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Limitations of working memory capacity: The cognitive and social consequences

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ABSTRACT

This paper aimed to explore, from the perspective of cognitive psychology, the natural limitations of human cognition that determine our capabilities to deal with information overflow. These limitations are related mainly to the working memory system. This system is conceived to be composed of the storage components, which are responsible for active maintenance, and executive control that supervises the storage units. People differ in their working memory capacities, and because virtually every complex cognitive activity requires the temporal availability of a certain amount of cognitive representations, these differences are predictive of many outcomes. In the area of 'cold' cognition, these outcomes include intelligence and verbal reasoning, multitasking, language comprehension and verbal fluency, whereas in the area of 'hot' cognition, they include mentalising, stereotyping and self-control. Natural limitations in working memory capacity may be overcome (to some extent) through the training of working memory skills or the application of processing strategies (e.g. task simplification, using external environment as in situated or distributed cognition, changing a code of mental representation).

1. Introduction

In recent years, the concept of 'overflow' has occupied researchers in many fields: from economics to management, consulting and consumer studies, politics, education and so forth (Czarniawska & Löfgren,, 2012). However, when one specifically refers to overflow of information, the topic seems particularly relevant to cognitive psychology. Information overflow is defined as a situation in which 'an individual's efficiency in using information in their work is hampered by the amount of relevant, and potentially useful, information available to them' (Bawden & Robinson, 2008, p. 3). This concept is closely related to cognitive load, i.e. the state caused by excessive information supply and demand, continuous multitasking and interruptions, and inadequate workplace infrastructure (Kirsh, 2000). Among other conceptualisations, information overflow has been conceived specifically in relation to working memory (WM), a cognitive system that is responsible for maintaining access to goal-relevant information in support of ongoing cognitive tasks or behaviour (Baddeley, 1983, 2007). Accordingly, information overflow takes place when the amount of information exceeds the capacity of an individual's WM (Fournier, 1996). This constraint is seen as the primary impediment to knowledge construction (Sweller, 1994) and as a potential cause of everyday failures (Klingberg, 2009).

As Kirsh (2000) noted, studies on information overload were focused on its *consequences* (see: Bawden & Robinson, 2008), such as information anxiety, i.e. a state of uneasiness caused by the inability to access or process necessary information (Wurman, 1990), or information withdrawal, i.e. a state of avoidance of superfluous sources of information (Savolainen, 2007). It seems that not enough attention has been paid to the *sources* of this phenomenon. From the perspective of cognitive psychology, overflow may result from structural limitations of basic mental mechanisms that allow exertion and maintenance of control over informational demands.

This paper aimed to show that humans are structurally limited in their cognitive capacities and, consequently, that they are limited in their ability to deal with information overflow. We provide evidence that human cognitive limitations are rooted in the structure and functions of WM, which allows short-term storage and manipulation of task-relevant data. WM is severely limited in its capacity to deal with complex tasks and situations. Moreover, this capacity is not equally distributed among individuals and among task situations. In other words, WM capacity can be conceptualised

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in terms of both a stable trait and a transient state. We demonstrate that these inter- and intra-individual differences can account for a variety of phenomena, including the human (in)ability to deal with information overflow in the social context. First, we describe the concept of WM. Next, we address the issue of WM capacity. Finally, we discuss the significance of WM capacity for understanding some important psychological and social phenomena implicated with information overflow.

2. The concept of working memory

In a way, the human cognitive system has evolved as a mean to deal with information overflow. For example, humans see only a small fraction of electromagnetic spectrum and hear only a tiny portion of acoustic waves. Our momentary awareness of informational content is also very limited. These limitations are fundamental properties of the human mind and brain. The central issue in cognitive psychology amounts to the exploration of such limitations.

The early conceptualisations of the limits of human cognition were related to the concept of short-term memory (STM), a system responsible for moment-to-moment retention of information (Broadbent, 1958). Peterson and Peterson (1959) were among the first psychologists to investigate the time constraints of STM. In their experiment, participants were asked to remember and recall (with a delay of 3, 6, 9, 12, 15 or 18 s) meaningless three-consonant syllables (trigrams), while counting backwards to prevent rehearsal. Very fast decay of information occurred because participants could recall 80% of trigrams correctly after 3 s of delay, as compared to less than 10% of trigrams after 18 s (Peterson & Peterson, 1959). At the same time, George Miller (1956) summarised evidence that people can repeat back only about seven randomly ordered, meaningful items or chunks of information (i.e. letters, digits or words). This early research suggested that STM is very limited in both duration and capacity.

