PSICOLÓGICA

Problematic internet use may be linked to issues with verbal processing

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Abstract

Problematic internet users (PIUs) tend to have poorer attentional control, impaired working memory (WM), and poorer executive functions. Based on previous results using verbal and visuospatial WM tasks, there might be a difference in the processing efficiency of various types of information. Visuospatial processing skills might be enhanced in PIUs, however, studies considering a possible association with verbal processing skills are scarce. Here we investigated how performance on verbal and visuospatial tasks are associated with measures of PIU. Participants (N=51) completed a dot-finding and a 1-back single task with both verbal and visuospatial stimuli, and a dual task that combined the two single tasks. Thus, we manipulated task Difficulty (Single vs Dual) and Modality (Verbal vs Visuospatial). We used the Problematic Internet Use Questionnaire (PIUQ) to measure PIU. People scoring higher (compared to those scoring lower) on control disorder and obsession subscales of PIUQ performed worse on the verbal and better on the visuospatial condition. Higher PIUQ total scores correlated with more difficulty on the single-task and lower difficulty with dual-task performance. In conclusion, although participants more prone to PIU were better in task switching, higher levels of PIU may be associated with worse verbal processing and increased distractibility.

Keywords: multitasking; task switching; verbal; non-verbal; working memory; attention.

Psicológica (2024)

DOI
10.20350/digitalCSIC/16117

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Introduction

Although Young (1998) first described internet addiction two decades ago and the topic received increasing interest since, we still have relatively little information on how internet use shapes cognitive processes. Internet addiction involves excessive, compulsive internet use that interferes with daily life, relationships, and responsibilities. Signs include preoccupation with the internet, loss of control, neglect of real-life duties, social isolation, and negative impacts on physical and mental health. Behavioral addictions have been shown to have a pervasive and domain-general effect on cognitive processes (McCusker, 2001), possibly through the dysfunction of the prefrontal cortex (Goldstein & Volkow, 2011) and dorsal anterior cingulate cortex (Luijten et al., 2014). Although still not considered a distinct mental disorder, problematic internet use (PIU) is often compared to other behavioral addictions (Block, 2008; Shapira et al., 2003). Indeed, some cognitive processes likely have similar biases and alterations in relevant brain regions and networks to that of pathological gambling (Goldstein & Volkow, 2011) or other behavioral, as well as substance addictions (Chamberlain et al., 2016; Luijten et al., 2014). PIU is known as a multidimensional behavioral addiction that is formed by the interaction of multiple factors such as personality, cognitive, and affective dimensions (Brand et al., 2016). Recent studies showed that impaired cognitive control-related areas – i.e., working memory (WM), executive functions, and impulsivity traits (Hong et al., 2018; Zhou et al., 2014) – are the most prominent factors that affect the addictive use of the Internet (Khanbabaei et al., 2022). Furthermore, problematic internet users (PIUs) tend to have impaired inhibition control (Metcalf & Pammer, 2014; Nie et al., 2016), poorer attentional control (Metcalf & Pammer, 2014), impaired working memory (Nie et al., 2016), deficits in the orienting network (Fu et al., 2018), poorer executive functions (Loh & Kanai, 2016) and learning attention (Kuo et al., 2018). The involvement of other cognitive factors, such as those related to language and verbal processing is still not well documented.

Verbal processing deficits may also be linked to PIU. A previous study (Goldstein et al., 2004) assessing twenty neuropsychological tests in people with cocaine addiction, alcohol addiction, and healthy controls showed impairments in verbal knowledge, visual and verbal memory, and attention/executive functioning in the addiction groups. Importantly, the verbal knowledge scale represented a compromised premorbid level of functioning. In fact, children with language processing problems have a greater risk of developing addictions (Beitchman et al., 1999) and other problematic behaviors (Chow & Wehby, 2018) compared to their typically developing peers (Curtis et al., 2018). The psychosocial proneness of problematic behaviors is associated with internet addiction and PIU (Ko et al., 2008). Thus, issues in verbal processing may lead to a heightened risk of PIU. Nevertheless, previous studies mainly focused on the change in literacy skills due to the widening range of internet access and the ever-growing social network site use among teenagers (Hamm et al., 2015). A study (Pfost et al., 2013) including 1226 secondary school students showed a negative correlation between online activities – e.g. e-mail or chatting – and reading achievement. Yet, to this date, to our knowledge, there is only one study (Nie et al., 2017) exploring the involvement of language skills in PIU. Nie and colleagues (2017) used a verbal fluency test and showed that participants scoring high on a questionnaire measuring PIU showed poorer performance in semantic verbal fluency compared to controls. While a pioneering study, Nie and colleagues do not identify the underlying cognitive mechanism, such as the roles of various WM processes (such as verbal WM and cognitive control). Thus, in the present study, we sought to examine the role of cognitive control-related functions in verbal processing in PIU.

