Cognitive, Affective, & Behavioral Neuroscience (2018) 18:1145–1158
https://doi.org/10.3758/s13415-018-0627-z

For whom is social-network usage associated with anxiety? The moderating role of neural working-memory filtering of Facebook information

Nurit Sternberg[1] · Roy Luria[1,2] · Gal Sheppes[1,2]

Published online: 9 August 2018

Abstract
Is Facebook usage bad for mental health? Existing studies provide mixed results, and direct evidence for neural underlying moderators is lacking. We suggest that being able to filter social-network information from accessing working memory is essential to preserve limited cognitive resources to pursue relevant goals. Accordingly, among individuals with impaired neural social-network filtering ability, enhanced social-network usage would be associated with negative mental health. Specifically, participants performed a novel electrophysiological paradigm that isolates neural Facebook filtering ability. Participants' actual Facebook behavior and anxious symptomatology were assessed. Confirming evidence showed that enhanced Facebook usage was associated with anxious symptoms among individuals with impaired neural Facebook filtering ability. Although less robust and tentative, additional suggestive evidence indicated that this specific Facebook filtering impairment was not better explained by a general filtering deficit. These results involving a neural social-network filtering moderator, may help understand for whom increased online social-network usage is associated with negative mental health.

Keywords Filtering · Online social networks · Facebook · Working memory · Anxiety · EEG

Half a billion Facebook users log in multiple times a day and spend 18 minutes on average per visit (Facebook, 2015). The notion that so many people are connected to Facebook for such a significant portion of their time, raises significant worries that are perhaps best captured in press titles such as "Social Media Is Parents' Greatest Online Fear" (Johnston, 2014) or "7 Ways Facebook Is Bad for Your Mental Health" (Kenrick, 2014).

Armed with these worries, scientists have recently begun to examine whether enhanced online social-network (OSN) usage is associated with maladaptive psychological aspects. Emerging evidence suggests a complex answer to this relatively straightforward question. Specifically, whereas several studies found that enhanced OSN usage is associated with maladaptive aspects such as a general decrease in well-being and happiness (Brooks, 2015; Verduyn, Ybarra, Résibois, Jonides, & Kross, 2017) or more anxious (Koc & Gulyagci, 2013; Zaffar, Mahmood, Saleem, & Zakaria, 2015) and depressive symptoms (Feinstein, Bhatia, Latack, & Davila, 2015; Pantic et al., 2012; Toseeb & Inkster, 2015), other studies did not find such an association (Acar, 2008; Shaw, Timpano, Tran, & Joormann, 2015).

These empirical inconsistences suggest that whether OSN usage is associated with maladaptive aspects or not likely depends on moderating processes. In this manuscript, we offer one such moderator. We suggest that it is necessary to be able to filter irrelevant OSN information from accessing working memory in order to preserve limited cognitive resources to pursue relevant goals, and that individuals vary in their ability to control and filter these OSN cues. For example, some individuals may fail to overcome the urge to click an open Facebook tab when needing to work on a school project. We argue that for these individuals in particular, enhanced OSN usage may be associated with maladaptive psychological aspects such as enhanced anxiety.

Our central focus on the moderating role of OSN filtering ability in the relationship between ONS usage and maladaptive psychological aspects, is influenced by previous studies

✉ Nurit Sternberg
nuritstr@post.tau.ac.il

✉ Gal Sheppes
sheppes@post.tau.ac.il

[1] The School of Psychological Sciences, Tel Aviv University, 6997801 Tel Aviv, Israel

