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Cost of Being Online for Brain: Changing Working Memory Attributes, Associated Metacognitive Knowledge and Long-Term Memory Processing

Çevrimiçi Olmanın Beyin İçin Maliyeti: Çalışan Bellek Niteliklerinin Değişimi, İlişkili Üstbilişsel Bilgi ve Uzun Süreli Bilgi İşleme

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ABSTRACT

Converging evidence from neuroscience and psychological sciences demonstrates that continuous sensory stimulation within the intensive internet use affects brain functioning on a broad scale. This includes essential memory, and metacognitive functions extend to the healthiness and disorders which are critical for the adaptive behavior and learning processes. This study aims to show the relation between intensive internet use and the responds of the brain in neural and behavioral levels through some working memory attributes and associated metacognitive functions and long-term memory processing. Accordingly, functional magnetic resonance imaging (fMRI) studies suggest that being online intensively has an impact on activation levels in Anterior Cingulate Cortex, Dorsolateral Prefrontal Cortex, Orbitofrontal Cortex, Medial and Medial frontal Gyrus, ventral striatum, and the dynamic connectivity pathways including frontal, medial and parietal networks such as Default Mode Network and Task Network which are important for memory and metacognitive functions. Moreover, intensive internet use habits affect some cognitive skills such as the selection of information cues, manipulation and retention of the information and attentional control; evaluation of one's present knowledge, and regulation of the learning processes for; encoding, consolidation and retrieval of information for long-term memory processes are the effected features. As a conclusion, intensive internet use has a critical impact on neural processes in modular and whole brain level and could play a strong role for the alteration of memory and metacognitive processes.
Keywords: Internet use, metacognition, working memory, long-term memory, prefrontal cortex

ÖZ

Sinir bilimi ve psikolojik bilimlerden elde edilen birleşen kanıtlar, yoğun internet kullanımı sırasındaki sürekli duyusal uyarılmanın beyin fonksiyonlarını geniş ölçekte etkilediğini göstermektedir. Bu, temel hafızayı içerir ve üstbilişsel işlevler, uyum sağlayıcı davranış ve öğrenme süreçleri için kritik olan sağlık ve bozukluklara kadar uzanır. Bu çalışma, yoğun internet kullanımı ile beynin sinirsel ve davranışsal düzeydeki tepkileri arasındaki ilişkiyi, bazı çalışma belleği özellikleri ve ilişkili üstbilişsel işlevler ve uzun süreli bellek işleme yoluyla göstermeyi amaçlamaktadır. Buna göre, fonksiyonel magnetik resonans görüntüleme (fMRI) çalışmaları, yoğun bir şekilde çevrimiçi olmanın Anterior Singulat Korteks, Dorsolateral Prefrontal Korteks, Orbitofrontal Korteks, Medial ve Medial frontal Girus, ventral striatum ve frontal, medial ve parietal alanları içeren dinamik bağlantı yolları ile bellek ve üstbilişsel işlevler için önemli olan Varsayılan Mod Ağı ve Görev Ağı ağlarındaki aktivasyon düzeyleri üzerinde etkili olduğunu göstermektedir. Bu bağlamda, özellikle yoğun internet kullanım alışkanlıkları çalışma belleği, üstbiliş ve uzun süreli bellek süreçlerini etkilemektedir. Buna göre, bilgi ipuçlarının seçimi, bilginin manipülasyonu ve tutulması ve dikkat kontrolü; kişinin mevcut bilgisini değerlendirmesi ve öğrenme süreçlerinin düzenlenmesi; uzun süreli bellek süreçleri için bilginin kodlanması, birleştirilmesi ve geri getirilmesi gibi bazı bilişsel özellikler etkilenen özelliklerdir. Sonuç olarak, yoğun internet kullanımının öğrenme üzerinde kritik bir etkisi vardır.
Anahtar sözcükler: İnternet kullanımı, üst biliş, çalışan bellek, uzun süreli bellek, prefrontal korteks

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Introduction

In today's world both the number of people and the number of hours for internet use are very high. Approximately, there are 5.18 billion internet users all around the world, and they daily spend six hours and forty minutes online on average (Statista 2023), which is very intense. The concept of internet use involves some different habits such as searching information, using social media, gaming etc. In this regard, internet use may affect many different cognitive functions. Converging evidence from neuroscience and psychological sciences demonstrates that intensive internet use with the continuous sensory stimulation affects brain functioning in a broad scale. This includes essential memory and metacognitive functions extend to the healthiness and disorders which are critical for the adaptive behavior, learning processes and homeostasis (Manwell et al. 2022).