Issues in verbal processing linked to WM could be a key factor in understanding potential language processing deficits in PIU. WM, one of the central components in cognitive processing, has been widely investigated regarding PIU. The central executive in WM temporarily holds and manipulates information to support advanced cognitive processes such as reasoning, planning, and learning (Cowan, 2016). Cognitive control-related deficits can be tested by increasing task load, i.e., making a task harder and, for instance, examining the success of maintaining information in the WM while a different task is performed (Bonato et al., 2015; Lisi et al., 2015). Digital media and PIU have the potential to affect WM in both negative and positive ways, such as decreasing the cognitive control capacity but increasing visuospatial processing. Recent studies have suggested that individuals with higher PIU (Khanbabaei et al., 2022; Zhou et al., 2014) and heavier digital media consumption (Ophir et al., 2009) tend to have decreased WM abilities (Zhou et al., 2014). This might be due to the imbalance of the limbic reward system and the prefrontal control system, the latter of which is involved in WM (Cole & Schneider, 2007; Gallinat et al., 2006; Zanto et al., 2011). However, there are contradictory results related to the role of WM in PIU. Several types of internet activities, such as playing video games online, could promote positive changes in cognitive processes. For example, findings from online video gaming studies demonstrated that playing online video games enhances visuospatial cognition (Hubert-Wallander et al., 2010; Oei & Patterson, 2014), and the time spent online gaming is positively associated with WM performance on nonclinical samples (Colzato et al., 2013; Waris et al., 2019). The complexity of WM provides a great variety of assessments and pitfalls, namely, the capacity and processing of visuospatial and verbal stimuli. On the one hand, the mixed results regarding the link between PIU and WM may be due to the modality of the task (i.e., verbal or visuospatial) used to measure WM capacity. Hence, in the present study, we aim to use both modalities to address this issue. If the correlation between internet use and performance on visuospatial tasks is positive and negative on verbal tasks that might mean that verbal WM is an important link between verbal processing issues and PIU. On the other hand, increasing the difficulty of a task – by e.g., introducing a secondary task modality – could exaggerate individual differences. To fully understand how WM is affected by Internet use, performance on tasks tapping into the verbal and visuospatial aspects of WM needs to be directly compared.

There is indirect evidence suggesting the possibility of verbal processing deficits in PIU. A previous study (Inhóf et al., 2019) found a correlation between a questionnaire measuring PIU and the volume of the right pars opercularis – an area that contributes to language functions, including aspects of speech production, syntax, and comprehension – suggesting a potential alternation in the pars opercularis (and hence language functions) in PIU. Furthermore, other studies utilizing resting-state connectivity in PIU identified regional abnormalities in brain areas strongly related to language processing (Sepede et al., 2016), for instance, the left superior frontal gyrus (Liu et al., 2010) – involved in language switching (Huili et al., 2009) –, right inferior frontal gyrus – involved in verbal discrimination (Hsieh et al., 2001) – and left superior temporal and middle temporal gyri – involved in phonological and semantic processing (Démonet et al., 1992). Indeed, alternations of the language system have been shown in other behavioral addictions like gambling (Conversano et al., 2012; Regard et al., 2003), alcohol dependence (Goudriaan et al., 2006), opiate addiction (Guerra et al., 1987), and cocaine addiction (Lorea et al., 2010). Therefore, exploring the association between PIU and verbal WM could possibly have important theoretical and practical implications in e.g., clinical practice, research, and education.

The overarching goal of the present study was to explore whether higher levels of PIU correlate with worse verbal WM performance due to issues related to cognitive control. In particular, we aimed to investigate the link between PIU and verbal and visuospatial WM performance. Higher levels of PIU may be linked to decreased verbal WM abilities. Therefore, our first hypothesis was that individuals with higher levels of PIU would have a worse WM performance, especially on trials including verbal stimuli. Further, our second hypothesis was that this effect would be more pronounced in a dual-task situation due to potential cognitive control-related deficits previously shown in PIU.

Methods

Participants

Fifty-one university students (23 females, mean age 22.2 years, ranging from 19 to 28 years) volunteered in the experiment. The required sample size for this experiment was determined by computing estimated statistical power ($f=.40$, $\beta > .8$) using G*Power (Faul et al., 2007). The analysis indicated a required total sample size of 16. With a more conservative approach that used a smaller effect size to estimate the sample size needed ($f=.25$, $\beta > .95$), the required sample size was 49; thus, even with a conservative approach, our study was adequately powered. All participants were right-handed, with normal or corrected-to-normal vision. None of them had a history of neurological disease or mental disorder (including anxiety, depression, alcohol, or other substance abuse), as noted through self-report. Participants with chronic illnesses, and neurological or psychiatric disorders were not included. Our research was approved by the Regional and Institutional Research Ethics Committee of the University of Pécs (nr. 7476-PTE2018) and carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent for experimentation with human subjects was obtained.

Assessment

Internet addiction was assessed using the Problematic Internet Use Questionnaire (PUIQ) (Demetrovics et al., 2008). The questionnaire consists of 18 items, and three subscales: Obsession, Neglect, and Control Disorder. All items are answered on a 5-point scale (never, rarely, sometimes, often, and always). The Obsession subscale mostly refers to the craving, i.e., mental engagement with the Internet and anxiety, worry, and depression caused by the lack of Internet use. The Neglect subscale assesses neglect of everyday activities and essential needs. The Control disorder subscale refers to the loss of control – i.e., dyscontrol – over own actions regarding the use of the Internet. The three subscales add up to the total score, where a higher score signifies a higher level of addiction. The test has good psychometric properties with a Cronbach's alpha of .87 (Demetrovics et al., 2008). In the present study, we used test scores as continuous variables in the absence of a clear clinical cut-off point.