Nowadays, the concept of STM has been replaced by the notion of WM, first introduced by Miller, Galanter, and Pribram (1960) and then developed by Baddeley and Hitch (1974). WM is supposed to be an active, multicomponent system of information storage and processing. Initially, the model involved the supervisory 'central executive' system and two unimodal storage systems: the phonological loop and the visuospatial sketchpad (Baddeley & Hitch, 1974). The central executive system was envisioned as a control structure of limited attentional capacity, responsible for manipulating information in the WM and controlling the two subordinate subsystems. In contrast, both short-term storages, as domain specific, were responsible for maintaining verbal or visuospatial information, respectively. Several years later, Baddeley (2000) supplemented his model with the episodic buffer—a limited capacity multimodal store responsible for integrating information in various codes and, with regard to time axis, into unitary episodic representations. The three storage subsystems are controlled by the central executive system, which is additionally responsible for integrating information from various sources into coherent episodes. Importantly, all the systems proposed by Baddeley were of limited capacity, although in different ways. The central executive was conceived as a limited capacity pool of general processing resources, while the phonological loop, the visuospatial sketchpad and the episodic buffer were subjected to both time and span constraints.

In the model proposed by Nelson Cowan (1988, 2001), WM is conceived dynamically as a workspace that consists of temporarily active representations stored permanently in long-term memory. In other words, this model identifies WM with a process of maintaining access to information that is necessary to carry out current tasks. In Cowan's view, WM is subdivided into two basic elements: the central executive system and a homogeneous memory system. The central executive is responsible for directing attention and voluntary processing. The representations stored in the memory system vary in their level of activation, as determined by the current task. The focus of attention is composed of a subset of the activated representations and their associations. The focus can be directed both outward (to the external environment) and inward (to the existing memory traces). Importantly, Cowan abandoned the idea of separateness of memory storage systems, suggesting that the memory store has a domain-general character (Saults & Cowan, 2007).

Finally, Klaus Oberauer concluded that 'working memory (…) is not genuinely a memory. Rather, it is an attentional system that interacts equally with perception and with (long-term) memory' (Oberauer, 2009, p. 50). The author believes that WM consists of highly activated memory representations—a fairly dynamic maintenance component used for ongoing cognition. The information is actively maintained because of the process of allocation of attention. However, WM is also responsible for retrieval of task-relevant information through cue-dependent retrieval processes (see also, Unsworth & Engle, 2007). Furthermore, Oberauer (2009) distinguished between declarative WM and procedural WM. Both systems are conceptualised as largely analogous—as three embedded components that reflect three successive levels of selection of representations. The declarative WM includes the activated part of LTM, the region of direct access and the focus of attention. The procedural part of WM includes the activated procedural representations from LTM, the bridge (which holds the currently operative task set) and the response focus. The procedural WM includes both primary and executive processes. The primary processes produce manipulations of declarative representations or overt actions, while the executive processes can control primary processes.

In summary, although all theories of WM presented above point to slightly different research directions (Gruszka & Orzechowski, 2016), they emphasize the role of attentional mechanisms in the functioning of WM. Information overflow impairs WM processing by narrowing the scope of attention and restricting the range of cues that are encoded and processed. In concordance, limits of attention have also been recognised in the organisational literature as limits in 'span of control' (Stea, Linder, & Foss, 2015). Gifford (1992) discussed formal models of allocation of entrepreneurial attention and optimising techniques or rules that guide behaviour in this regard. Some of the discussed models recognise only limits in the ability to take in new information (that can be related to the attention component of WM), but others also recognise limits in the ability to recall previously obtained information (that can be related more to the mnemonic component of WM). Importantly, as Gifford (1992) pointed out, limited attention has a very important role in organisation as a whole because it constrains to the span of control of an individual. We believe that cognitive psychology can add to the understanding of this problem by helping specify the WM mechanisms. One factor overlooked in the organisational literature seems to be the issue of individual differences in WM abilities.

3. Working memory capacity

Although the term WM refers to a hypothetical cognitive system responsible for providing access to information required for ongoing cognitive processes, the term working memory capacity (WMC) is used to refer to individual differences that pertain to the personal level of WM efficiency (Wilhelm, Hildebrandt, & Oberauer, 2013). These authors distinguished between three theoretical views on WMC: the executive attention view (Engle, 2002), the primary/secondary memory view (Unsworth & Engle, 2007) and the binding hypothesis (Oberauer, 2009).