[2] Sagol School of Neuroscience, Tel Aviv University, 6997801 Tel Aviv, Israel

that examined direct relationships between each pair of these three constructs. Specifically, strengthening the aforementioned direct link between OSN usage and maladaptive psychological aspects (e.g., Brooks, 2015; Feinstein et al., 2015), several longitudinal experience-sampling studies were able that rule out reversed directionality that maladaptive aspects influence OSN usage (e.g., Kross et al., 2013; Verduyn et al., 2015). A second line of studies examined the direct link between filtering associated impairments and excessive technology usage. Specifically, studies showed that excessive computer-game playing (Ko et al., 2014; Littel et al., 2012) and excessive smartphone usage (Chen, Liang, Mai, Zhong, & Qu, 2016) were associated with neural deficits in inhibitory control. More specific to filtering, a handful of studies found a negative relationship between enhanced simultaneous media consumption (media multitasking) and lower behavioral filtering ability (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Ophir, Nass, & Wagner, 2009). Finally, a third line of studies examined the direct link between filtering-associated impairments and maladaptive psychological aspects. Specifically, electrophysiological and behavioral studies showed that inefficient filtering of irrelevant distractors from working memory was associated with anxious symptoms and worry (Qi, Ding, & Li, 2014; Stout, Shackman, Johnson, & Larson, 2015; Stout, Shackman, & Larson, 2013).

While prior studies are clearly important, three notable limitations should be noted. First, given that prior studies only examined direct links between each pair of the three constructs that constitute our moderation model, they cannot provide support for our account, arguing that OSN filtering ability would moderate the relationship between OSN usage and maladaptive psychological aspects. Specifically, the aforementioned studies that examined the direct link between OSN usage and maladaptive psychological aspects did not investigate the moderating role of OSN filtering ability. The aforementioned studies that examined the direct link between technology usage and filtering did not study the relationship to maladaptive psychological aspects, and the aforementioned studies that examined the direct link between filtering and maladaptive psychological aspects did not study the relationship to OSN usage. Therefore, a moderation model has the potential to resolve prior inconsistencies in the literature. Second, prior studies focused on a general nonspecific filtering ability rather than on the examination of an online neural measure of filtering OSN information. Third, most prior studies evaluated OSN usage using self-report measures that are susceptible to multiple biases (Intapong, Achalakul, & Ohkura, 2017; Junco, 2013; Otten, Littenberg, & Harvey-Berino, 2010) rather than on measures of actual OSN usage.

To overcome these three significant limitations, the present study was the first to test an interactive model, examining the moderating role of a specific online neural mechanism of filtering irrelevant OSN information in the relationship between actual OSN usage and maladaptive psychological aspects.

Specifically, in the present study we developed a novel laboratory paradigm where filtering irrelevant OSN information from accessing working memory is required to adequately perform on a main goal-directed task. In our paradigm we decided to focus specifically on filtering of Facebook irrelevant information because Facebook is the largest, most popular, and, accordingly, most studied OSN (Błachnio, Przepiórka, & Rudnicka, 2013; Kuss & Griffiths, 2011; Ryan, Chester, Reece, & Xenos, 2014; Wilson, Gosling, & Graham, 2012).

Adopting a cognitive perspective on filtering, we argue that ongoing task performance relies on representing relevant information in visual working memory (VWM) that is an online buffer that can hold limited information (3–4 objects) in an active state (Luck & Vogel, 2013). This specific property of VWM capacity has been linked to many aptitude measures and cognitive abilities (Luck & Vogel, 2013). Since VWM is a limited workspace, there is a central control process that is responsible for filtering the processing of task-irrelevant information (Luck & Vogel, 2013; Luria, Balaban, Awh, & Vogel, 2016; Vogel, McCollough, & Machizawa, 2005). At any given point, VWM contains all currently active representations, including task-related information needed to complete goal-directed behaviors, as well as task-irrelevant information that was not successfully filtered out.

To measure individual online filtering ability, we modified a classic VWM filtering task (Vogel et al., 2005) that involves three conditions (see Fig. 1): two conditions in which only task-relevant targets (two or four colored circles) are presented, and a third filtering condition consisting of two relevant color targets and two irrelevant visual distractors. For the present purpose, we modified the third condition such that the distractors were two potent Facebook stimuli (actual Facebook icons). Theoretically, maximal filtering ability involves fully filtering the two irrelevant Facebook distractors from VWM and representing only the two-color targets. Conversely, minimal filtering ability involves fully failing to filter the two irrelevant representations of Facebook distractors alongside the two targets.