Apparatus

The experiment was run on a PC, using PsychoPy Software version 1.83 for Windows (Peirce, 2007). The stimuli appeared on a 19-inch LCD color monitor with a visible area of 17in. and a resolution of 1366×768, 5:4 aspect ratio, refresh rate, and a sampling rate of 100Hz, 24-bit color format

Stimuli and tasks

The basic paradigm used in this study was similar to previous studies investigating the effects of task load (Bonato et al., 2015; Lisi et al., 2015). We manipulated task Difficulty (Single vs Dual) and Modality (Verbal vs Visuospatial). Participants completed a dot-finding and a 1-back single task with both verbal and visuospatial stimuli, and a dual-task composed of the two tasks. See Figure 1 for an overview of the tasks.

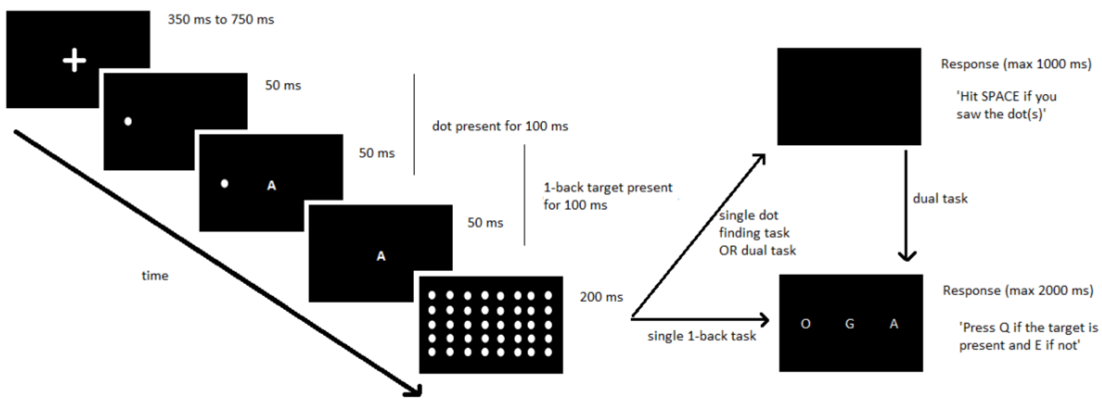

Figure 1 – Schematic representation of an experimental trial. Every trial started with a fixation cross, then two targets (dot on the right, left, or both sides and a letter or arrow at fixation) were presented for the two single tasks (dot finding and 1-back); followed by a mask. In the dot-finding single task, participants had to indicate whether they saw the dot. In the 1-back task, participants had to indicate whether the previously seen letter or arrow was present or absent among the shown options. In the dual-task condition participants first completed the dot-finding task, then proceeded to the 1-back task.

Visual stimuli were presented on a black background and consisted of lateralized targets (white dots) for the dot-finding task. The single dot-finding task was introduced to measure participants' distractibility by maintaining verbal or visuospatial information. This – i.e., the baseline – condition was a simple motor vigilance task where participants indicated if they saw a dot on the screen or not. The lateralized targets consisted of white dots (.75° diameter), appearing either on the left, on the right, or on both sides of the screen (eccentricity 14°) for 100 ms. During the task, a secondary object (letter for verbal, arrow for visuospatial) also appeared in the center of the screen for 100 ms with a 50 ms delay.

This object served as a task-irrelevant distractor for the single dot-finding task and could be verbal or nonverbal (see the description of Target modality, as the same object was used as the target in the 1-back task). Then a mask was presented for 200 ms that consisted of 40 white dots, covering the whole screen including the target positions. After the mask, a blank screen was presented for 1000 ms or until response. In the dot finding, task participants had to indicate whether the dot(s) appeared on the screen or not by pressing the SPACE button.

In the single 1-back task, the secondary object presented after the dots served as the target to be remembered, and the dots were to be ignored. The target could be either a verbal (letter) or a visuospatial (arrow) symbol. After the mask and blank screen, participants saw a recognition recall task (for 2000 ms or until response) where three possible answers were presented to the 1-back task from the same category (letter or arrow) as the target. Respondents had to indicate whether the target was among them or not by pressing different buttons on the keyboard (Q - yes, E - no). The probability of the target being present was 50% across the trials.

The Target Modality was manipulated across experimental blocks. In verbal blocks, one of six white letters (A, B, E, G, L, O) was shown at fixation. We used letters as verbal stimuli due to the very brief onset times. Letters have a verbal nature and previous studies have shown that they load on verbal WM, i.e. the phonological loop, (Naert et al., 2018), and that they activate the left hemisphere more because of its dominance for language (Majerus et al., 2012). In visuospatial blocks, a white arrow was shown at fixation indicating one of the six possible arrows (plus or minus 45°, 90°, and 135° from vertical). We did not use 0° and 180° to avoid similarity to letters V and A. We used arrows instead of, e.g., geometric figures to avoid a possible naming effect where participants could have used verbal beside visual feature coding, i.e., the name of the object, to remember it. Thus, the visuospatial task is primarily loaded on the visuospatial sketchpad of the WM. The targets were of the same size as the dots. In the single-task version of the 1-back task, the screen with the possible answers directly followed the mask and participants did not respond to the dots.

