if yes, when. Then the interviewer went through the work biography in reverse. Each interviewee
was requested to give a detailed description of all tasks since 1996 (e.g., screw, weld, paint). Task changes were noted thoroughly. Afterwards, 'multiple' versus 'zero or one' WTC were determined for each participant in consensus meetings that involved all four interviewers as well as the Mobilis project members.

**MRI data processing and analysis.** Structural T1-weighted anatomical brain scans were acquired on a 3-Tesla Siemens Allegra whole-body magnetic resonance tomograph (MPRAGE sequence, TR of 2300 ms, 176 slices with $1 \times 1 \times 1$ mm$^3$ isotropic resolution). The anatomical brain scans were part of a larger MRI protocol. The entire MRI protocol lasted about 90 minutes.

Preprocessing and analysis of T1-weighted images were performed using the VBM 8 toolbox (http://dbm.neuro.uni-jena.de/vbm/; Structural Brain Mapping Group, University of Jena, Germany) in SPM8 (http://www.fil.ion.ucl.ac.uk/spm/; Wellcome Trust Centre for Neuroimaging, University College London, London, UK) running on MATLAB version R2011b (The MathWorks, Sherborn, MA, USA). We applied the standard VBM8 routines and default parameters. The preprocessing procedure implemented in VBM8 consists of (1) a correction for bias-field inhomogeneities, (2) a high-dimensional spatial DARTEL (Diffeomorphic Anatomical Registration Through Exponentiated Lie Algebra) normalization into MNI (Montreal Neurological Institute) space, (3) tissue segmentation into gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF), and (4) a modulation step in which GM images were multiplied by the local value derived from the deformation field (in order to account for individual brain size differences and restore within-voxel volumes that may have been altered during normalization). The modulated GM volumes were smoothed with an 8 mm FWHM (full width half maximum) Gaussian kernel. The normalized, modulated, and smoothed GM images were used for statistical analyses.

**Statistical analysis.** Comparisons of regional GM volumes between participants with multiple versus zero or only one WTC in 17 years were performed using both voxel- and
cluster-level inference within the framework of the GLM. Full-factorial ANCOVA was used to investigate regional GM volume differences across the whole brain between the two groups. Current participation in cognitively stimulating leisure time activities was added to the model as covariate. Prior to analysis, GM volumes with less than 0.2 tissue class probability were excluded. Due to our very small sample size, statistical parametric GM maps were thresholded with $p < 0.001$ (uncorrected). We used the empirically determined extent threshold of $k = 56$ voxels per cluster to correct for multiple comparisons. That is, only voxel clusters exceeding a size of more than 56 voxels will be reported.

*Correlating individual brain volume with cognitive performance.* Since this study was part of a larger study protocol within the Mobilis project, we had individual data on processing speed and working memory performance available. We aimed to use this information in order to validate potential group differences in regional GM volume. Therefore, we extracted individual GM volumes from significant VBM clusters with the help of the MarsBar toolbox for SPM (http://marsbar.sourceforge.net) and related the size of each cluster with processing speed and working memory performance (in a partial correlation analysis, controlling for current leisure time activity). Processing speed and working memory are known to be key indicators of cognitive functioning (Salthouse, 1996; Finkel et al., 2007). Processing speed was measured via the identical pictures test (Ghisletta et al., 2006). It presents a target figure in the upper half and five response alternatives in the lower half of a computer screen. Subjects were instructed to identify as fast and as accurately as possible the one figure among the five response alternatives that equals the target figure and click on it (Ghisletta et al., 2006). In total, 46 trials were available. However, the test ended automatically after 80 seconds. According to the standard (see Ghisletta et al., 2006), the identical pictures test resorts to the number of correctly solved trials within this time frame as a measure of processing speed. Therefore, $z$-scores of the number of correctly solved trials within 80 seconds were used in the statistical analyses.
Working memory performance was assessed with an N-back task (Jaeggi et al., 2010). Participants had to remember a span of separately presented letters and compare the current item with the one N items before. The task was administered at two levels of difficulty, as 1-back and 2-back task. In the 1-back task, participants were instructed to press a left button with their left index finger whenever the current letter equaled the one presented immediately before, and press a right button with their right index finger if the current letter was different from the one presented immediately before. Similarly, in the 2-back task, they had to press a left button if the current letter was equal to the one presented two items earlier, and press the right button if this was not the case. All subjects started with the 1-back task and were shown a randomized sequence of 80 letters at both levels of difficulty (37.5% match trials). z-scores of the response accuracies of the 1-back and 2-back tasks were used to create a composite n-back score as outcome variable.

Results

The VBM analysis revealed five regions with significant differences in regional GM volume between participants with multiple versus zero or one WTC in 17 years (see Table 11; Figure 6). Specifically, we found four voxel clusters in which participants with multiple WTC indicated more GM volume than participants with zero or one WTC: two clusters comprised lower parts of the left and right caudate, one of them extending into the right rostral anterior cingulate cortex (ACC). In addition to that, there were another two clusters in the right medial frontal gyrus and in the left insula. In contrast, production workers with zero or one WTC showed more GM volume in one cluster in the left inferior temporal gyrus, thereby indicating a negative relationship between GM volume and WTC in this region.
### Table 11. Regional differences in gray matter volume between production workers with multiple versus zero or one WTC (adjusted for leisure time activity)