Importantly, in our modified VWM filtering task, we utilize recent advances in cognitive neuroscience in order to evaluate the online neural ability to filter irrelevant information. To do so we rely on the contralateral delay activity (CDA), an event related potential (ERP) component that reflects the total number of online representations, including relevant and irrelevant information, that is currently active in VWM (Luck & Vogel, 2013). The CDA allows measuring the efficiency of filtering irrelevant task distractors even without any overt response. Specifically, maximal filtering efficiency will manifest in CDA amplitude in the filtering condition that is similar to

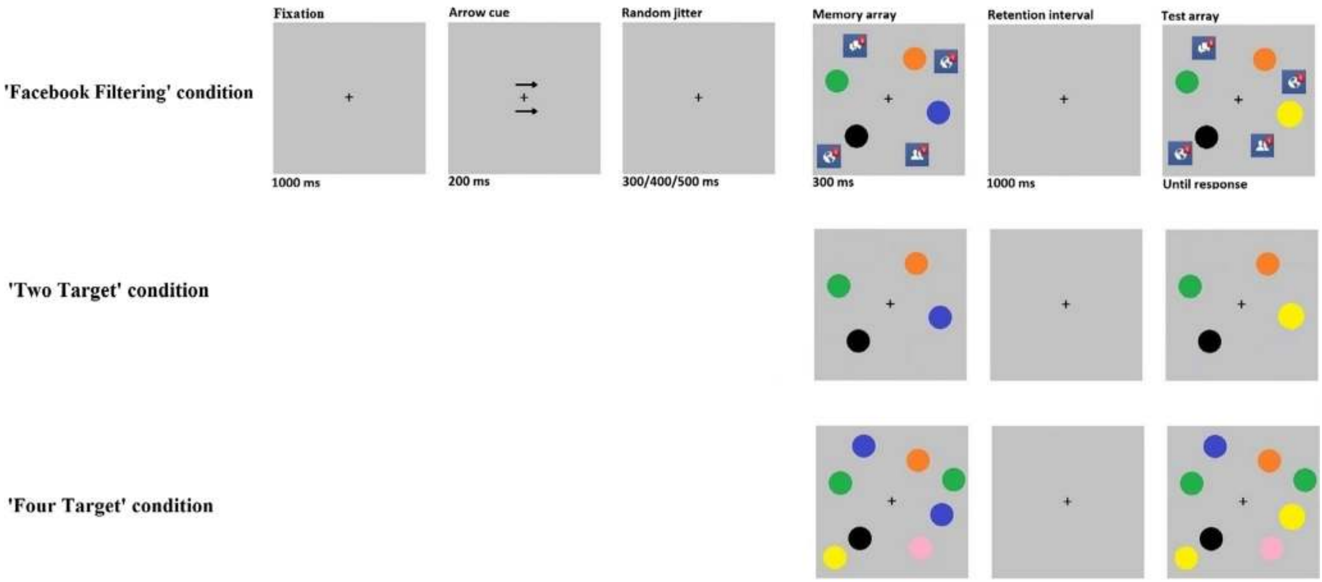


Fig. 1 Trial Structure. Example of a trial in the different conditions that constitute the neural Facebook filtering ability task. In each condition, items appeared on both sides of the screen, but subjects were asked to attend to only one side, indicated by the arrow cues. Following convention, we refer only to the number of items that were presented on the relevant side. Note that the CDA waveforms take into consideration both sides of the screen, since it is composed of subtracting ipsilateral activity from contralateral activity. (Color figure online)

the two-relevant target condition, and minimal filtering efficiency will manifest in CDA amplitude in the filtering condition that is similar to the four-relevant target condition. This method of using EEG and specifically the CDA to assess filtering efficiency was successfully used in the past to demonstrate impairments in old age, Parkinson's, and in anxious individuals (Jost, Bryck, Vogel, & Mayr, 2011; Lee et al., 2010; Meconi, Luria, & Sessa, 2014).

In order to test our interactive model, in addition to the measurement of neural Facebook filtering ability, we assessed Facebook usage and maladaptive psychological aspects. Specifically, we measured Facebook usage, by looking at the actual amount of activity and time participants spent on Facebook in the laboratory. Measuring actual Facebook usage provides a clear advantage over the majority of studies in this field that rely on self-reported measures of OSN usage that are susceptible to multiple biases (Intapong et al., 2017; Junco, 2013; Otten et al., 2010). To evaluate maladaptive psychological aspects, we concentrated on two well-established questionnaires previously associated with OSN usage (Feinstein et al., 2015; Pantic et al., 2012; Zaffar et al., 2015) that assessed participants' anxious and depressive symptoms.