How the internet use has been changed our lives, habits and cognitive skills is a very common discussion among different research fields. Findings from neuroscience and psychology lead us to consider that internet use shapes our brains and cognitive abilities, particularly our ability to think deeply, evaluate and remember. When these skills are examined in more detail regarding internet use, it is noted that working memory and related long-term memory and metacognitive skills, such as attention, task switching, selection, retention, and use of important information, change significantly (Lorenz-Spreen et al. 2019). These skills are linked together in neural and behavioral matter and very critical for the development of long-term cognitive habits, turning them into behavioral outputs and increasing our state of well-being (Small et al. 2020). In the absence of these skills, negative outcomes such as depression, burnout, or social deficit may occur, and well-being status may be negatively affected (Gippert 2022). For example, depression symptoms are significantly correlated with self-controlled behavioral mechanisms that are closely related to working memory, attention, and metacognitive monitoring. The studies shown that long-term intensive internet use may impair these cognitive skills and induce bigger, long-term problems. In this regard, present studies have examined different cognitive skills in a narrower context. On the other hand, addressing the problem of internet use in a more general framework in terms of the relation working memory, metacognitive knowledge and long-term information processing may help to evaluate the consequences of internet use in a more holistic way. Therefore, this review aims to establish a connection between working memory, metacognition, and long-term memory elements depending on intensive internet use by utilizing neuroscientific and psychological findings. Thus, the review aims to fulfill the gap in the literature by linking present working memory and related metacognitive, long-term memory studies and drawing a general picture about the effects of intensive internet use.

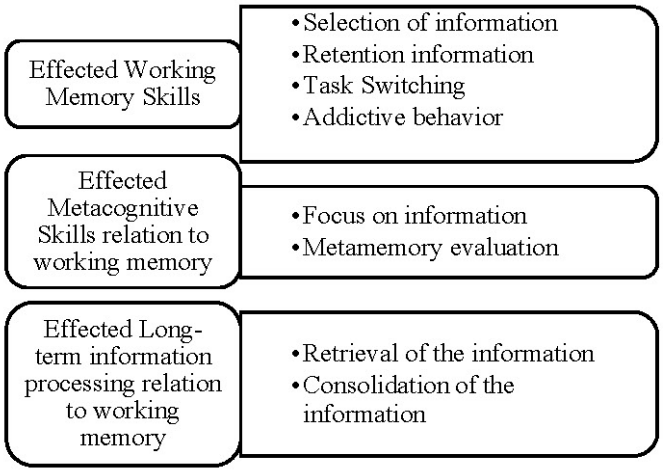

Figure 1. Evaluated working memory and related metacognitive and long-term memory skills in the study.

This review involves related experimental fMRI and psychological studies with the method of aggregative review. Empirical data is collected to describe and broaden the concepts of the present researches (Gough et al. 2012). Accordingly, fMRI studies suggest that some specific areas of brain such as Anterior Cingulate Cortex (ACC) (Webb et al. 2018, Solly et al. 2021), or Dorsolateral Prefrontal Cortex (DLPF) (Park et al. 2017) show different activation levels during and after intensive internet use than normal activation level expected in the daily routine without digital stimulus. Similarly, intensive internet use affects functional network connectivity. The studies suggested that internet use affects default mode network (DMN) and Task Network (TN) (Wang et al. 2019). It is known that these networks and specific brain areas are essential for memory and metacognitive functioning. The changes in these networks and the specific areas may result in changes in behaviors directly or indirectly.

Nevertheless, the effect of internet use was observed in behavioral studies. Accordingly, intensive internet use may damage the skills like attention or task switching. After long-term internet use, people cannot select or keep the information in their working memory, they cannot do effective task switching and have worse cognitive performance. In general, affected cognitive functions might be linked to first working memory skills then interrelated metacognitive and long-term memory skills. Further investigations were made in the related headings below.

Intensive Internet Use and Working Memory Processes: Selectivity, Retention, Task Switching and Addiction

Working memory is a critical cognitive function that helps maintain temporary but goal-relevant information (Kandel et al. 2021). It also plays a crucial role in managing complex mental processes by temporarily storing information and is particularly used for short-term recall of newly learned information or focusing on a task (Watanabe 2017 Banich and Compton 2018). This process occurs through communication between various brain regions, and frontal and parietal lobes play an important role in the functioning of working memory processes. These regions facilitate effective use of working memory by processing information, managing attention, and coordinating decision-making processes (Bear et al. 2016). Especially frontal regions are responsible for higher cognitive functions such as decision-making, problem-solving, and attention control. In working memory processes, frontal regions manage the information processing and coordinate this information with other cognitive functions as needed (Sun et al. 2021). For example, when faced with a problem, the frontal lobes analyze the problem, evaluate solution pathways, and manage the solution process by focusing attention on the problem.