**Contrast: Multiple WTC > Zero or one WTC**

<table>
<thead>
<tr>
<th>Region</th>
<th>Hemisphere</th>
<th>Letter in Figure 2</th>
<th>MNI coordinates</th>
<th>Cluster size</th>
<th>t-value (df = 15)</th>
<th>p &lt; 0.001 (unc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caudate/ ACC</td>
<td>R</td>
<td>a</td>
<td>11 21 -6</td>
<td>195</td>
<td>4.91</td>
<td></td>
</tr>
<tr>
<td>Caudate</td>
<td>L</td>
<td>b</td>
<td>-5 11 -3</td>
<td>62</td>
<td>4.47</td>
<td></td>
</tr>
<tr>
<td>Medial frontal gyrus</td>
<td>R</td>
<td>c</td>
<td>11 44 -14</td>
<td>67</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>Insula</td>
<td>L</td>
<td>d</td>
<td>-36 6 4</td>
<td>109</td>
<td>4.86</td>
<td></td>
</tr>
</tbody>
</table>

**Contrast: Zero or one WTC > Multiple WTC**

<table>
<thead>
<tr>
<th>Region</th>
<th>Hemisphere</th>
<th>Letter in Figure 2</th>
<th>MNI coordinates</th>
<th>Cluster size</th>
<th>t-value (df = 15)</th>
<th>p &lt; 0.001 (unc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferior temporal gyrus</td>
<td>L</td>
<td>e</td>
<td>-56 -21 -29</td>
<td>267</td>
<td>5.95</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* WTC = Work-task changes, MNI = Montreal Neurological Institute, k = extent threshold, ACC = Anterior cingulate cortex, p = significance threshold, R = right, L = left
In a follow-up analysis and in order to validate the factual importance of the regions detected in our VBM analysis, we correlated the individual cluster size of each of these clusters with processing speed and working memory performance, respectively. Results suggest moderately high correlations between performance in the identical pictures test (but not the N-back task) and the four clusters that were positively associated with WTC: particularly the two clusters comprising the left and right caudate and rostral ACC but also the two clusters in the left insula and the right medial frontal gyrus depicted moderately high correlations between $r = 0.22$ and $r = 0.46$ with performance in the identical pictures test. That is, the more GM volume we observed in these regions the more correct trials an individual reached in the identical pictures test. In contrast, the one cluster in the left inferior temporal gyrus that was negatively related to WTC did not show any significant correlation with processing speed (see Table 12).
Figure 6. Gray matter volume differences between production workers with multiple versus zero or one WTC (adjusted for leisure time activity). Red and blue clusters indicate significantly more (red, a-d) or less (blue, e) gray matter volume in participants with multiple WTC as opposed to participants with only one or zero WTC. Multiple WTC were associated with more gray matter volume in the left (a) and right caudate (b), as well as in the medial frontal gyrus (c) and the insular cortex (d). Zero or one WTC were associated with more gray matter volume in the inferior temporal gyrus (e). The letter 'R' indicates the right hemisphere. Letters a, b, c, d, e refer to the voxel clusters depicted in Table 1. x, y and z specify the MNI coordinates.
Discussion

Based on the idea that recurrent novel experience at work and the learning of new skills and materials are conducive to the maintenance of gray matter (GM) volume, the present study investigated the effect of multiple work-task changes (WTC) on regional GM volume in middle-aged production workers. We used a case-control study design with matched samples and controlled for the influence of cognitively stimulating leisure time activities in order to explore differences in regional GM volume between participants with work biographies that are shaped by multiple versus zero or only one WTC in 17 years. Our results suggest that multiple WTC are positively associated with GM volume in parts of the left and right caudate, the right rostral anterior cingulate cortex (ACC), the left insular cortex, as well as the medial frontal gyrus. In addition to that, we found that individual GM volume in these regions (left and right caudate, right rostral ACC, and left insular cortex) was positively correlated with performance in the identical pictures test (Ghisletta et al., 2006), a cognitive performance test measuring speed of processing. In contrast, zero or one WTC as compared to multiple WTC were associated with more GM volume in parts of the inferior temporal gyrus. However, GM volumes in this region were not related to processing speed performance.

All in all, these results corroborate and extend our initial assumptions. We expected WTC to correlate positively with GM volume in frontal and striatal regions, because frontal and striatal regions are heavily involved in motor learning and skill acquisition and particularly affected by early GM volume loss. According to Doyon and Benali (2005), skill acquisition follows several distinct learning stages such as consolidation and automation in which acquisition and execution of newly learned skills are mediated by a network of striatal, frontal, and motor cortical regions (‘cortico-striatal system’). In line with this theory, Seidler (2010) found bilateral striatal activation along with activation in the frontal, pre-motor, and supplementary motor cortex in the early stage of a kinematic motor adaption task. In addition to that, overall GM volume shrinks by approximately 14% across the lifespan (Jernigan et al.,
2001) and begins to decrease already after young adulthood (with the exception of the hippocampus which seems to depict no shrinkage before the age of 50; Greenwood, 2007). The greatest early GM volume loss has been observed particularly in the caudate and frontal regions (Lockhart & DeCarli, 2014; Park & Reuter-Lorenz, 2009; Raz et al., 2005; Taki et al., 2013). That is, if at all we could expect differences in GM volume between our two middle-aged samples, they were very likely to manifest in striatal and frontal regions.