In the dual-task version, participants had to respond to both the dot-finding and the 1-back task. This task was more demanding as they had to be vigilant to respond to the appearance of the dot target while maintaining the verbal (letter) or visuospatial (arrow) information in the WM presented in the center of the screen serving as the target in the secondary task. Due to the added WM load performance could be worse on the dual dot-probe compared to the single condition where the objects in the center could be ignored. Also, due to the added vigilance task performance on the dual 1-back task could be worse compared to the single condition as participants had to divide their attention and, thus, memorizing the target was harder. With the dual-task condition, thus, we could examine the role of the central executive of the WM, which has a key role in executive functioning.

Each task (single dot finding, single 1-back, dual) comprised 108 trials (6 repetitions x 6 shapes x 3 spatial positions). Response hand and the order of task presentation were counterbalanced across participants. The experiment lasted approximately 30 minutes.

Procedure

The experiment was conducted in a quiet and dimly lit room. Participants were seated with their heads positioned on a chin rest at a distance of 60 cm from the computer screen. They received both oral and written task instructions (in this order) and the importance of maintaining gaze at fixation was stressed before each task.

Participants started with 54 practice trials (18 single dot-finding, 18 single 1-back, and 18 dual-task trials). Then, they completed the experiment with short breaks between each task. Each trial started with a white fixation cross on a black background appearing for a random time interval between 350 ms to 750 ms. Then, the dots appeared in various positions (left, right, or bilaterally) for 100 ms. The 1-back target appeared at fixation with a 50 ms delay for 100 ms. This was followed by a mask for 200 ms. In the single dot-finding task respondents had to indicate if they saw the dot appear and then proceeded to the next trial. In the single 1-back task participants did not have to respond until a black screen with three possible targets appeared right after the mask. Here, they had to indicate whether the previously appearing target at fixation was present or not. In the dual-task condition, participants responded to the dot-finding task and then to the 1-back task as well.

Data analyses

Statistical analyses were performed using the JASP Statistics Program (Version 0.8.6 for Windows). We excluded outliers, defined as a reaction time (RT) greater than ±2 standard deviations of the group mean (< 2% of all the collected data) for each variable, separately. Only RTs for correct responses were analyzed, and the error rates varied between 3.3% to 7.0% in overall conditions. The RTs and correct responses were averaged over trials yielding four variables for both the dot finding task (single vs dual x verbal vs visuospatial) and 1-back task (single vs dual x verbal vs visuospatial). Due to a technical issue with one of the computers in the laboratory, the data on the 1-back tasks could not be recovered from four participants. We only discovered this after concluding the data collection. We decided to analyze the available data points, so we used all available data (51 in the dot-finding task, and 47 in the 1-back task) in the analyses. Please note that due to this, degrees of freedom of the error terms differ in the two tasks.

To integrate accuracy scores with RTs , inverse efficiency scores (IES) were calculated (Bruyer & Brysbaert, 2011; Bucker & Theeuwes, 2017) for all aforementioned conditions by dividing RTs (in seconds) by the proportion of correct (PC) responses (IES = RT/PC). The IES is a measure of the average energy consumed by the system over time (Bruyer & Brysbaert, 2011; Townsend & Ashby, 1983), i.e. could be used to measure the cost of task load. Higher IES scores signal greater energy consumption and higher effort. The distribution of the variables did not deviate significantly from a normal distribution.

The IES scores for the dot finding and 1-back conditions were analyzed separately using a 2x2 repeated-measures analysis of variance (rANOVA) with task Difficulty (Single or Dual) and Modality (Verbal or Visuospatial) as within-subject factors. Then, we performed General Linear Model tests (GLMs) by repeating the rANOVAs and also adding PIUQ subscales as independent variables. The interaction terms between the covariate variable and the within-subject factors were also entered into the model because our hypotheses were concerned with these effects. All assumptions of GLM were met. All PIUQ subscales and the total score were normally distributed (Skewness values were between .36 to 1.02, and Kurtosis values were between -.01 to -1.06). Further descriptive analysis regarding the PIUQ total scale revealed that 55.7% of participants scored below and 42.6% scored above the mean score. Follow-up paired Student t-tests or correlations were used where applicable, to investigate significant interactions or main effects. Assumptions for using Student t-tests were also met.

Results

IES analysis in the dot-finding task

Both the main effect of task Difficulty ($F(1,48)=431.90$, $p<.001$, $\eta 2p=.90$) and Modality ($F(1,48)=261.12$, $p<.001$, $\eta 2p=.85$) were significant. As expected, IES for the dot finding task was lower in the dual-task ($M=.72$, $SD=.13$) compared to the single task ($M=.31$, $SD=.07$) condition. Furthermore, respondents were slower to respond when the task-irrelevant 1-back target stimuli were visuospatial ($M=.67$, $SD=.13$) compared to when they were verbal ($M=.36$, $SD=.08$).