According to the first viewpoint, WMC does not reflect individual differences in memory storage but individual variation in the ability to control attention to maintain information in an active, easy-to-retrieve state (Engle, 2002). Thus, 'WM capacity is not directly about memory—it is about using attention to maintain or suppress information' (Engle, 2002, p. 20). Greater WMC results from greater ability to control attention rather than larger memory store, and it is linked to the ability to avoid distraction (Redick, Heitz, & Engle, 2007). Kane and Engle (2000) tested this hypothesis in two experiments. According to the obtained results, low WMC participants exhibited greater proactive interference when memorising a subsequent (but not the first) list of words than high WMC participants under the single task condition. However, both groups showed equivalent proactive interference under the divided attention condition. Thus, only high WMC individuals suffered from increased cognitive load, suggesting that they could more flexibly allocate attention in response to the task demands. It also implies that individual differences in WMC are related to inhibition conceived as an active goal-directed process of suppression of irrelevant material (Redick et al., 2007).

According to the second viewpoint (Unsworth & Engle, 2007), primary memory is responsible for maintaining relevant representations in the activated state by means of continued allocation of attention. Its capacity limit amounts to approximately four items (Cowan, 2001). Items present in primary memory are retrieved from secondary memory—i.e. a long-term memory store. Their retrieval requires a cue-dependent search. Thus, individual differences in WMC result from variation in maintenance (primary memory) and retrieval (secondary memory). Thus, low WMC individuals, as compared to high WMC individuals, perform worse when active maintenance of information is required. Furthermore, they are more likely to be distracted and, in result, lose access to the goal-relevant information. They are also worse at retrieving relevant information because of poor discrimination of relevant and irrelevant data. Finally, low WMC persons are also more likely to use context cues that activate more irrelevant information, which leads to both slower and less accurate recall (Unsworth & Engle, 2007).

Finally, according to the third viewpoint (Oberauer, Süß, Wilhelm, & Sander, 2008), WM is primarily responsible for building, maintaining and rapidly updating arbitrary bindings. For example, items in a to-be-remembered list are bound to form a new structure (a list), in which objects are bound to locations in space, whereas concepts are bound to a new mental model. New temporary bindings are generated in the process of construction and manipulation of novel structures that are utilised for reasoning. According to the binding hypothesis of WMC (Oberauer et al., 2008; Wilhelm, Hildebrandt, & Oberauer, 2013), 'the limited capacity of working memory arises from interference between bindings, which effectively limits the complexity of new structural representations, and thereby constrains reasoning ability' (Wilhelm et al., 2013, p. 4). Such interference leads to the partial overwriting of feature-based representations of the items held in the WM. This process lessens the overall activation of the item, effectively reducing the probability and the rate of its recollection. In sum, three different mechanisms have been proposed as a source of individual variation in the executive component of WM, namely attentional control (goal-maintenance), cognitive inhibition and interference resolution.

WMC is generally considered to be a relatively stable individual trait, although developmental changes across the life span are expected. The direct evidence of its stability has been described by the test–retest reliability (Klein & Fiss, 1999). An indirect indication of WMC stability can be inferred from its strong relation to general fluid intelligence (e.g. Conway, Kane, & Engle, 2003). Nevertheless, it is evident that WMC performance fluctuates in different contexts, and this intra-individual variation led the researchers to the conclusion that WMC can be conceptualised not only as a trait but also as a transient state (Ilkowska & Engle, 2010). Thus, state WMC refers to the transitory changes from the baseline trait WMC. These variations can be induced by situational influences: physiological factors such as sleep deprivation (Alhola & Polo-Kantola, 2007) or cognitive fatigue (Anguera et al., 2012). For instance, even minor aggression from a customer can strongly affect the immediate cognitive performance of customer service employees by disrupting WM (Rafaeli et al., 2012). Such a transient shift in WMC efficacy can be transferred to another task for which WMC is an underlying factor. For example, Anguera et al (2012) showed that the temporal depletion of spatial WM resources by means of cognitive exhaustion negatively affected the rate of early motor skill learning. What is even more surprising, the mere perception of resource depletion (i.e. illusory fatigue induced by a task-related feedback, as opposed to the actual depletion) seems to be sufficient to produce deficits in state WMC (Clarkson, Hirt, Austin Chapman, & Jia, 2011).

Interestingly, improvements in the temporarily available resources (i.e. state-WMC) that can be obtained by means of psychological intervention have been also reported. For example, Autin and Croizet (2012) developed a brief intervention that was meant to alleviate concerns about the incompetence faced by school children in the context of demanding tasks. The study has revealed that a 10-min intervention designed to reframe metacognitive interpretation of task difficulty (as attributable to learning rather than of someone's own incompetence), received prior to the difficult anagram task, increased the children's WM complex span and improved reading comprehension. The intervention also reduced the accessibility of self-related thoughts of incompetence as measured by the accessibility of self-knowledge related to competence or incompetence.