The parietal lobes also play a crucial role in processing visual and spatial information. In working memory processes, the parietal lobes organize information in visual or spatial contexts and integrate this information with other mental processes. For instance, when giving directions on a map or determining the location of an object in space, the parietal lobes are active and facilitate the effective use of working memory in these processes (Gazzaniga et al. 2019). In this way, the frontal lobes and parietal lobes manage the complexity of working memory processes by processing information, directing attention, and coordinating decision-making processes, allowing for effective utilization of working memory. For instance, as it was mentioned in Baddeley and Hitch working memory model executive and phonological and visuospatial functions work together for the generation of temporary memory (Baddeley and Hitch 2000).

The previous studies shown that intensive internet use may affect working memory processes in several ways (Small et al. 2020). First, long-term intensive internet use habits have an impact on information selection mechanism (which is also prior to long-term consolidation). Normally, there is a security wall in working memory processes that selects the information to operate. While some information is selected by working memory processes, the others are excluded. It is a vital skill to differentiate the important information (for example, in schizophrenia patients this skill is damaged Banich and Compton, 2018). Intensive internet use may damage this skill as well. Since internet offers so much information from different sources reachable instantly and this security wall for selection have a limited capacity to process, this creates a burden for WM processes, and it reduces its selectivity (Wang et al. 2019). For instance, digital text-based learning sources (with their links to different visual and textual sources on internet) offers too much information and make learning difficult. It requires much more efforts and digital literacy pre-requirements for the selection and navigation through the necessary information (Burin et al. 2018).

Nevertheless, activation in frontal cortex and parietal networks necessary for managing selectivity processes may decrease because of too much information exposure. For example, ventral stream and parietal dorsal networks are important for the selective attention (Blumenfeld and Ranganath 2006, Essex et al. 2012, Seow et al. 2021). Normally, more activation is required in these regions during more attentive and better working memory performance (Sturm et al. 2016). However, it was revealed in a study that when the participants faced with new information, and are required to learn them from internet, there was less activation in left ventral stream and parietal medial cortices. It was noted in the study that people get difficulties with novel trials (Dong and Potenza 2016). It was also mentioned in other studies that intensive internet use scores affect resting state brain activation. Accordingly, it was revealed in the studies that there could be significant reduction in the pathway between right frontal pole and ventral stream and also lateral prefrontal regions. It was noted in the studies that this could be related to the inhibitor effect of long-term internet use, because internet use stimulates the brain with visual channels too much (Takeuchi et al. 2018, Firth et al. 2020). Additionally, another study also mentioned that the activation level in the parietal dorsal attention network in resting state decreases in

people with intensive internet use. It was noted in the study that it also prevents attention and selecting new information processing (Wang et al. 2019).

Internet also affects task switching performance adversely. Normally, when task switching occurs, the connections in brain are reshaped (De Baene et al. 2012). If there is too much task switching, it is harder to shape the connections again and again and remember previous task. And it also causes time loss for the processing of the same information. In the ordinary course of events, the same type of information should be processed for longer period. In contrast, it was shown in the studies that people with more task switching with internet use causes worse task and remembering performance (Loh and Kanai 2016). It was shown in a study that performers with too much task switching connected to their amount of internet use spend almost same time for the secondary tasks instead of caring about the primary task, and it decreased their performance (Rosen et al. 2013). Moreover, the effect of task-switching with internet use may create broader adverse results by creating interruptions during work time at work places or schools (Kuznekoff and Titsworth 2013, Mark 2015).

Brain imaging studies also revealed that intensive task switching performance within internet use was correlated with lower-level activation in frontal areas which is essential for selection and maintenance of goal-based learning. For instance, normally, high level activation in frontopolar cortex (Brodman's area 10) is important for the sustainability of the related tasks (Mazor et al. 2020, Soutschek et al. 2021, Kroger and Kim 2022). Some recent studies shown that frontopolar activation may reduce because of intensive task switching and and it can ruin the goal-based task switching performance (Loh and Kanai 2014, Solly et al. 2021). Accordingly, a study shown that participants with higher internet use had worse mathematical task performance and could not filter the distractors. Their brain shown less frontopolar activity during task (Han and Kim 2022). Similarly, resting state studies shown that the gray matter in neural pathways between frontopolar area and ACC (which is also essential for control of information) and also between ACC and precuneus can decrease because of intensive internet use (voxel-based morphometry study) and it may affect the regulation of task switching performance (Loh and Kanai 2014, Solly et al. 2021).