The interaction between task Difficulty and Modality was also found significant ($F(1,48)=328.88$, $p<.001$, $\eta 2p=.87$). See Figure 2 and Table 1 for the mean IES and SD values. Follow-up paired-samples Student t-tests were conducted with Bonferroni correction. The difference between IES in the dot-finding single-task and dot-finding dual-task for both verbal ($t(48)=5.52$, $p<.001$, Cohen's $d=.79$) and visuospatial ($t(48)=22.36$, $p<.001$, Cohen's $d=3.20$) conditions. IES scores were lower in single tasks. We also found a significant difference between the verbal and visuospatial versions of the dual-task ($t(48)=17.45$, $p<.001$, Cohen's $d=2.49$), but not in the single-task ($t<1$, $p>.1$), indicating that the visuospatial task was harder than the verbal task.

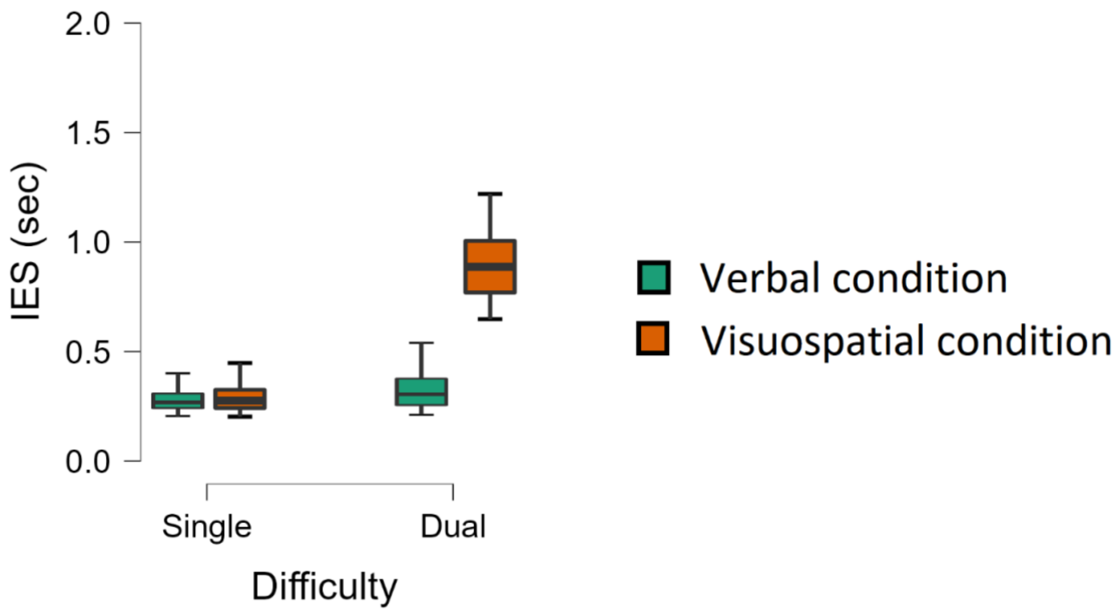

Figure 2 – Significant interaction between task Difficulty and Modality in the dot-finding task. Follow-up analyses revealed that participants were slower for the visuospatial (right panel) dual-task condition compared to the visuospatial single and the verbal (left panel) conditions. Means, standard deviations, and distributions are presented for each condition.

Table 1 – Descriptive data for the dot findings task and 1-back task separately for each condition. Means and SD values for Inverse Efficiency Scores are presented in milliseconds.

Task	Difficulty	Modality	Mean	SD
Dot finding	Single	Verbal	310	75
		Visuospatial	308	70
	Dual	Verbal	411	118
		Visuospatial	1036	229
1-back	Single	Verbal	717	114
		Visuospatial	1101	179
	Dual	Verbal	1057	199
		Visuospatial	1385	253

The GLM revealed a statistically significant interaction between the Control Disorder subscale of PIUQ and task Modality ($F(1,45)=6.72$, $p=.013$, $\eta^2_p=.13$) and the task Difficulty x Modality x Control Disorder interaction ($F(1,45)=10.60$, $p=.002$, $\eta^2_p=.19$) was also significant. We teased apart the three-way interaction by dividing it by the Modality of the task. While the Difficulty x Control Disorder interaction was nonsignificant for the verbal task ($F(1,45)=1.43$, $p=.024$, $\eta^2_p=.031$), it was significant for the nonverbal task ($F(1,45)=7.29$, $p=.010$, $\eta^2_p=.14$).

Follow-up Pearson correlation revealed a positive trend between the Control Disorder subscale and IES of verbal tasks ($r=.21$). In contrast, a negative trend was found between Control Disorder and IES of visuospatial tasks ($r=-.19$). However, this trend was only present in the dual tasks ($r=.27$ for verbal and $r=-.21$ for visuospatial) but not for the single tasks ($r=-.01$ for verbal and $r=.02$ for visuospatial). The Obsession and Neglect subscales showed no significant effects (Fs<1, ps>.1).

Table 2 –Results of the GLM with dot finding task performance as the dependent, task Difficulty and Modality as within-subject factors, and PIUQ subscales as independent predictors.