The studies described above indicate that WMC is malleable and may be very sensitive to situational and contextual influences. If so, the question arises, how can it predict one's general level of performance? This issue can be resolved when we refer to the notion of maximal and typical performance introduced by Ackerman (Ackerman & Heggestad, 1997) in the context of IQ testing. According to this author, in a maximum performance situation (assuming high levels of motivation), differences in functioning are attributable primarily to the differences in cognitive abilities. Thus, intelligence is more highly related with maximum performance than with typical performance. In contrast, personality is more predictive of typical performance because it is measured by means of questionnaires, which are constructed as aggregative measures of behaviour. As WMC is strongly related to general fluid intelligence, it can be expected to predict the maximal performance in any natural settings (e.g. job performance).

4. Predictive power of WMC: general cognition

WM may be seen as a mental 'engine', and as such, it must be implicated in many complex cognitive activities that require controlled effortful processing (Conway & Engle, 1996). Broadway, Redick, and Engle (2010) reviewed how individual differences in WMC affect abilities to selectively attend and remember information and use it effectively to achieve simple goals defined in experimental settings. They also depicted the role of WMC outside the experimental environment, such as in retrieving autobiographical memories, suppressing unwanted thoughts and resisting mind wandering, which suggests a strong role of WMC in self-control. Furthermore, Redick et al. (2007) reviewed the cognitive and social consequences of WMC related to the differences in inhibitory control. According to these authors, separate inhibitory functions affect different stages of information processing, namely *access* to the information that occurs at the early perceptual stage, *deletion* that takes place at the intermediate stage (when information enters focus of attention) and *restraint* that occurs at the final stage of information processing. The authors offered the applications of executive-attention theory of WMC to social phenomena related to the ability to supress irrelevant thoughts, such as posttraumatic stress disorder, depression, life stress and stereotype threat.

4.1. Intelligence and reasoning

One of the strongest and most consistent findings in the literature is that WMC capacity is highly related to reasoning ability and general fluid intelligence (Chuderski, 2015; Conway et al., 2003; Chuderski & Nęcka, 2012; Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990). For example, in one of the first studies using latent variable approach, Kyllonen and Christal (1990) demonstrated very strong correlations (near unity) between WMC and reasoning ability. More precisely, Engle et al. (1999) showed that the latent variable derived from the WM complex span tasks is a significant predictor of general fluid ability, while the latent variable derived from the simple span tasks was not. Individual variation in both WMC and reasoning can be explained by the capacity of the focus of attention and the effectiveness of executive control over WM (Chuderski & Nęcka, 2012).

It is interesting to note, however, that more recent studies have uncovered more fine-grained details of the links between WMC and intelligence. For example, Chuderski (2015) suggested a moderating role of time pressure during fluid intelligence testing on the relationship between fluid reasoning and WMC. It implies that the 'fast' measurement of intelligence may primarily tap the WMC, whereas 'slow (er)' intelligence testing (i.e. with no time limit) may also depend on some other cognitive processes beyond WM. It all suggests that WMC and general intelligence are highly related but not identical (Conway et al., 2003).

4.2. Multitasking

Another phenomenon that is linked to WMC is multitasking, i.e. situation when an individual is performing multiple concurrent tasks, which is prevalent in our everyday life and job-related circumstances. For example, in one study, nurses had on average 10 or more activities waiting to be performed at any given time and experienced 3.4 interruptions per hour (Potter et al., 2005; Wolf et al., 2006), while unfulfilled goals can interfere with later tasks (Masicampo & Baumeister, 2011). In laboratory settings, multitasking is most often investigated by means of dual task performance. The typical result in such a situation would be a performance decrement observed under a dual task condition, as compared to a single task condition, because absorbing a substantial amount of limited capacity processing system by a concurrent activity must have deleterious effects on the performance, even when they do not have 'an obvious' storage component (Repovs & Baddeley, 2006). Multitasking is related to both intelligence and WMC, but only WMC (its processing and storage components) predicts multitasking when the simultaneous relationship of IQ, WMC and multitasking is considered (Colom, Martínez-Molina, Shih, & Santacreu, 2010).

Interesting insights concerning multitasking also come from more applied settings, although research on predicting multitasking performance as an aspect of job performance is rare. For example (and hardly surprising), speaking on the mobile impairs simulated driving performance (Strayer & Drews, 2007). This decrement is accompanied by concomitant reductions in brain driving-related activity by approximately 37% (Just, Keller, & Cynkar, 2008). Interestingly, Watson and Strayer (2010) showed that approximately 2.5% (frequency significantly greater than chance) of their sample revealed absolutely no performance decrement with regard to the dual tasks condition. The researchers called the participants 'supertaskers' because in the single task condition, they scored in the top quartile on all driving indices and on complex WMC tasks. It suggests that WMC is one of the best predictors of multitasking performance.