**Table 12.** Correlations of average gray matter volumes in significant clusters with cognitive performance (adjusted for leisure time activity)

<table>
<thead>
<tr>
<th>Brain areas</th>
<th>Hemisphere</th>
<th>Letter in Figure 1</th>
<th>Indicator of cognitive performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Identical pictures</td>
</tr>
<tr>
<td>Caudate /ACC</td>
<td>R</td>
<td>a</td>
<td>.403†</td>
</tr>
<tr>
<td>Caudate</td>
<td>L</td>
<td>b</td>
<td>.466*</td>
</tr>
<tr>
<td>Medial frontal gyrus</td>
<td>R</td>
<td>c</td>
<td>.227</td>
</tr>
<tr>
<td>Insula</td>
<td>L</td>
<td>d</td>
<td>.346</td>
</tr>
<tr>
<td>Inferior temporal gyrus</td>
<td>L</td>
<td>e</td>
<td>-.126</td>
</tr>
</tbody>
</table>

*Note. Average gray matter volumes were partially correlated with composite z-scores of performance in the identical pictures test and N-back task. ACC = Anterior cingulate cortex; R = right; L = left; * = p < 0.05; † = p < 0.1.*

We interpret our findings such that multiple as opposed to zero or only one WTC in 17 years at a low level of job complexity represent a work context that is characterized by repeated confrontation with novelty at work (e.g., recurrent skill acquisition, automation, and motor adaption) which facilitated plasticity of GM volume in striatal and frontal regions. In the context of long-term exposure to the detrimental effects of repetitive and monotonous production work, multiple as compared to zero or one WTC may have placed higher demands on the ‘cortico-striatal system’ which in turn affected GM volume in parts of the medial frontal gyrus as well as in the left and right caudate. Interestingly, both striatal and frontal
regions are also part of the dopamine system (Li et al., 2010; Samanez-Larkin et al., 2012) which is assumed to play an essential role in rewarded learning (Bäckman, et al., 2010; Shohamy & Wimmer, 2013). At the same time, it is known that dopaminergic receptors decrease with age, mainly in the caudate but also in frontal regions and the ACC (which is associated with cognitive decline; see the ‘correlative triad’ between age, dopamine receptor loss, and cognitive functioning; Bäckman et al., 2010; Li et al., 2001). Thus there may be reason to assume that recurrent learning experience in repeated skill acquisition and automation of new work procedures under multiple WTC as opposed to prolonged routine under zero or one WTC affected the dopamine receptors in striatal and frontal areas and diminished age-related receptor loss in these regions.

The mechanisms that underlie the effect of WTC on GM volume in the rostral ACC and the insular cortex may be more difficult to understand. However, both regions depict age-related GM volume loss (Mann et al., 2011; Taki et al., 2013) and both regions seem to be related to learning processes and cognitive functioning. The ACC is commonly involved in error detection and conflict monitoring (Bush et al., 2000; Elmer et al., 2014). Experimental research has provided evidence for the monitoring role of the ACC in executive functioning (Abutalebi et al., 2012; Elmer et al., 2014). In five to ten year-old children, ACC activation mediated age-related improvements on the Simon task. The insular cortex, on the other hand, is involved in a multitude of processes. Next to visceral and autonomic activities such as heart rate, bladder, and bowel distension, there is evidence that it plays an important role in cognitive functioning (e.g., Nelson et al., 2010). For instance, the insular cortex was related to working memory performance, processing speed, and executive functioning (Müller et al., 2014; Ruscheweyh et al., 2013; Zakzanis et al., 2005). Indeed, it has been stated that a functional network involving the insular cortex and parts of the ACC and the medial frontal cortex are among the most frequently activated brain regions in any cognitive task (Ebisch et al., 2013). The connectivity strength of this network has been linked to higher levels of
performance in tests of executive functioning and logical reasoning (Ebisch et al., 2013; Müller et al., 2014).

It is an interesting observation that participants with zero or only one WTC in 17 years disclose more GM volume in parts of the inferior temporal gyrus than their multiple WTC counterparts. The inferior temporal gyrus is typically known to be a higher level component of the ventral stream. As such, it is critically involved in the visual identification of objects such as faces and hands (Gross, 2008; Milner & Goodale, 2008). Amongst others, GM volume in the inferior temporal gyrus has been positively related to manual dexterity (Kühn et al., 2012). The authors argued that manual dexterity implies precise, spatially and temporarily coordinated, and visually controlled hand movements which necessitate permanent object recognition. How this may be related to WTC is a question we can only speculate about. It is possible, that prolonged routine and automation of hand movements under zero or one WTC as compared to repeated changes under multiple WTC require a higher need for resources in the inferior temporal gyrus and yield increased synaptogenesis (or at least reduced GM loss) in this region. However, our data suggests that there is no link between GM volume in the inferior temporal gyrus and processing speed performance. To our knowledge, this is consistent with the existing literature. It will be interesting to see whether future studies corroborate our finding.

Implications, Limitations, and Future Directions

Our results provide a first hint that WTC may positively affect GM volume in striatal, frontal, and insular regions; regions that depict pronounced age-related decline and that have shown to be critically involved in skill acquisition, learning processes, and cognitive functioning. Building on such findings one might argue that cumulative long-term negative effects of low complexity work could be avoided by systematically introducing work-task changes. With this, our work is not only one of the first studies that related working
conditions to brain structure but also the first study to find a feasible way to diminish cumulative long-term effects of low job complexity on brain aging, independent of cognitively stimulating leisure time behavior. Therefore, multiple WTC offer a strategic occupational health management instrument to sustain regional GM volume in middle-aged production workers. It may be worthwhile to further investigate this concept in future research. On a more general level, it is important to note that our results provide evidence that recurrent exposure to new work tasks and novel work situations over a prolonged period of time (in our case 17 years) may have the potential to facilitate neural plasticity.