Effect	**df**	**F**	**p**	**$\eta^2 p$**
Difficulty	1, 45	33.105	< .001	0.424
Difficulty x PIUQ Obsession	1, 45	3.959	0.053	0.081
Difficulty x PIUQ Neglect	1, 45	0.003	0.956	< .001
Difficulty x PIUQ Control disorder	1, 45	2.475	0.123	0.052
Modality	1, 45	36.582	< .001	0.448
Modality x PIUQ Obsession	1, 45	2.399	0.128	0.051
Modality x PIUQ Neglect	1, 45	0.006	0.938	< .001
Modality x PIUQ Control disorder	1, 45	6.718	0.013	0.130
Difficulty x Modality	1, 45	49.475	< .001	0.524
Difficulty x Modality x PIUQ Obsession	1, 45	1.812	0.185	0.039
Difficulty x Modality x PIUQ Neglect	1, 45	0.440	0.510	0.010
Difficulty x Modality x PIUQ Control disorder	1, 45	10.595	0.002	0.191
PIUQ Obsession	1, 45	4.150	0.048	0.082
PIUQ Neglect	1, 45	0.133	0.717	0.003
PIUQ Control disorder	1, 45	1.436	0.237	0.028

IES analysis in the 1-back task

Both the main effect of task Difficulty ($F(1,45)=98.62$, $p<.001$, $\eta^2 p=.69$) and Modality ($F(1,45)=563.18$, $p<.001$, $\eta^2 p=.93$) on IES in the 1-back task were found statistically significant. Similarly to the dot finding tasks, the task was harder in the dual-task (M=1.22, SD=.22) compared to the single task (M=.91, SD=.14) conditions. Moreover, IES for the 1-back task was higher, indicating a harder task, when the 1-back target stimuli were visuospatial (M=1.24, SD=.17) compared to when they were verbal (M=.89, SD=.13).

We also found a significant interaction between task Difficulty and Modality ($F(1,45)=5.47$, $p=.024$, $\eta2p=.11$). See Figure 3 and Table 1 for the mean IES and SD values. Follow-up t-tests showed significant differences between the verbal and visuospatial versions of the single task ($t(46)=19.83$, $p<.001$, Cohen's $d=2.92$) and in the dual-task ($t(46)=17.31$, $p<.001$, Cohen's $d=2.52$). IES scores were higher for the visuospatial versions of the tasks. Furthermore, the difference between single-task and dual-task was significant for both verbal ($t(46)=12.19$, $p<.001$, Cohen's $d=1.78$) and visuospatial ($t(46)=7.29$, $p<.001$, Cohen's $d=1.08$) conditions. IES scores were higher for the dual-task versions of the tasks. However, this latter difference in the visuospatial condition was present with a smaller mean difference (.28) and larger SE of the difference between the means (.04) compared to the other conditions (d=.38, SE=.02 for single verbal vs visuospatial, d=.33, SE=.02 for dual verbal vs visuospatial, d=.34, SE=.03 for single vs dual verbal), which could account for the significant interaction.

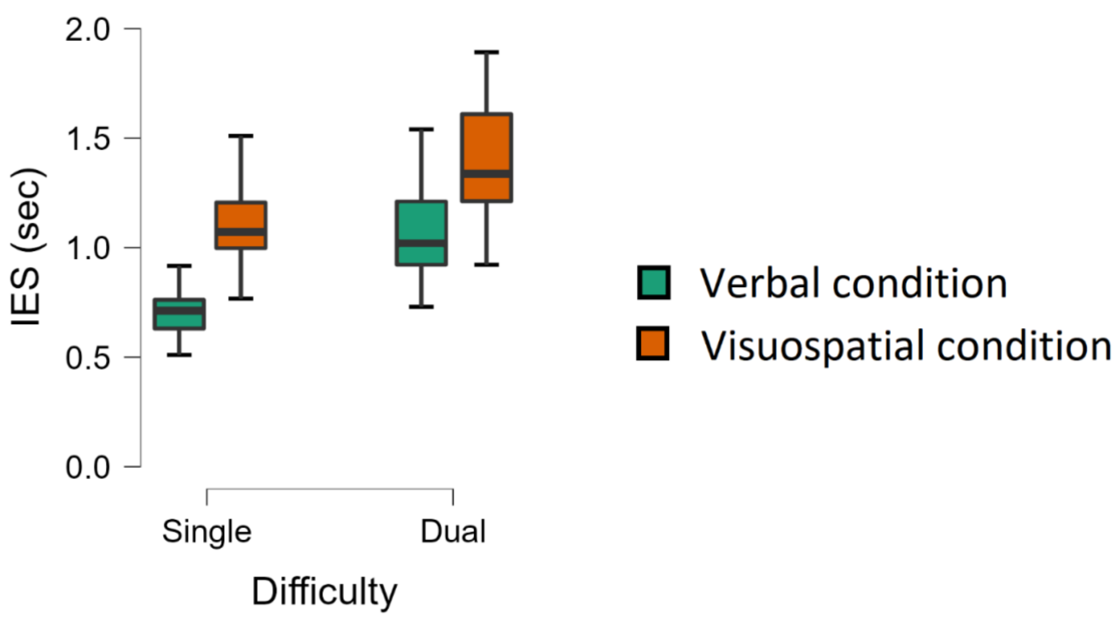

Figure 3 – Significant effects of task Difficulty and Modality in the 1-back task. Participants' performance was better in the verbal 1-back (left panel) compared to the visuospatial condition (right). Responses were faster in the single compared to the dual-task condition. Means, standard deviations, and distributions are presented for each condition.