Addiction is another effect of intensive internet use related to working memory processes. People who have intensive internet use for-long time, their reward system becomes more sensitive for internet use (Chen et al. 2023). Even it is hard to diagnose this addiction at first glance for lots of internet user, studies showed that internet becomes an inevitable craving object when it is often used (Wang et al. 2017, Small et al. 2020).

Intensive internet use may deficit reward system and dopamine pathways (Busch 2021, Fujiwara et al. 2022). For instance, unbalanced dopamine release is one of the leading factors for the addictive behavior (Banich and Compton 2018, Kandel et al. 2021), and internet use causes this type of dopamine release (Brand et al. 2019, Gong et al. 2022). Some studies revealed these findings in activation level of some specific brain areas (Kühn and Gallinat 2015). For instance, ventral striatum (part of basal ganglia) which is a region for dopaminergic production (Goldstein and Volkow 2011) may increase or decrease too much depending on long-term internet use habits. Similarly, lateral striatum which provides dopamine for different motor functions shows lower activation after a while of long-term internet use (Wang and Wang et al. 2022).

Additionally, the development of an addiction for internet and changes in brain activation in some regions such as DLPFC, ACC or some temporal regions seem to be some other indicators (Wan et al. 2022). When internet is used as primary source to search information, activation in DLPFC shows higher activation (Dong et al. 2017, Wang et al. 2017). Although we can infer that internet use may contribute working memory processes thanks to DLPFC activation at first glance, primary reason for this contribution may be based on formation of addiction (Potenza et al. 2012, Dong et al. 2017, Wang et al. 2017). The behaviors during internet use demonstrate the classical addictive behavior. For example, in different types of addiction, when addictive people meet the addiction object, they show inflated reactions. It was also reported in the previous studies for internet use (Weinstein 2022). Similarly, abnormalities in orbitofrontal cortex was observed during excessive use of internet which is a region related to reward-related behaviors (Dong et al. 2011) and intensive internet use causes thickness within this region (Hong et al. 2013). It is plausible to infer with this data that long-term intensive internet use may induce addiction and ruin the emotional stability in a broad scale (Brand et al. 2014, Zhu et al. 2015, Dong and Potenza 2016, Kurniasanti et al. 2019).

Previous studies also demonstrated that in functional connectivity level. While people are reaching the internet, gray matter volume in default mode network increases and craving behavior occurs (Weinstein 2022). It was also reported in a study that the orchestration between default mode network and visual attention network was ruined because of intensive internet use (Wang et al. 2019). Similarly, other studies reported that there was an alteration in the activation in prefrontal-striatal network decreases after long-term intensive internet use (Wang and Wang et al. 2022). This is also supported by morphometric network pathway studies. The functional

networks between orbitofrontal cortex and anterior cingulate which is important for reward management processes becomes thinner in excessive use as well (Lee et al. 2018). On the other hand, activation level decreases and cortical thickness wanes in long-term internet use (Takeuchi et al. 2018). Consequently, intensive internet use may create addictive behavior, people become only enthusiastic, when they interact with internet, and it may create cognitive decline by time (Wan et al. 2022).

Intensive Internet Use and Metacognitive Knowledge: Relation to Focus, and Metamemory

Metacognition is the cognitive process that enables one to evaluate, monitor her own knowledge, and take further action towards the learning goal and the outcome (Proust 2014, Boldt and Gilbert 2020). With the several repetitive questions, thoughts around the present task, one examines her own existing knowledge, and creates a general picture of her own meta/memory (Proust 2009). Thus, thanks to metacognitive ability, one may be aware of her prior knowledge and weaknesses then develop learning and behavioral strategies (Baird et al. 2013). Previous studies shown that being expert in a topic by time requires robust metacognitive skills (Ertmer and Newby 1996). Additionally, the quality of metacognitive knowledge is highly connected to working memory skills. How the information is selected, kept, and retrieved play an important role in metacognition (Pintrich 2002), and frontal and medial regions (and the connectivity between) are again prominent in metacognitive activity (Fleming and Dolan 2014, Rouault et al. 2018).