4.3. Verbal comprehension

Evolutionary psychologists see language and object behaviour as derivatives of WM. Reading and listening to speech involve not only comprehension of a stream of separate words but also computation of the semantic and syntactic relations among them. It suggests the crucial role of WMC in language comprehension (Just & Carpenter, 1980). The results of a meta-analysis of over 70 studies on the association between WMC and language comprehension reported by Daneman and Merikle (1996) support this view: WMC is a good predictor of verbal comprehension. The measures that tap the combined processing and storage capacity of WM (e.g. reading span, listening span) have been shown as better predictors of comprehension than the measures that tap only the storage capacity (e.g. word span, digit span).

Individual differences in WMC can account for several aspects of language comprehension, such as syntactic modularity, when high WMC allows interaction among syntactic and pragmatic information, or syntactic ambiguity, when high WMC allows maintaining multiple interpretations (Just & Carpenter, 1992). WMC also supports sentence parsing, and certain difficulties in this regard observed in the clinical populations may be potentially related to WMC impairment (Moser, Fridriksson, & Healy, 2007). It should be noted, however, that not all studies support the strong role of WMC in language comprehension (Van Dyke, Johns, & Kukona, 2014).

4.4. Verbal fluency

Verbal fluency refers to the lexical access ability, which supports retrieval of the grammatical representations and sound forms of words from the mental lexicon. It is operationalised in terms of verbal fluency performance. Typically, participants are required to generate as many exemplars from a given category as possible (category fluency) (Benton, 1968), or as many unique words starting with a given letter (letter fluency) as possible, within 1 min. The fluency tasks are also often used as valid tools to assess executive control in both cognitive and neuropsychological investigations. Several studies have revealed relations between measures of WMC and verbal fluency. For example, Rosen and Engle (1997) investigated the effects of individual differences in WMC on verbal fluency under various secondary load conditions (i.e. different types of secondary tasks). In their study, high WMC participants consistently recalled more exemplars than low WMC individuals. However, the former were more affected by load conditions, as revealed by a decline in their recall performance (not present in low WMC participants). Unsworth, Spillers, and Brewer (2011) used structural equation modelling to determine the relationship between verbal fluency and other cognitive constructs such as WMC, vocabulary, processing speed and inhibition that have been implicated in fluency performance by prior works. The analysis revealed that fluency was related to all cognitive abilities under investigation. However, it was more strongly related to WMC than the other constructs under consideration. This result confirms an important role of WMC in lexical access.

In summary, WMC affects our reasoning ability, multitasking ability, verbal comprehension and verbal fluency. All these mental faculties are crucial for dealing with complex professional tasks, in which the information overflow is very likely to occur. What is more, WMC becomes even smaller under stress and time pressure. Thus, stress caused by information overflow diminishes our mental faculties that depend on WMC, which consequently decreases our capacity to cope with the effects of information overflow. This kind of feedback loop must have important consequences for our social life.

5. Predictive power of WMC: social cognition

Although the literature described above demonstrates the importance of WMC in so-called 'cold cognition', its role in 'hot cognition' cannot be overseen. The area of social cognition and emotional control also depends on WMC, which will be illustrated in reference to three phenomena: mentalising, stereotyping and self-regulation.

5.1. Mentalising

Mentalising, also known as the theory of mind (ToM), is an ability to 'read' other people's minds to understand someone else's perspective. Processing social cognitive information, such as other peoples' mental states or traits, is crucial for survival in social world. This world is very complicated, and our proficiency in navigating in there must be somehow related to our cognitive capacities. According to the 'social brain hypothesis'—also referred to as Machiavellian intelligence—the information-processing capacity of the primate brain (implemented primarily in the neocortex) explains inter-species differences in social group size among the primates (Dunbar, 1998). On this basis, Stiller and Dunbar (2007) hypothesised that individual differences in core cognitive abilities, including WMC and mentalising, are likely to determine the group size within an individual's social network (obviously, subjected also to social, demographic and other circumstantial factors). Their study revealed that perspective-taking competence correlates with the number of core contacts of an individual—a size of a so-called clique (i.e. people who would support an individual in case of a personal problem). In contrast, a size of a so-called sympathy group (a larger group of 12–20 the most frequent social partners) is determined mainly by the capacity to retain information within a short period of time. Interestingly, memory performance itself explained approximately 35% of the variance in performance on the mindreading tasks. It corresponds with an observation that people usually fail when questions contain more than five levels of perspective taking (Kinderman, Dunbar, & Bentall, 1998), which can be interpreted as requirements exceeding WMC.