The GLM revealed that the Obsession subscale had a significant main effect ($F(1,42)=6.23$, $p=.017$, $\eta2p=.12$). A correlation analysis showed that scores on the Obsession subscale were in a positive relationship with IES scores ($r=.35$) across all four experimental conditions. We also found a statistically significant interaction between the Obsession subscale and task Modality ($F(1,42)=5.10$, $p=.029$,

$\eta 2p=.11$). The Obsession subscale had a stronger positive correlation with task performance in the visuospatial condition (r=.38) compared to the verbal condition (r=.27).

Table 3 –Results of the GLM with 1-back task performance as the dependent, task Difficulty and Modality as within-subject factors, and PIUQ subscales as independent predictors.

Effect	**df**	**F**	**p**	**$\eta^2 p$**
Difficulty	1, 42	22.097	< .001	.345
Difficulty x PIUQ Obsession	1, 42	.010	.919	< .001
Difficulty x PIUQ Neglect	1, 42	.197	.660	.005
Difficulty x PIUQ Control disorder	1, 42	.113	.738	.003
Modality	1, 42	55.524	< .001	.569
Modality x PIUQ Obsession	1, 42	5.096	.029	.108
Modality x PIUQ Neglect	1, 42	2.049	.160	.047
Modality x PIUQ Control disorder	1, 42	.067	.797	.002
Difficulty x Modality	1, 42	.589	.447	.014
Difficulty x Modality x PIUQ Obsession	1, 42	< .001	.979	< .001
Difficulty x Modality x PIUQ Neglect	1, 42	2.059	.159	.047
Difficulty x Modality x PIUQ Control disorder	1, 42	.779	.383	.018
PIUQ Obsession	1, 42	6.228	.017	.119
PIUQ Neglect	1, 42	3.770	.059	.072
PIUQ Control disorder	1, 42	.129	.721	.002

Discussion

Verbal processing deficits could facilitate problematic behaviors such as PIU (Beitchman et al., 1999; Chow & Wehby, 2018; van Daal et al., 2007) possibly due to problems with attention, control functions, and information processing (Petersen et al., 2013; Tallal et al., 1989). Yet, to this date, to our knowledge, there is only one study (Nie et al., 2017) directly exploring the involvement of verbal processing in PIU. However, this study only linked PIU to semantic fluency deficits but did not point to the underlying cognitive mechanism. Consequently, our goal in the present study was to investigate the association between PIU and verbal and visuospatial WM performance in a group of young adults. We investigated this matter by targeting two key WM functions, the phonological loop (verbal processing) and the visuospatial sketchpad (visuospatial processing) using single and dual-task settings to increase task load.

The dot-finding task and 1-back task results showed that the single task was harder than the dual-task condition in both modalities. This is in line with past studies investigating the effect of task load (Bonato et al., 2015; Lisi et al., 2015). The increased task load in the dual task means that the WM has to hold and manipulate more information at a given time compared to the single task condition, which affects processing and responding to these stimuli (Cowan, 2016). Additionally, the visuospatial dual-task was more challenging than the verbal dual-task, but there was no significant difference in difficulty between verbal and visuospatial single tasks. This is also in line with the results of past research (Bonato et al., 2015; Sims & Hegarty, 1997). The dot-finding task and the 1-back tasks using arrows were both visuospatial and consequently, used similar processes (the visuospatial sketchpad of the WM) resulting in a greater overall load compared to the 1-back task with letters. Further, in the dual task condition when the target was a letter participants could verbalize it and rely on the phonological loop of the WM to maintain the information until the recall task. In contrast, when the target was an arrow (a direction), they could not verbalize it. Indeed, we made sure to avoid any similarities to letters (such as A or V) and exclude directions that can be easily verbalized (such as < and >).

Our results regarding the connection of task performance and PIU showed that: (1) In the dot finding dual-task higher levels of control disorder correlated with greater difficulty for the verbal condition and lower difficulty for the visuospatial condition. (2) The execution of both verbal and visuospatial WM tasks correlated with the Obsession score: A greater difficulty in the task was associated with a greater tendency of obsessive symptoms. (3) The execution of the single WM task correlated with greater difficulty in participants with higher levels of PIU, while the exact opposite, i.e., lower difficulty, was true for the dual WM task. However, we should note that these correlations were minimal.

We found that higher levels of control disorder resulted in increased distractibility by verbal but not by visuospatial stimuli. That is, we found decreasing performance in the dot finding duals task when the task-relevant distractor was a verbal stimulus, while the performance increased with visuospatial distractors. This supports the findings of Nie and colleagues (2017) who showed that participants scoring high on a questionnaire measuring PIU had poorer performance in semantic verbal fluency compared to controls. Also, several types of internet activities, such as playing video games online, could promote positive changes in cognitive processes. Our results are also in line with more recent studies showing decreased WM abilities in PIUs and media multitaskers (Khanbabaei et al., 2022; Ophir et al., 2009; Zhou et al., 2014) and enhanced visuospatial cognition in video gamers (Colzato et al., 2013; Hubert-Wallander et al., 2010; Oei & Patterson, 2014). Since PIU is a mix of various activities, ranging from browsing social media sites, watching videos, or playing online games just to mention a few, it has a complex effect tapping into a wide range of WM processes (D'Hondt et al., 2015; Shahrajabian et al., 2023).