On the basis of our data, we cannot disentangle the mechanisms that underlie the promising effect of WTC. Whether the regional GM volume differences between participants with multiple versus zero or only one WTC in 17 years are a consequence of increments in GM or a consequence of reduced loss under multiple WTC, we cannot say. As we interpret our results, repeated confrontation with novel experience, skill acquisition, and automation of new routines places higher demands on the cortico-striatal (and perhaps the dopamine) system. These characteristics may spark neural scaffolding processes (e.g., augmented synaptogenesis; see Markham & Greenough, 2004; also see Park & Reuter-Lorenz, 2009; Petersen, van Mier, Fiez, & Raichle, 1998). On the other hand, increased disuse of the cortico-striatal (and dopamine) system in zero or only one WTC may aggravate cognitive aging through reductions in neural activity and decreases in synapse numbers (Hubel & Wiesel, 1965; Kleim & Jones, 2008). However, our work does not allow final conclusions about these mechanisms. This is an avenue for future research.

Another question which has to be answered in future research relates to the effects of multiple WTC in late life. The present study investigated middle-aged production workers ($M_{age} = 47$ years) and found regional GM volume differences between participants with multiple versus zero or only one WTC in 17 years. The available literature indicates that these effects can be deteriorated later in life when the processes of brain aging gain in severity. On
a behavioral level, high job complexity in mid-life was shown to unfold greater influence on cognitive functioning in late-life (Schooler et al., 1999). On neurophysiological level, this was accompanied by reduced volume loss in old age (Suo et al., 2012).

One limitation of our study was that, although our sample seems to be representative of the initial group of 166 workers that returned the screening questionnaire, we had only 20 participants in total and ten participants in each of the two experimental groups (multiple versus zero or one WTC). That is why we had to report VBM results at an uncorrected level, thresholded with $p < 0.001$. To correct for multiple comparisons we applied an (empirically determined) extent threshold of $k = 56$ voxels and thus were able to identify only larger voxel clusters of GM volume differences. There is reason to assume that our results could have been stronger with a greater sample size. A second limitation relates to the case-control study design. We did not have pre- and post-assessments of GM volume and could not manipulate the number of WTC experimentally. As a consequence, we cannot entirely rule out the possibility of selection biases. Our hope is that we minimized this problem with an accurate matching of the experimental- and control group on all relevant covariates. But some of these covariates had to be assessed retrospectively and we cannot guarantee their reliability. In order to further scrutinize our findings, future studies should aim for longitudinal designs with greater sample sizes and pre- and post-assessment of all relevant covariates and measures of GM volume.

Within these limitations, however, our results may give first cautious hints that multiple WTC (i.e. recurrent confrontation with new work tasks and novel work situations) can spark neural plasticity, especially in striatal, frontal, and insular regions; regions that (1) show pronounced age-related GM volume loss, (2) are important agents in learning and skill acquisition, and (3) seem to be critically involved in cognitive functioning. With this, the present study may have presented a strategic instrument to diminish cumulative long-term effects of low job complexity, independent of cognitively stimulating leisure time behavior.
and already in mid-life. It may therefore be worthwhile to further investigate the concept of WTC in future research.
IX. DISCUSSION

In Germany as well as in most industrialized countries of the Western hemisphere, the workforce is constantly ‘aging’ (Shannon, 2013; Statistisches Bundesamt, 2014). Increasing age, however, is associated with a number of health risks (e.g., Dekkers-Sánchez et al., 2008; Lidwall, et al., 2009). Age-related cognitive decline may be a particular challenge to psychological health at work. Good mental health is but a necessary prerequisite to preserve well-being, work ability, and good productivity. Although the detrimental mechanisms of low mental stimulation at work on brain and cognition have been well-established for more than three decades (Kohn & Schooler, 1978), no research has been conducted on how to counteract these effects. Therefore, this dissertation set out to fill this gap. Adopting a lifespan perspective on occupational health, I aimed to identify important mechanisms that facilitate positive plasticity in adult cognitive functioning in order to apply these mechanisms to the work context and investigate their potential to diminish the negative long-term effects of low mental stimulation at work on a behavioral and neurophysiological level. In order to do so, I conducted three studies: a conceptual literature review which systematized the available evidence on 'in vivo' mental stimulation as well as two experimental studies that investigated the effect of multiple work-task changes (WTC) on the cognitive functioning and brain anatomy of long-term industrial production workers.

Review of the Findings

The literature review in Study 1 brought to light that the careless use of composite scores of mental stimulation with varying combinations of leisure time behavior at least partly accounts for the existing inconsistency in the findings on 'in vivo' mental stimulation. In many studies there were great differences with regard to how composite scores were created. Some
IX. DISCUSSION

studies considered a broad range of behavior, spanning activities such as reading and writing, playing games or a musical instrument, volunteering, attending educational courses, or working with a computer (e.g., Salthouse et al., 2002; Schinka et al., 2005). In contrast, other studies focused on a small number of very specific activities (e.g., Wilson et al., 2003; 2005). Great diversity also exists in terms of whether physical activity or social components were included in composite scores of mental stimulation (e.g., Arbuckle et al., 1986; Christensen et al., 1996; Newson & Kemps, 2005; Yu et al., 2009).