One of the most important contributions of metacognitive knowledge to mental activities is that it encourages more detailed, higher order thinking. With better metacognitive ability one may analyze the problems in a more detailed and creative way, solve more complex problems, and present behavioral outcomes (Zhou et al. 2023). However, this process requires better focusing on the same sort of information, retaining this information longer, and allowing implicit knowledge in the backhand (unconscious processing) to create improvised connections. Internet use may affect this metacognitive process in two ways. First, because internet offers too much information from too many sources and it may impair focus time and therefore metacognitive repetition process (Şendurur and Yildirim 2019, Burin et al. 2020). For instance, the performers were asked to search from internet and hard-copy separately in a study. The study revealed that the performers with the internet use had shallower conceptual reasoning, and it was related to amount of information in the internet (Stadtler and Bromme 2007). With a broader analyze, the other recent study revealed that individuals who access the redundant content in internet show limited attention, quicker exhaustion in different topics such as social or scientific (Lorenz-Spreen et al. 2019). As a result, the overwhelming flow of information on the Internet reduces focus time and makes it difficult to stay on a topic for longer to have metacognition on the same topic.

Second, long-term internet use may induce false or overwhelmed metacognitive belief. This phenomenon can occur in two ways. First, too much knowledge on internet may create metacognitive confusion because every different information may tell something that cannot be checked. For instance, online health related search may create confusion and false metacognitive beliefs because of too much information in internet from different sources (Fergus and Spada 2017). Second, this may create biased overconfidence. Unrestricted access to information may make people think that they have the information in themselves (Fisher et al. 2015). For instance, it was noted in some studies that people with internet use had more confident about their memory performance, but lower scores in remembering in the task (Ward 2013, Hamilton and Yao 2018). Other studies also reported when a task is given to participants with the support of internet, they avoid performing the task (especially when the task is harder) by inferring that they already have the answer (Pieschl 2021, Mattes and Pieschl 2022). Moreover, metacognitive false belief about internet use itself may also occur because of intensive internet use. It may threaten one's metacognitive ability to evaluate how intensive internet use might be problematic for himself/herself (Casale et al. 2021). As a result, intensive internet use may impair metacognitive knowledge by damaging some working memory features such as focusing or retrieving information.

Studies shown that the relation between metacognitive ability and excessive internet use may be correlated with medial prefrontal regions and their functional connectivity which is related to prospective task decisions (Dong et al. 2011, Darnai et al. 2019). Accordingly, it was revealed in a functional connectivity study that participants with intensive internet use who performed worse at learning the meaning of concepts in the experiment shown significant deactivation in functional networks between precuneus and posterior cingulate gyrus (related to DMN) (Darnai et al. 2019). Another study also revealed that people with lower memory scores had less activation in precuneus and posterior cingulate gyrus during internet search. It was noted in the study that these associative areas integrate information from different sensory and memory sources. Therefore, excessive internet use may impair these prospective sensory and memory related metacognitive processes (Dong and

Potenza 2016). On the other hand, higher activation was observed in the dorsal anterior cingulate and left caudate nucleus of participants who used the internet intensely. It was noted in the study that this might be related to metacognitive knowledge that creates conflicts through the past experiences (Seok et al. 2015).

On the other hand, some studies shown that internet use with better metacognitive skills may support metacognitive knowledge by providing the variety of information that is needed for specific tasks (Small et al. 2020). It was revealed in a study that older adults with better metacognitive skills had higher task performance with higher activation in frontal region during online information search (Small et al. 2009). Since internet offers lots of information from different valid sources, one's metacognitive control skills may be developed with the help of better metacognitive skills. For instance, someone who has more accurate metacognitive monitoring assessments about her/his own knowledge, she/he can have better task performance with online information search (Casale et al. 2016, Balıkçı et al. 2020, Hamidi and Ghasedi 2020). Because metacognition reinforces better information evaluation and decision making processes with the help of perception or memory (Fleming and Lau 2014, Fleur et al. 2021), people may benefit from internet sources with better metacognitive skills (Azevedo and Aleven 2007, Aydın et al. 2020). For example, it was revealed in a study that, participants who had more accurate metacognitive monitoring performed their writings better by catching better information from internet and having action to write (Zhang and Qin 2018). Thus, better metacognitive performance may result in better learning processes with the help of internet use (Firmanto et al. 2019, Ariffin et al. 2021).

Intensive Internet Use and Long-Term Memory Formation, Retrieval and Consolidation Processes

Long-term memory refers to the ability to last certain information for a long time (e.g. years or a lifetime). The brain has ability to change its neural connections through the experience, and to learn. Learning is associated this neural changing, and it might be accomplished with several ways within the specialized different brain regions. Different sort of information such as semantic, episodic, emotional, or procedural information requires different certain brain regions such as basal ganglia, amygdala or hippocampus. Nonetheless, frontal lobe (especially neocortex) plays a common and an important role for the formation of long-term information processing. The system is kind of a feedback system that first information is sent from neocortex to hippocampus and entorhinal and parahippocampal cortex then sent back to the neocortex again for the long-term formation (Gazzaniga et al. 2019). As it might be guessed, this dynamic feedback system shapes long-term memory, and it is highly related to working memory processes (Banich and Compton 2018, Sun et al. 2021). As a result consolidation of the information depends on active retrieval and requires dynamic activation of these frontal and medial regions.