Further, more symptoms of addictive behavior in general were associated with decreasing performance on single WM tasks, while it was associated with increasing performance on dual tasks. On the one hand, impaired cognitive capacity could lead to worse task performance (Lieberman, 2007). On the other hand, it is possible that due to the characteristics of the online environment, there is a demand for quick switching between several tasks and multiple sources (Loh & Kanai, 2016). Earlier research

(Alzahabi & Becker, 2013) found that high media multitaskers are better at task switching than low media multitaskers. Therefore, higher levels of PIU may correlate with reduced costs alternating between tasks. Another possible explanation would be that lower levels of cognitive control could lead to more distractor interference in attentional processing (Lavie, 2010). Previous studies (Cain & Mitroff, 2011; Lin, 2009; Ophir et al., 2009) showed that Internet-related multitasking behavior could result in poorer inhibition of the processing of irrelevant stimuli. In this study, participants had to remember the distractor in the dual-task condition. Thus, increased distractibility would result in more attention to the (task-irrelevant) stimulus in the single task, the stimulus that had to be remembered in the dual task. Hence the better performance in the dual-task setting. Nonetheless, this explanation does not account for the lack of correlation between control disorder and single-task performance.

Participants with a greater tendency to obsession (feeling anxiety, depression, and craving caused by the lack of Internet use) showed worse performance on working memory-related tasks. According to a recent theory (Anticevic et al., 2014; Cole et al., 2014), the indirect disruption of the control system capacity by regulating craving, anxiety, and depression could lead to reduced capacity for cognitive demands. Indeed, WM performance has been shown to be sensitive to anxiety and depression (Günther et al., 2004; Han et al., 2016; Vytal et al., 2013). Similarly to our results, another study (Vytal et al., 2013) found that anxiety impairs both verbal and spatial processes assessed in an n-back task even in healthy participants. Previous research (Anticevic et al., 2012; Cole et al., 2014; Lieberman, 2007) argues that an intact capacity of the control functions and normal levels of subjective factors are necessary for healthy functioning. Therefore, our results may have practical implications for clinical prevention. Interventions should focus on solving the issues, e.g., targeting students showing language problems, that lead to compensatory internet use (Kardefelt-Winther, 2014) thus heightening the risk of developing PIU.

The reason behind the fact that each task showed a relationship with a specific scale but not with the other two scales is presumably because the scales tapped into different aspects of PIU, and consequently can be linked to different cognitive processes (D'Hondt et al., 2015; Demetrovics et al., 2008). Obsession symptoms have to do with the regulation of thoughts about the internet and are possibly related to WM capacity. Control disorder measures dyscontrol over actions which is presumably related to executive functions. Neglect measures neglect of needs, and, thus, the least connected to functions measured here.

Limitations of this study include the reliance on self-report measures of PIU. Although PIUQ has proven to be a well-established and reliable measure, future studies are needed to validate our results by using objective measures of PIU (e.g., tracking internet use on multiple devices for a typical week for each participant). Furthermore, as PIU is not considered a distinct mental disorder, our sample does not include diagnosed PIUs. However, we treat PIU as a continuous variable to observe the relationship between the amount of use and the cognitive abilities in a normally distributed population which could also be a strength of the present investigation. Our sample comprised still healthy individuals who could compensate for the deficit in the control system capacity. Also, Internet use is a broad topic, i.e., whether participants mainly used smartphones or PCs, played games, or used social media was not addressed, and the study population may have been overly heterogeneous in this regard. Lastly, we only used letters as verbal stimuli and directions/arrows as visuospatial stimuli. While this is in line with previous research conducted in this field, more complex stimuli would presumably result in stronger effects and more distinct differences. Future research is needed to examine the effect of various types and contexts of verbal stimulus; e.g., if they are related or not to the activity the participant most of them uses the Internet for.

Conclusions

In sum, our results help clarify the findings of past studies regarding the connection between WM and PIU. That is, higher levels of PIU are associated with decreased verbal WM (Zhou et al., 2014) but increased visuospatial WM abilities (Hubert-Wallander et al., 2010; Oei & Patterson, 2014). Further, while negative emotions associated with the lack of Internet use decreases WM performance – possibly due to a lesser available WM capacity due to the obsessive symptoms (Cole et al., 2014) – in general, higher PIU may lead to better performance in dual-task settings due to the effect of media multitasking. We believe that the current work reveals important findings regarding the connection between problematic internet use and WM functions. According to our results, although better in task switching, people with higher levels of PIU may have worse verbal WM performance and may be more easily distractible. Furthermore, increased levels of obsession may lead to a heightened need for mental effort to solve tasks that utilize executive functions. Overall, we emphasize the importance of early intervention and prevention programs because problematic internet use may be associated with verbal processing issues due to deficits in WM-related functions.

Acknowledgments

ANZS was supported by the ÚNKP-23-5 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund, the OTKA PD 137588 and OTKA FK 146604 research grants, and the János Bolyai Research Scholarship provided by the Hungarian Academy of Sciences. CB was supported by the ÚNKP-23-3 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund. AN was supported by the OTKA PD 146197 research grant.

Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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