Study 1 further revealed that there is reason to discuss at least two characteristics of mentally stimulating behavior that seem to be critical to cognitive plasticity: Besides the complexity of a given (work) situation, active learning and novelty are important contextual features in order for positive plasticity to manifest. In contrast to that, the effect of passive information processing on cognitive performance may be less distinct. For instance, technology use and developmental activity were repeatedly associated with better memory performance whereas watching TV and experiential activity were not (Jopp & Hertzog, 2010). Similarly, although an active lifestyle and novel information processing were both associated with better cognitive functioning at baseline, only novel information processing was related to changes in cognition over six and 18 years (Hultsch et al., 1999; Mitchell et al., 2012). In addition to that, several experimental studies provided evidence that cognitive functioning could be improved more effectively by active learning rather than by receptive engagement (Chan et al., 2014; Park et al., 2014).

On the other hand, Study 1 provided sound evidence for a link between job complexity and cognitive functioning (Fisher et al., 2014; Schooler et al., 1999; 2004). Interesting results also exist for the more specific association between complexity with people and data (but not things) and processing speed and visuospatial ability (Finkel et al., 2009). However, the literature review in Study 1 also brought to light that the effect of mental stimulation on cognitive functioning is probably not domain-specific. Most cognitive abilities seem to
IX. DISCUSSION

benefit from learning and novel information processing in a similar way. Spatial abilities may
be an exception to this rule.

Based on these insights, Study 2 investigated the influence of multiple WTC (as an
indicator of recurrent exposure to novelty at work) on processing speed and working memory
performance in long-term industrial production workers. Due to highly standardized and
monotonous work routines as well as minimal decision latitude, industrial production work is
characterized by low levels of mental stimulation. This has been linked with lower levels of
cognitive performance (Schooler et al., 1999; 2004) and maladaptive neuropsychological
functioning in task switching (Gajewski et al., 2010) as well as with a higher risk of cognitive
impairment (Bosma, van Boxtel, Ponds, Houx, Burdorf, & Jolles, 2003) and dementia (Andel
et al., 2005; Potter, Helms, Burke, Steffens, & Plassman, 2007). Multiple WTC imply
recurrent confrontation with novel work situations, new skill learning, and unfamiliar work
tasks over a prolonged period of time. WTC were therefore hypothesized to counteract non-
adaptive 'routinization' and provide the novelty that seems vital to cognitive plasticity (also
see Bowen et al., 2011; Carlson et al., 2012; Park et al., 2013; Tournier et al., 2012).

Controlling for the influence of age, job level, and educational attainment, as well as
leisure time activity (at outcome and at baseline), and openness to experience (at baseline),
Study 2 revealed that industrial production workers who underwent multiple WTC over 17
years showed higher levels of processing speed and working memory performance as
compared to a matched control group of workers with zero or one WTC. In both tasks,
multiple WTC were associated with better cognitive performance. There is thus justified
reason to assume that recurrent exposure to novelty at work can have the potential to diminish
the negative impact of non-adaptive working conditions in industrial production work (e.g.,
monotonous work, routinization, low job complexity) and facilitate positive cognitive
plasticity at low levels of job complexity.
IX. DISCUSSION

Finally, Study 3 investigated differences in regional gray matter (GM) volume between industrial production workers with multiple versus zero or only one WTC in 17 years. The results disclosed that multiple WTC were positively associated with more gray matter volume in frontal, striatal, and insular regions. Moreover, the individual GM volumes in these regions were positively correlated with processing speed performance. In contrast, participants with zero or only one WTC in 17 years depicted more GM volume in parts of the inferior temporal gyrus than subjects with multiple WTC. However, individual GM volumes in this region were not related to cognitive functioning. Study 3 therefore provided first cautious hints that multiple WTC could be conducive to regional GM volume at a low level of job complexity, especially in striatal, frontal, and insular regions; regions that (1) show pronounced age-related volume loss, (2) are important agents in learning and skill acquisition, and seem to be (3) critically involved in cognitive functioning. With this, the results of Study 3 corroborate and extend the findings of Study 2. They point out that recurrent exposure to novelty at work (indicated by multiple WTC) over 17 years has the potential to facilitate not only cognitive but also neural plasticity.

Novelty and Learning as Facilitators of Cognitive Change

Besides the complexity of a given task or situation, active learning and novelty are important contextual characteristics in order to leave average trajectories of adult cognitive development and trigger positive changes in cognitive functioning across time. This has been one of the main conclusions of the literature review in Study 1 and has been confirmed in the behavioral experiments in Study 2. This observation is in line with theoretical discussions of cognitive plasticity as well as with recent empirical evidence suggesting that variety in mental stimulation may be more important in terms of plasticity than the frequency of participation in mentally stimulating activities (Carlson et al., 2012). The MRI experiment in Study 3 corroborated these results on a neurophysiological level. It disclosed that recurrent novelty
and learning at work may have the potential to facilitate neural plasticity (e.g., neural scaffolding processes; Reuter-Lorenz & Park, 2014) in specified brain regions. With this, our findings extend the existing knowledge on the critical contextual features that foster cognitive and neural plasticity: besides the complexity of a given task or situation (Schooler et al., 1999), recurrent exposure to novelty (at work or in general) is another crucial component for positive plasticity to manifest.