As it was mentioned earlier, intensive internet use might deficit working memory and metacognitive attributes such as focus, selectivity, retention, repetition. However, intensive internet use may influence retrieval and consolidation processes as well which might block formation of long-term memory (Ward 2013). While the internet creates false beliefs that generally disrupt metacognitive knowledge and impair general creativity, deeper thinking, it also prevents the repetition of certain information related to working memory skills and disrupts long-term memory processes. For example, transactive memory systems are the tools for storing extra information which is more than the human mind may hold. Because internet offers all the necessary information all the time as a transactive memory storage, it gives a possibility to our brains not to keep the specific information itself. Necessary information is always reachable in internet. Therefore, the way how people attend to keep and use the information alters (Näsi and Koivusilta 2013). As a result, the retrieval and consolidation of information processes may not occur to strengthen long-term memory. The phenomenon is called as digital amnesia (Mastrogiorgio et al. 2021). Some studies shown that participants who use internet as a daily routine fail to retrieve the specific information. Dong and Potenza shown (2015) in their study that the participants with intensive internet use could remember the information in a short period, but they were not good at retrieving the certain information in a longer period.

Because the Internet gives the impression of a more reliable source of information than our own memory, people are less inclined to make efforts to retrieve certain information, and therefore consolidation processes may be weakened. (Finley and Naaz 2023). A study shown that people who use the internet tend to quickly change their focus and switch to different information, rather than spending time on specific information. (Fisher et al. 2022). As a result, intensive internet use habits are potent to make necessary processes for long-term memory formation difficult. The more people use internet, the more they get used to the internet as an information source. Therefore, they don't perform retrieval, and consolidation processes (Sparrow et al. 2011, Yang et al. 2014, Storm et al. 2017). When there is external available source for obtaining information, internal long-term

memory becomes no longer necessary (Loh and Kanai 2016, Hu et al. 2019, Weis and Wiese 2019). As a result, no retrieval and consolidation were presented.

The effect of intensive internet use was also measured in the recent studies in neural level. A recent study shown that even after short-term intensive internet use (6 days training), individual ability to recollect specific information was disrupted. The activity level and local functional homogeneity in the temporal gyrus, the middle frontal gyrus, and the postcentral gyrus decreases, whereas normally, long-term memory processes depend on the higher activation in the areas (Liu et al. 2018). Another study also revealed similar results that the participants shown lower response time during retrieval of specific information. And their brains shown reduction in the activation level in right superior longitudinal fasciculus after 6 days training with internet use. (Dong and Potenza 2016). Moreover, Dong and Potenza (2015) also shown in another study that participants with lower accuracy in retrieving the specific information during a spontaneous internet-based search shown lower activation levels in ventral stream. It was noted in the study that reduction in the activation in these areas might be preventing retrieval and consolidation for long-term memory because of different types of internet use habits. If there is no retrieval for certain information explicitly, or implicitly, long-term information may not be consolidated (Schooler and Storm 2021, Sparrow et al. 2011, Ward 2013a). As recent studies shown, especially the reduction in the activation in prefrontal cortex during information recollection may be the important sign (Fisher et al. 2015, Kühn and Gallinat 2015, Dong and Potenza 2015, 2016).

Lastly, intensive internet use may affect retention and recalling the visual and related information during short-term internet research. Normally, retention and retrieval the verbal information requires the amount of activation in frontoparietal regions (Kandel et al. 2021). However, it was revealed in a study that long term internet use habits may disrupt visual-verbal information retention and retrieval processes. Accordingly, the young participants with intensive internet use performed worse in retrieval of the content of the ink matched with a color. It was measured in the study that bilateral precuneus shown less amount of activation which is necessary recollecting and the integration of the information. Therefore, it was noted that intensive internet use may damage visual semantic retrieval and consolidation processes, especially for the development of neural structure in young adults (Darnai et al. 2019). Liu and his colleges' (2018) also shown that while participants are searching for visuospatial information on internet, functional connectivity between parietal lobe and parietal gyrus increases. It was noted in the study that this might be related to the spatial perception of participants because participants perceive the internet as a natural navigation space for finding the necessary information. As a result, the activation in visuospatial processing may increase for finding where the information is rather than retrieving the information itself from existing long-term memory (Kang 2022).