Mentalising is considered to play a vital role in social interactions, and its deficits account for inadequate behaviour. Deficits in ToM have been identified in autism, Asperger's syndrome and schizophrenic disorders. In a way, mentalising can be seen as a complex problem solving, and as such, it is closely related to WMC. Ample empirical evidence supports this claim. For example, Mutter, Alcorn, and Welsh (2006) showed that in the age 3–5, performance on the false belief task can be predicted by inhibitory control and WMC, with WMC being a somewhat stronger predictor than inhibition. Studies in adult populations suggest that interpretation of the behaviour of other people is particularly difficult for low WMC individuals and under high cognitive load demands (Lin, Keysar, & Epley, 2010). These findings suggest that morality is easy but lying is difficult because the latter requires taking a perspective of the other person. In other words, lying needs not only 'reading' the content of another person's mind but also 'writing' false beliefs within it. Indeed, it has been shown that low WMC will facilitate a tendency to be honest, while having more cognitive capacity would have enabled one to serve self-interest by lying (Van 't Veer, Stel, & van Beest, 2014). Interestingly, as Stea et al. (2015) suggested, individual differences in mentalising provide a natural complement to the attention-based view of the firm (outlined above). Although, in their opinion, the ToM allows for an understanding of the advantage that organisations have over markets within the attention-based view, this issue is underdeveloped.

5.2. Stereotyping

WMC determines the ability to incorporate new or inconsistent information into a pre-existing representation of an object. It potentially influences many social phenomena such as peoples' abilities to organise impressions, judgements or memories of others. Stereotype-based impression formation has been shown as less resource-consuming than individuation (Sherman, Macrae, & Bodenhausen, 2000). In agreement, Conway and Kane (2001) suggested that low WMC individuals form impressions at early stages of information-processing, resulting in more stereotypic group-based information in their representations of other people. While forming impressions, low WMC individuals may be more concerned with information about the target group rather than the information about a target person (Barrett, Tugade, & Engle, 2004). These hypotheses have been confirmed by Knuycky (2013). In her study, participants with low WMC committed a higher number of stereotype-consistent errors when performing a maintenance task and accurately recalled fewer stereotype-consistent words when performing a retrieval task. This result has been interpreted as showing that low WMC individuals are lacking resources necessary to supress automatic associations underlying stereotyped social perception.

5.3. Self-regulation

Self-regulation may have arisen through evolution, and its relationship to WM as a central system that supports goal-directed behaviour is clear (Broadway et al., 2010; Ilkowska & Engle, 2010). Barkley (2001) considered executive functions (consisting of visual and verbal WM, among other facets) to be 'composed of the major classes of behaviour toward oneself used in self-regulation' (Barkley, 2001, p. 5). Their adaptive value residues in their role in maximising the long-term social outcomes for an individual.

Ilkowska and Engle (2010) have offered a conceptual framework for linking WMC and self-regulation, i.e. 'the process by which one monitors, directs attention, maintains, and modifies behaviours to approach a desirable goal' (Ilkowska & Engle, 2010, p. 266). According to the authors, both self-regulation and WM defined as executive control involve overriding a prepotent response, and depletion of these resources may cause self-regulatory failures. For example, either alcohol or anxiety (stress) acts as an additional cognitive load, impairing goal-directed behaviour (alcohol intoxication narrows a range of perceived cues, and thus, functionally, narrows attentional focus). Indeed, low WMC has been shown as a potential mechanism underlying a failure to inhibit unwanted intrusions (Brewin & Beaton, 2002) or increased tendency for mind wandering (McVay & Kane, 2009). In a similar vein, Broadway et al. (2010) saw the relevance of WMC to self-regulation and self-control as a primary mechanism, which determines the content of the mind by controlling selective attendance and retention of goal-relevant information. They linked WMC and efficacy of self-control through processes of retrieving relevant autobiographical memories, suppressing unwanted thoughts, resisting mind wandering and avoiding impulsive decision-making.

In summary, individual differences in WMC are related not only to the cognitive outcomes but also to our functioning in the social world. Low WMC, as compared to high WMC, is related to a reduced understanding of other peoples' thoughts and feelings, which presumably comes with a lack of empathy and reduced emotional intelligence. Our cognitive capacities, including mentalising and WMC, may even influence the size of our social network. Low WMC is also related to stereotyping and dogmatic attitudes as ways of dealing with too complex information.

6. Remediation

The final question that we would like to focus on is how we can overcome WMC limitations. Because of the links between WMC and a wide variety of real-world skills outlined above, the answer to this question may have many potential applications to the way people deal with overflow, both in the place of work and in everyday life.

6.1. WM training

Although WMC is most commonly viewed as a constant trait, many recent studies suggest that it can be improved by extended adaptive training. Klingberg (2010) reviewed the studies concluding that WM trainings provide an efficient method of improving WM performance. He found that improvements in trained WM tasks were approximately 30–40%, whereas those in non-trained WM tasks (used to assess the effect of transfer) were approximately 15%. Effect sizes relative to the control group were approximately 1.0 (Cohen's d). Moreover, Constantinidis and Klingberg (2016) reviewed neuroimaging data on WM training. It revealed that training increases the activity of prefrontal cortex (WM loci) and strengthens connectivity both inside this area and between the prefrontal cortex and parietal cortex.