According to the influential framework by Lövdén and colleagues, manifestations of plasticity occur only to the extent that an individual encounters a mismatch between his or her functional supply and the environmental demands (see above; Lövdén et al., 2010). If a cognitive system can effortlessly respond to a specific demand, no mismatch arises and no cognitive changes are induced. On the other hand, if environmental demands exceed the current range of cognitive capacity, a mismatch (and thus cognitive change) is absent as well. The cognitive system thus needs to be challenged optimally. Lövdén and colleagues do not state, however, which environmental characteristics are needed to induce such challenges. Against the background of the findings in this dissertation, it must be stated that novelty and learning (next to complexity) seem critical in order to facilitate positive changes in brain anatomy and cognitive functioning.

Lövdén and colleagues further explicate that the degree and likelihood of plasticity depend on the range of flexibility, that is, the capacity to process environmental stimuli by activating already existing neural representations (Lövdén et al., 2010). A more flexible individual can handle a larger range of environmental stimuli. And the bigger the range of flexibility, the less likely (or the less severe) is a mismatch between functional supply and environmental demands and the less likely are manifestations of plasticity. This assumption could implicate, however, that highly challenging (or highly complex) activities such as learning a foreign language or playing a musical instrument may be less stimulating as soon as a certain level of proficiency and routine is achieved. And indeed, routinization has been
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negatively associated with cognitive performance (Tournier et al., 2012). Similarly, preferences for routine were positively correlated with cognitive decline (Bergua et al., 2006). In addition to that, there is empirical evidence which suggests that variety in mental stimulation is more important in activating plasticity than the complexity/cognitive challenge associated with these activities (Carlson et al., 2012). That is, it is possible that cognitive variety/novelty could be more stimulating than complexity/cognitive challenge in case the latter has become a non-adaptive routine. On the other hand, the effect of variety/novelty may only shine through against lower levels of complexity/cognitive challenge. In that sense, variety and novelty may lose their impact on the cognitive system when compared to prolonged routine in highly complex/challenging activities. This is an interesting debate and a valuable avenue for future research. On the basis of my dissertation, however, I cannot resolve this discussion.

**Periodical WTC Buffer Cognitive and Brain Aging in Long-Term Production Work**

As elucidated above, industrial production work is characterized by low levels of mental stimulation. This has been linked with detrimental effects on brain and cognition. The behavioral and neurophysiological results in Study 2 and 3, however, point out that long-term industrial production workers whose work biographies are shaped by multiple as compared to only one or zero WTC in 17 years, depicted higher average levels of performance in two key indicators of cognitive functioning as well as more GM volume in (sub-)cortical regions which have been associated with learning and skill acquisition and which show pronounced age-related decline. There is hence justified reason to state that multiple WTC may have the potential to counteract the detrimental effects of long-term industrial production work on brain and cognition. With this, my dissertation is not only one of the first scientific projects to relate working conditions with both cognitive and brain development but also one of the first
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successful attempts to diminish cumulative long-term effects of low job complexity, independent of cognitively stimulating leisure time behavior.

On the basis of my analyses, I can unfortunately not disentangle the mechanisms that underlie the intriguing effect of multiple WTC. Whether the group differences in cognitive functioning and gray matter volume I found between participants with multiple versus only one or zero WTC are a consequence of positive plasticity (in terms of positive changes in regional GM volume and cognitive functioning) or a consequence of reduced decline/loss in workers with multiple WTC, I cannot say. As I interpret my results, multiple WTC represent work biographies that are shaped by repeated confrontation with novelty, skill acquisition, and automation of new routines. Due to higher demands on the cognitive system, these characteristics may have sparked positive changes in cognitive functioning and brain anatomy (e.g., mediated through supply-demand mismatches and neural scaffolding processes; Lövdén et al., 2010; Reuter-Lorenz & Park, 2014). On the other hand, increased disuse of the cognitive system in participants with only one or zero WTC may have aggravated cognitive and brain aging (e.g., Denney, 1984; Hubel & Wiesel, 1965). However, the results in my dissertation do not allow final conclusions about these mechanisms.

Regardless of these rather theoretical considerations, my findings may have important practical implications. Low complexity occupations such as assembly-line and industrial production work have detrimental effects on brain and cognition. However, an average of three to four WTC in 17 years yields considerable differences in both cognitive performance and brain anatomy. In other words, one WTC in four to five years could already help to preserve cognitive health and facilitate work ability, well-being, and productivity across the working lifespan at low levels of job complexity. Managing directors, company owners, as well as personnel and health executives may therefore want to consider WTC as strategic health management instrument.
The Lifespan Perspective: Expanding the Scope of Occupational Health Psychology

With these observations, I hope to spark additional interest in cognitive health and particularly cognitive aging as a vital but neglected field of action in modern occupational health psychology (OHP). Good cognitive health is a necessary prereqisite of work ability, well-being, and productivity. Nevertheless, cognitive aging has received only scant attention in the existing occupational health literature (Piotrowski, 2013; but see Fisher et al., 2014 for a recent exception). Working conditions, however, can greatly impact the development of brain and cognition. Given the fact that occupational health psychologists explicitly aim at creating 'healthy workplaces' (Quick et al., 1997), the lack of interest in cognitive health and aging as occupational health concerns is not plausible. The development of cognitive health across the lifespan and the impact of working conditions should become a central research concern of OHP in the 21st century.