In general, intensive, even short-term internet use habits may prevent the information retrieval consolidation processes which long-term memory depends on. Moreover, this sort of disruption in information processing may have a potential to change our learning habits in long-term.

Discussion

This study aims to provide a comprehensive overview of the impact of intensive internet use on certain working memory skills and its correlation with metacognitive knowledge and long-term memory formation. As the internet has become a prominent tool for daily cognitive tasks like information searching, social media usage, and gaming, it is increasingly important to understand its intensive use's dynamics on our brains and cognitive mechanisms. Previous studies have primarily focused on measuring working memory attributes such as attention, task switching, and information retrieval (Firth et al. 2020). However, research indicates that the internet may have a broader impact on general intelligence across populations, beginning with working memory skills (Ward 2013, Loh and Kanai 2016). Therefore, this study assesses the commonalities in working memory among these three cognitive skills under the influence of intensive internet use, drawing on neuroscientific insights.

Findings regarding the relationship between intensive internet use and working memory skills are typically categorized into four areas: selection, retention, task switching, and addictive behavior. Intensive internet use may impede the selection and retention processes of information. Individuals may struggle to focus on specific information, select relevant information, and retain it (Burin et al. 2018). Moreover, excessive task switching caused by internet use can impair information processing. The prevalence of frequent task switching, facilitated by platforms like search engines and social media, may be detrimental to working memory skills (Jiang et al. 2022). Another effect of intensive internet use is addiction. Addiction may be one of the most harmful effects

of intensive internet use. Intensive internet use may create addictive behavior and it may harm most of the memory related skills such as focus, task switching or metacognitive ability (Casale et al. 2021).

Furthermore, intensive internet use can impact metacognitive processes associated with certain working memory skills. It may impair focus skills, leading to difficulties in sustaining attention on content for extended periods, thus affecting creativity and higher-order thinking (Fisher et al. 2015). Besides, it may engender false metacognitive beliefs, contributing to confusion or overconfidence in one's existing metamemory (Casale et al. 2021). Lastly, intensive internet use may influence long-term memory formation again through some working memory skills. Accordingly, intensive internet use may induce digital amnesia. Internet is perceived as a transactive memory tool which always offers the necessary information. Therefore, people with intensive internet use avoid caring about certain information and have lower retrieval and consolidation processes. As a result, information may not be transferred into long-term memory channels (Dong and Potenza 2016).

Brain imaging studies also confirm this general picture with fMRI studies. Accordingly, information selection and retention processes might decline because of intensive internet use. The activation level and network connection in related brain regions processes was shown in the studies. İntensive internet use habits might result in decline the activation and gray matter level in some frontal brain regions, and it may deficit the orchestration of functional connectivity networks. In addition, recent studies shown that the alterations in dorsolateral prefrontal and anterior cingulate activation was also highly connected to task switching and focus (Loh and Kanai 2014, Solly et al. 2021).

Another robust fMRI finding about intensive internet use was related to addictive behavior. Especially the activation levels in striatal networks and striatum itself was one of the most important findings in intensive internet use. These confirmed that intensive internet use may cause lower or hyper activation in some of the dopaminergic production centers (Wang et al. 2022).

Although fMRI studies do not provide direct information about the relationship between metacognitive ability and creativity and higher order thinking, the findings suggested that the neural activation level changed in the brain regions related to prospective memory and information integration processing such as precuneus and posterior cingulate gyrus. However, it was also suggested that metacognitive false beliefs might depend on activation levels in anterior cingulate cortex related to overconfidence (Seok 2015). Lastly, more robust findings confirmed the intensive internet use may deficit long-term formation. Especially prefrontal areas shown less activation during retrieval processes during or because of intensive internet use (Dong and Potenza 2016). This suggests that internet has a memory blocking structure. Overall fMRI findings and behavioral outcomes are summarized in Table 1.

Consequently, it seems that there is a solid change in working memory processing and related metacognitive knowledge and long-term memory formation depending on intensive internet use. It is the reality that internet is changing our cognitive skills, transforming our brains into quicker machines. However, it is suspicious whether the evolutionary status of our brains is ready for this change or not. Therefore, our brains may fail at this kind of fast cognitive processing. Moreover, a bigger problem caused by intensive internet use is emotional corruptions. As it was mentioned earlier, working memory and related metacognitive skills are very essential for emotional and cognitive well-being. The Internet's increasing speed and accumulation of information can impair these memory and metacognitive processes and induce cognitive confusion. As a result, emotional disruption may occur with long-term cognitive laziness, and people may become more vulnerable to addiction.