It is important to note, however, that some authors do not support this optimistic view (Owen et al., 2010). One of the specific concerns refers to the issue of transfer of training effects to a wider variety of tasks (i.e. intelligence), to avoid the possibility that any cognitive improvement observed can be explained by task-specific learning (Shipstead, Redick, & Engle, 2012). In a recent meta-analysis of 20 n-back training studies with fluid intelligence as outcome measures, Au et al. (2015) showed small but significant positive effects. They concluded that short-term cognitive training may result in beneficial effects in relation to general intelligence. However, it is still unclear what kind of factors moderate these effects, how durable these effects are and how they translate into practical, real-world settings.

WMC performance can be improved by acquiring relevant strategies such as rehearsal of the material (Baddeley, 1983) or chunking (Bor, Duncan, Wiseman, & Owen, 2003; Cowan, 2001; Ericcson, Chase, & Faloon, 1980; Miller, 1956). These methods are based on conscious strategies for handling the material and are meant to overcome storage capacity limitations and allow the reduction of task complexity. Finally, WMC improvements can be also obtained by means of psychological intervention, such as expressive writing (Klein & Boals, 2001), or brief interventions meant to reframe metacognitive interpretation of a task difficulty as attributable to the learning process rather than someone's own incompetence (Autin & Croizet, 2012). In both these studies, WMC improvements were mediated by the reduction of self-related intrusive thoughts.

6.2. Task simplification

Tasks we deal with may be categorised according to two dimensions: difficulty and complexity (Liu & Li, 2012). The first dimension, difficulty, defines the probability of finding a tenable solution in a reasonable time horizon, whereas the second dimension, complexity, refers to the number of elements a problem at hand consists of. For overflowed and structurally limited minds, the tasks' complexity matters more than its difficulty, although both dimensions may operate in confluence. It is important to realise that, psychologically, the task's complexity is not objectively defined. Rather, it amounts to the number of elements we have to activate in our minds to be able to grasp the essence of the problem. In other words, task's complexity amounts to the complication of its cognitive representation. If so, we may try to cope with complexity by getting rid of those elements of task's mental representation that are superfluous or redundant. Typical professional problems are usually too difficult because of tremendous redundancy: important issues are intertwined with less important or even useless, with no clear indication which is which. Therefore, an important part of every professional's work consists in the selection of relevant issues to ignore irrelevant ones. Experienced experts know what is relevant and what is not a bit earlier than less experienced ones (Shanteau, 1992; Sheridan & Reingold, 2014).

Nevertheless, the ability to discern important elements of the task's structure is very rare even among experts. It may be strengthened in the process that Herbert Simon (1977) called 'familiarization': Recurrent attempts to solve a complicated task make it increasingly more familiar, in the sense of being better and better understood. During familiarization, a formerly chaotic, ill-structured situation gets increasingly more 'elegant', well-structured and organised. Suddenly, it becomes simplified enough to be manageable by WM, despite its well-known limitation. According to Simon, this strategy of task simplification supports scientific insight leading to discovery. Outside academia, this strategy of dealing with overflow may be efficient as well, although it needs large amount of time and effort. Another possible strategy proposed in the context of organisational research may rely on optimising organisational design. Kennedy (1994) examined the optimal structure of an organisation in which analysts process information on the behalf of decision-makers to overcome their natural limitations in attentional scope.

6.3. Situated and distributed cognition

Human minds are easily overflown while operating in isolation. However, cognition is always situated, which means that mental processes including thinking, problem solving and decision-making take place in a particular situation or context (Brown, Collins, Duguid, 1989). Therefore, the elements of the external context can be included into cognitive processes as its supportive elements. When overflown, people often use post-it notes and similar cues for memory retrieval. The so-called *method of loci* is a mnemonic technique that consists in imaginary location of memorised items in different places in a physical space, such as one's own apartment, a park or a shopping centre. Imaginary walking around this space facilitates memory retrieval, especially when the material has a linear structure (e.g. a talk or lecture). What is beneficial for memory retrieval may also support other cognitive processes, including problem solving and decision-making. Cognition does not need to occur as a set of symbolic processes hidden in one's individual brain. Rather, it may cross the borders defined by the skull to incorporate available external cues.