On a more general level, my findings may serve to illustrate the need of a lifespan developmental perspective in occupational health research. Modern OHP has in large parts neglected the fact that many work-related illnesses develop slowly over time. This is true for age-related cognitive decline but also for the magnitude of chronic diseases. Chronic diseases are the primary cause of death in Germany as well as in the United States. According to the World Health Organization (WHO, 2014a; 2014b), chronic diseases such as cancer and cardiovascular disease account for 92% of all death cases in Germany as well as for 88% of all death cases in the USA. Approximately, between 8% and 35% of these diseases are caused by preventable exposures to workplace hazards (Hämäläinen, Takala, & Saarela, 2007; Sorensen et al., 2011). Working conditions thus play an essential role in the development of chronic diseases, through detrimental long-term exposure to unfavorable physical (e.g., hazardous chemicals), organizational (e.g., shift work), and psychosocial work environments (e.g., high job strain, low decision latitude).
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More than ever, companies need to pursue preventive strategies in order to protect and restore the health of their aging workforce. Sustainable occupational health management must encompass preventive work and career designs. Therefore, I approached both cognitive health and cognitive aging from a lifespan developmental perspective. That is, I conceived cognitive health and cognitive aging as lifelong developmental processes which are shaped by permanent transactions between biological determinants and developmental resources (Baltes et al., 2006). The sum of resources available to an individual determines the range and limits of a given developmental trajectory (Staudinger et al., 1995). Adopting such a lifespan perspective allowed me to investigate trajectories of cognitive health as the outcome of a complex and prolonged developmental interplay between internal (e.g., initial levels of cognitive performance; flexibility) and external health resources (e.g., low mental stimulation at work). Which particular resources are to be considered obviously depends on the health domain in question. In terms of cognitive health, however, it has been demonstrated that mental stimulation in the form of recurrent confrontation with novelty, learning, and skill acquisition provides promising effects.

The lifespan scope may be well suited to counteract not only age-related health risks. As a basic principle, it could also prove beneficial in preventing any kind of work-related disease. It lies within the responsibility of researchers to identify and prioritize facilitating and detrimental health resources. Therefore, large-scale longitudinal research designs are needed which target the entire individual and the interplay of developmental contexts (e.g., work, home, leisure time) and which carve out the cumulative effects of these contexts over several years or decades. On the other hand, effective health promotion requires practitioners to proactively 'create' healthy work environments by systematically providing health resources and withdrawing unhealthy resources along the career path. That is, health executives need to work on the genesis of health across the entire working life. Company policies must allow for life-long career paths. Sustainable health management requires thinking in lifespan
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dimensions; it aims to promote healthy careers instead of healthy workplaces.

In line with this, it has been suggested that effective occupational health management needs to be systemic and dynamic (see Staudinger, in press). Systemic occupational health management means that the employee’s health has to be considered in the context of the specific work task, of colleagues, supervisors, and organizational characteristics. Dynamic occupational health management refers to the fact that work careers unfold across time and impact on an employees’ health cumulatively. That is, rather than waiting until the number of sick leave days increases or until constraints in work capacity occur, it seems worthwhile, both in terms of productivity and in terms of health, to compose careers that are characterized by in-time work-task changes. In this vein, the current dissertation adopted a dynamic occupational health approach. Multiple WTC can serve as a strategic management instrument to dynamically preserve cognitive health and employability. With this, my dissertation suggested how future personnel and career development could and should look like. Particularly in the industrial sector, the foundations have yet to be laid in order for employees to stay fit and healthy until retirement age. Health promotion has to become a core element in any managerial decision. To maintain and protect health across the entire working life must be a cross-functional responsibility on all organizational levels and asks for an integrated lifespan perspective. It is crucial to promote lifelong learning and employability right from the start of a career (Staudinger & Kocka, 2010). Therefore, the primacy of short-term success must be overcome in favor of a more differentiated and sustainable culture of learning in and through work.

Future Research: Where to Go From Here?

My dissertation is not without limitations. I have named the most important concerns throughout the three empirical studies. Nevertheless, several points seem vital to me. An important methodological constraint relates to the quasi-experimental study design in Study 2
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and 3. I was not able to randomize the study samples and could not manipulate the number of WTC experimentally. As a consequence, strict causality testing was impaired. I cannot rule out the possibility that the effects of WTC I found in Study 2 and 3 are a consequence of selection biases. I tried to address this problem with an accurate matching of the case- and control group on the most relevant covariates. Unfortunately, some of these covariates had to be assessed in retrospect. In particular, I employed academic performance to approximate baseline intellectual ability, used a retrospective questionnaire (LEQ; Valenzuela & Sachdev, 2007) to determine earlier and current participation in mentally stimulating leisure time activities, and created items to assess behaviors that indicate baseline openness to new experiences. Obviously, I cannot guarantee the reliability of these retrospective measures. And although I have developed several arguments throughout the two experimental studies which give reason to be confident that the measures taken reliably approximated all baseline covariates, future studies should aim for prospective longitudinal settings in which the development of work biographies can be pursued over prolonged time frames and in which cognitive and brain development can be assessed at multiple points in time in order to investigate causal relationships between these two variables. In addition to that, the cumulative influence of (changes in) leisure time behavior should be taken into account in a similar vein.