Furthermore, in order to provide a first step toward specificity of Facebook filtering deficit, we wanted to show that our results are not better explained by a general (nonspecific) filtering deficit. Therefore, in addition to participants who performed the Facebook filtering paradigm, we had a separate group of participants perform a matched paradigm that evaluates general filtering ability (see below for complete details).

Our main prediction was that enhanced Facebook activity would be associated with increased anxious and depressive symptoms among individuals with low (but not high) Facebook neural filtering ability. To provide a first step toward specificity of this result, we did not expect to find a moderating role for a general (non-Facebook) filtering ability.

Method

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Participants

Given that the present article is the first to describe a moderation model composed of an interaction between two factors (neural filtering ability and behavioral OSN usage) that predicts a third factor (anxious and depressive symptoms), there was no related effect size to choose from for a formal power analysis. Therefore, we settled on a sample size that is considerably larger than that of prior studies related to filtering ability (cf. Jost et al., 2011; Lee et al., 2010; Luria et al., 2016; Meconi et al., 2014; Owens, Koster, & Derakshan, 2012, 2013; Qi et al., 2014; Stout et al., 2013). Specifically, we aimed to recruit a minimum of 30 participants by the end of the academic semester. In practice, we were able to collect data from 37 participants who completed the experimental Facebook filtering session. Data from three participants (8.8%) were excluded from further analyses. Two participants were excluded because they did not have enough valid trials for EEG analysis: one participant due to exceptionally low behavioral accuracy (56% in a 50% chance performance context) and one participant due to excessive ocular artifacts (more than 40% of rejected trials). One additional participant was excluded because of extreme (>±2 *SD*) scores in the filtering ability measure. Therefore, the final sample consisted of 34 Caucasian participants, including 20 females with an average of 13.03 (*SD* = 1.90) years of education and an average age of 23.91 years (*SD* = 2.85).

In addition to the main Facebook filtering group, a separate group of participants performed a matched paradigm that evaluates general filtering ability. In an effort to match the sample size of the Facebook filtering group, for the general filtering group we collected data from 38 participants. Data from three participants (8.6%) were excluded from further analyses, one due to excessive ocular artifacts and two were excluded because of extreme (>±2 *SD*) scores in the filtering-ability measure. Therefore, the final sample of the general filtering group consisted of 35 Caucasian participants (14 females, years of education = 13.31 years, *SD* = 1.62; average age = 25.46 years, *SD* = 3.50). Inclusion criteria involved having normal or corrected-to-normal visual acuity, normal color vision and having an active Facebook account. The participants provided their written informed consent before the experiment. All experimental procedures were approved by the Research Ethics Board of Tel Aviv University and were performed in accordance with the approved guidelines.

General procedure

The experiment consisted of two sessions within a 24-hour period. Session 1 started with the completion of two questionnaires that assessed anxious and depressive symptoms. Then, in an effort to motivate participants and enhance the saliency to use Facebook in a laboratory task that took place in Session 2 (see details and relevant analyses below), participants' access to Facebook was deactivated for 48 hours by changing their Facebook password. Session 2 took place 24 hours after the first session. First, participants completed a VWM capacity task, and then one group of participants performed the Facebook neural filtering ability task that assessed their ability to filter out specific Facebook distractors (see details below). A second group of participants underwent the above procedure exactly, with the sole exception of performing a general filtering-ability task that assessed their ability to filter general control distractors. Facebook and general neural filtering abilities were examined between subjects because each EEG task is very long to complete (~2.5 hours) and to avoid contextual effects where exposure to Facebook stimuli can contaminate the general (non-Facebook) condition (Balaban & Luria, 2016).

Following the neural filtering-ability task, participants completed an OSN usage laboratory task that examined actual activity and time on Facebook.[1] Specifically, participants' Facebook account was temporarily reactivated for free use for 30-minutes, following the 24 hours of Facebook deprivation (that started at Session 1) and before another 24 hours of deprivation (following Session 2).