Human cognition is also distributed, which means that complex mental processes occur in the social network (Gureckis &

Goldstone, 2006), and cognitive properties of groups may differ from those of the individuals who comprise them (Hutchins, 1991). Working in teams may substantially increase productivity, provided that team members are trained for that and obey the rules of cooperation. The effect of synergy, as it seems, occurs if every team member can offer an added value to the collective work. Contrariwise, it does not occur if team members cannot overcome their individual limitations and drawbacks by benefitting from someone else's competencies. As to WM limitations, they are quite robust and universal, but people substantially differ in their WMC. In addition, this individual trait tends to fluctuate because of emotional distress, intrusive thoughts or just fatigue. Hence, there is a possibility that team members who experience relatively small limitations of WMC, be it for good or at the moment, take over the most overloading part of the team's activity. Moreover, team members can deliberately divide a complex task into smaller elements, which will be less demanding for WMC. Finally, even though all team members are equally deprived of substantial part of their WMC, for instance at the end of the exhausting day, it is fairly possible that every individual member retains in his/her WM an important chunk of information that is lacking in other persons' mind. The point is that the sum of limited and overloaded minds may nevertheless generate a collective mind of reasonable quality.

Distributed cognition also refers to the use of electronic devices, such as computers, phones, and tablets (Hollan, Hutchins, & Kirsh, 2000). It is still not clear if such devices are beneficial for our memory. On the one hand, they store information, help to keep deadlines and take off our heads many dull chores. On the other hand, their long-term influence may be harmful because electronic devices make us less likely to master and train our WM skills. For instance, in everyday life, people are decreasingly less dependent on mental arithmetic, i.e. counting in memory, although in the past it was ubiquitous (e.g. while shopping). It is well established that mental arithmetic is a task heavily dependent on WMC (DeStefano & LeFevre, 2004), so the less we count in memory, the more we lose opportunities to enhance our minds through everyday practice. However, this issue is not investigated enough to allow conclusive statements.

6.4. *Benefits of dual coding*

Complex problems may become less complex after change of their mental representation. In particular, the switch from verbal code to the imaginary form of representation usually makes a difference. According to Alan Paivio (1971), there are two co-operating systems of the human mind: verbal and non-verbal. Although they co-operate, one of them usually dominates over the other one in a particular problem situation. The dominant system can transfer data to the subservient one, but it takes time and effort, not to speak about inevitable loss of information. However, such transfers may result in greater cognitive flexibility. They may also reduce the task's complexity to the extent that makes it manageable by WM of very limited capacity. Let us suppose that we have to describe in words how the standard chessboard looks like. It is a doable albeit time-consuming and error-prone job, and nevertheless, it is likely that the recipients of our message will be puzzled. Now, let us suppose that we have to describe not only how the chessboard looks like but also what is the situation in the particular chess game. It is much easier and quicker to draw the situation on the checkerboard. In general, the use of visual channel results in simplification of the problem at hand so as to make it manageable for WM.

Typically, we benefit from imagination, but sometimes switching to the verbal code makes the problem easier. In such instances, an elegant verbal phrase, or a notion of exceptional semantic density, reduces the overwhelming complexity of the task situation. Charles Darwin reduced our mental representation of the process of evolution through the introduction of the notion of 'natural selection'. We are aware what artificial selection is as it has been practiced for thousands of years in breeding plants and animals. Darwin persuaded us that something similar is happening in nature, without any deliberate planning, because it is the environment that plays the role of a 'breeder'. Scientific notions have great explanatory power when used properly; they are also apt to transform an overwhelmingly complex problem into a simpler one without loss of information. The use of metaphor may have similar results because metaphorical language is both synthetic and figurative. It has been showed that the use of metaphor in thinking and problem solving is an effective intellectual tool, particularly in creativity and divergent thinking. From our perspective, it is important to underscore that 'metaphors we live by' (Lakoff & Johnson, 1980) make our minds better prepared to deal with task complexity, despite the natural limitations of our WM system. Unfortunately, imagination was described as a missing factor in the literature dealing with leadership and organisation (Witt, 1998).

7. Conclusions

The review of the concept of WM and research on its functional significance presented here provides some explanation as to why people suffer from information overload. Current theories agree that WM constitutes an 'engine' of human mind. It is a complex, processing and storage system, and its fundamental property is the basic capacity limit. Importantly, WMC limits seem to be arising mainly from the functional constraints on the attentional mechanisms in WM (Oberauer, 2009), an issue that has also been recognised by organisational researchers (see Gifford, 1992 for review). People differ in their WM abilities, and these differences are predictive not only for the 'cold' cognition but also for the 'hot' social or emotional functions. Therefore, WMC is predictive of many cognitive and social outcomes. Fortunately, these limitations may be overcome (to some extent) through instruments such as training of WM skills, task simplification strategies, situated and distributed cognition, and adjusting appropriate cognitive strategies.

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