Nonetheless, although intensive internet use may have negative effects on our cognitive functions, it is inevitable to disregard this cognitive source in our daily lives. Therefore, it is very critical to examine the cognitive processes detailed related to internet use and bring some regulations for using this tool. In that context of memory and metacognition, such following subjects may be researched in the further investigations:

The effect of intensive internet use was measured in the studies with narrower questions. However, the effect of the tool on general cognition may be measured in a broader scale and longer time with the associations between different cognitive skills. Thus, sensitive and strong cognitive skills may be detected, and some precautions may be taken against the negative effects of internet use.

Intensive internet use addictive behavior studies are critical to understand the present situations in cognitive development. Since it is hard to distinguish regular internet users from addicted users, it is essential to draw a line and to describe which is what and explain how it influences related skills. At that point, impulsivity research may be considered in terms of brain imagining studies. Understanding both neural structures and behavioral compositions of addiction may represent important clues about how internet is changing our cognitive skills.

Table 1. Neural activation levels and behavioral findings after long and short term intensive internet use

Cognitive skills affected by internet use	Activation level in related brain areas	Related cognitive functions	Behavioral tendency
Fundamental Working Memory Skills: Selectivity, Retention, Task Switching and Addiction	Low level activation in Ventral stream, Parietal Dorsal Attention Network	Selective attention for the specific information	Loss of attention on a specific information
	Low level activation in Frontopolar cortex, ACC, Precuneus	Retention of the specific information	Lack of interaction with a specific information
	Higher level activation in ventral striatum, prefrontal-striatal pathways, and orbitofrontal cortex, Low level activation in, DLPFC, DMN, and Visual Attention Network	Addictive behavior	Craving for the internet use
Metacognitive Knowledge; related working memory and metamemory skills	Low level activation in frontopolar cortex, ACC and the network between ACC and frontopolar cortex; between ACC and precuneus	Metacognitive knowledge	Lack of higher order thinking processes because of lack of metacognitive knowledge
	Low level activation in precuneus and posterior cingulate gyrus (related to DMN), and superior/middle/inferior temporal gyrus, and middle frontal gyrus	Metacognitive monitoring skills, metamemory	Misbelief about the one's own existing information
Long-term memory formation, related working memory skills: retrieval and consolidation skills	Low level activation in the temporal gyrus, the middle frontal gyrus, and the postcentral gyrus	Consolidation of the information	Tendency not to keep and repeat for the same specific information
	Low level activation in ventral stream including occipital gyrus, inferior temporal gyrus Activation increases parietal gyrus	Recalling of the specific information	Tendency not to retrieve the specific information from long-term memory
	High level activation in post parietal cortex	Visuospatial information seeking	Searching the visuospatial information on internet screen

ACC: Anterior Cingulate Cortex; DLPFC: Dorsolateral Prefrontal Cortex; DMN: Default Mode Network.

Internet use may be evaluated in different contexts and different groups to explain its effect and opportunities. For example, the memory studies done with older adults by using internet as an information source put insights about how memory performance can be advanced. Similarly, internet may be used in educational interventions for better metacognition and memory skills. There are different effects of internet use on different groups. For instance, persons with better metacognitive skills may benefit from internet in a better way. Therefore, it is important to investigate internet use with different contextual.

Smart phone use, and media multitasking are other prior topics for internet use. Studies shown that these new type of behaviors have influence to change memory and metacognition skills (Piñeyro Salvidegoitia et al. 2019). Since these actions are inevitable for our daily routine, it is very essential to analyze the situation and put different sides of these for different cognitive skills.

The neural, molecular occurrences in the brain may construct the brain and thereby behavior in long-term as much as incidental. Especially what happens during and after sleep is very critical for memory, metacognition and related cognitive skills (Wang and Wu et al. 2022). Recent studies shown that internet use may create sleep problems therewith some other cognitive issues (Alimoradi et al. 2019). Therefore, it is very essential to observe what happens in brain related4 to internet use in sleep and in long-term.

Conclusion

Intensive internet use has profound effects on memory, metacognition, and how brain works. Research indicates that the constant influx of digital information can lead to diminished attentional capacities, impairing the ability to encode and retrieve information effectively and metacognitive false belief. This often results in a reliance on external memory sources, such as search engines, rather than internal cognitive processes. Metacognitive abilities, including self-awareness and self-regulation of cognitive tasks, may also be adversely affected, leading to reduced accuracy in self-assessment and decision-making. Neuroimaging studies reveal structural and functional changes in the brain, particularly in regions associated with attention, memory, and metacognition. These alterations suggest that while the internet offers unparalleled access to information, its intensive use may require a balanced approach to mitigate potential cognitive and neurological impairment

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