It is important to note that my work was exploratory field research. I aimed to investigate the cumulative effect of multiple WTC over a prolonged period of time (17 years). Work biographies, however, are the outcome of individual decision making. WTC cannot be instructed. Sound ethical reasons do not allow that. That is why I needed to resort to group comparisons of work biographies. Case-control study designs represented the most feasible research approach. Still, there may be ways to realize prospective longitudinal research settings under these conditions. Large-scale longitudinal aging surveys such as the Socio-Economic Panel (SOEP) or the Survey of Health, Aging, and Retirement in Europe (SHARE),
for instance, provide reliable longitudinal records of intellectual ability, leisure time activity, and work history. Gaining access to the participants of such databases in order to conduct comprehensive (neuro-)psychological testing may represent an option for future researchers to seize reliable baseline information. Another possible avenue could be offered by the fact that many companies raise intelligence and personality data in their recruitment processes (at least on higher levels of job hierarchy). Such data could serve as baseline information as well. However, this approach may bring about obstacles in terms of employee privacy and data protection.

It is another limitation of my dissertation that the results in Study 2 and 3 are based on the same dataset. That is, my behavioral and neurophysiological findings are interdependent. This is a relevant constraint to the interpretability of my results and it is of the essence to keep in mind when assessing the positive effect of WTC on brain and cognition I found in my work. In addition to that, the entire dataset consists of production workers which were all employed at the same company. Obviously, this selectivity in the composition of the study sample impairs its representativeness. Future studies should therefore try to seize a greater variance of companies from varying industry sectors and of varying sizes. In this regard, it may be important to note that the company I co-operated with can be characterized as rather positive example of a German manufacturing environment. It ranks among the largest and most successful companies of the world. It is probably rather progressive in terms of labor organization, work strain reduction, and health management. There is thus reason to assume that similar experiments might have yielded different and perhaps stronger results in medium-sized companies or in companies with lower standards in health protection.

Apart from that, three more questions will be interesting to pursue in future research. I have already pointed out the possibility that the effect of multiple WTC may only shine through against low levels of complexity/cognitive challenge at work. That is, when studying WTC in highly stimulating work tasks instead of low complexity jobs, the impact of recurrent
novelty and learning on brain and cognition could turn out to be less pronounced. The effect of complexity could counteract the effect of novelty. It is also possible, however, that novelty and complexity in combination yield additive effects. In this sense, repeated novelty and learning of high complexity content amplifies the effect of high mental stimulation at work. This is an interesting debate and a valuable avenue for future research. Yet, there may also be a reason to assume that high complexity jobs inherently implicate repeated confrontation with novelty and learning. In this regard, it may be complicated to disentangle the effect of novelty from the effect of complexity under high levels of complexity at work.

Another open question refers to whether multiple WTC can have personalized effects. It is possible that, depending on specific personality variables or the value system, some individuals benefit more from multiple WTC than others. For instance, values such as tradition and security versus stimulation and achievement (see Schwartz, 1992) may affect an individual's openness to multiple changes of the work task. Similarly, a certain level of learning self-efficacy could influence the confidence to master such changes.

Furthermore, it will also be interesting to see in future work how work biographies of multiple versus rare WTC impinge on cognitive and brain development later in life as, for instance, after retirement. There is evidence to suggest that high versus low levels of job complexity in midlife have an effect on the rate of cognitive decline after retirement (e.g., Finkel et al., 2009) and predict late-life regional GM volume loss (Suo et al., 2012). Thus there is good reason to assume that multiple WTC not only impact contemporary levels of cognitive functioning and brain development but that this impact is extended into later in life. On the basis of the well-established relationship between job complexity and dementia (Andel et al., 2005; Potter et al., 2007), it may even be speculated that work biographies of multiple versus rare WTC are associated with cognitive impairment.
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Summary & Conclusion

My dissertation provides first cautious evidence that recurrent exposure to novelty at work (as indicated by multiple WTC) can have beneficial effects on the cognitive and brain development of long-term industrial production workers. Controlling for cognitively stimulating leisure time behavior, multiple (i.e., two or more) versus zero or one WTC in 17 years were associated with better processing speed and working memory performance as well as with more gray matter volume in frontal, striatal, and insular brain regions. My findings suggest multiple WTC as strategic health management instrument in order to counteract the detrimental effects on brain and cognition as conveyed by prolonged exposure to low mental stimulation at work. My work has substantiated existing theoretical conceptions of cognitive and neural plasticity. I have demonstrated that novelty and learning can serve as valuable facilitators of positive change in the cognitive system. On a more general level, I hope to spark interest in cognitive health and cognitive aging as vital but neglected fields in occupational health psychology. On average, aging is associated with a decline of cognitive performance levels as well as with fundamental transformations in the structure and function of the brain. Long-term exposure to detrimental working conditions is known to negatively affect brain and cognition. Good cognitive health, however, is a necessary prerequisite of well-being, work ability, and productivity. As my findings indicate, a lifespan-oriented strategic occupational health management can positively influence the development of cognitive health across the working life. With this, my dissertation emphasizes the need for a lifespan perspective on occupational health in which the genesis of health and disease trajectories is investigated across time and in which health is conceptualized as the outcome of a complex and cumulative interplay of positive and negative health resources. Such an approach requires thinking in lifespan dimensions; it aims to promote healthy careers instead of healthy workplaces.
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Statutory Declaration
(on Authorship of a Dissertation)

I, Jan Oltmanns, hereby declare that I have written this PhD thesis independently, unless where clearly stated otherwise. I have used only the sources, the data, and the support that I have clearly mentioned. This PhD thesis has not been submitted for conferral of degree elsewhere.

I confirm that no rights of third parties will be infringed by the publication of this thesis.

Bremen, August 17, 2015

Signature ___________________________________________________________