Measures

OSN usage Following studies showing that deprivation increases the value and motivation to act on an object (Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003), we deprived participants from their Facebook account by changing their password 24 hours prior to and following the laboratory task. During the laboratory task, participants were seated in front of a computer, where they were asked to remain for the entire session and were told that their Facebook accounts were temporary reactivated after a 24-hour deprivation. Participants were guided to use this time in any way they would like to, but were reminded that this is their only opportunity to log in to their Facebook account in the next 24 hours. The main purpose of the second 24-hour deprivation was to increase the value and motivation to use Facebook at the laboratory during Session 2. Specifically, we were concerned that without the second 24-hour deprivation, participants would prefer not to use their Facebook account in the lab, but rather use it at home immediately after the end of the session. During the task we measured the amount of Facebook activities made by participants (e.g., "like" status, comments on pictures, posts on friends' walls using the Facebook activity log) as well as the exact amount of time participants spent on Facebook (using the timeStats application).

In general, deprivation procedures are well-established in human and animal studies across many fields, including decision-making (Chib, Rangel, Shimojo, & O'Doherty, 2009), addictions such as substance abuse (Grimm, Hope, Wise, & Shaham, 2001; Hefner, Starr, & Curtin, 2015), alcohol dependence (Spanagel, Hölter, Allingham, Landgraf, & Zieglgänsberger, 1996; Vengeliene, Bilbao, & Spanagel, 2014), caffeine dependence (Juliano & Griffiths, 2004), and even in a study examining Internet usage (Osborne et al., 2016) that is closely related to the present study.

Importantly, in an effort to mitigate concerns that our deprivation procedure biases naturally occurring OSN usage, we examined the relation between deprived Facebook activity and Facebook usage time in the laboratory and between nondeprived Facebook activity and Facebook usage time at

[1] As a pilot for future experiments that aim to explore the relationship between asymmetric anterior brain activation and Facebook usage, we measured participants' resting EEG state (Tomarken, Davidson, Wheeler, & Kinney, 1992). Since this measure is not central to current hypotheses, we do not report it further.

home in the week that followed Facebook access reactivation. The deprived and nondeprived measures were highly correlated, $r_{(\text{laboratory activity and home activity})} = .71$, $p < .001$; $r_{(\text{laboratory time and home time})} = .44$, $p < .001$.[2]

Facebook neural filtering-ability task In order to examine specific Facebook filtering ability, a closely matched variant of a neural filtering-ability task (Vogel et al., 2005) was created. The task included three experimental conditions, where participants were instructed to remember the colors (randomly selected from a set of six colors: orange, blue, green, pink, yellow, or black) of (a) two circle targets, (b) four circle targets, or (c) two circle targets while ignoring two potent well-recognized Facebook distractors (i.e., unread notification, unread message, and new friend request icons).

Each trial started with the presentation of a fixation point ("+") in the middle of the screen for 1,000 ms. The arrow cues indicate the relevant side for the upcoming trial (200 ms; right or left, with an equal probability), followed by random jitter (300/400/500 ms), followed by the memory array that included two colored target circles, or four colored target circles or two colored target circles and two Facebook distractors (presented for 300 ms), followed by a retention interval of 1,000 ms, followed by the test array (see Fig. 1). Participants had to indicate (using the "Z" and "/" keys on a computer keyboard) whether targets presented in the cued side of the memory array were the same or different from those presented in the cued side of the test array (with an equal probability for same and different trials; and with the restriction that the test array at the uncued side were always identical to the memory array). Participants' response terminated the trial, and data was analyzed for the 200–2,000 ms time window. Following initial performance of 14 trials, participants completed a total of 15 blocks, each consisting of 60 trials. The first block was considered practice, and the remaining 14 blocks (840 trials) were analyzed.

ERPs recording and analysis. EEG was recorded using a Biosemi ActiveTwo EEG recording system (Biosemi B. V., Amsterdam, The Netherlands). Data was recorded from 64 scalp electrodes at locations of the extended 10–20 system, as well as from two electrodes placed on the left and right mastoids. The horizontal electrooculogram (EOG) was recorded from electrodes placed 1 cm to the left and right of the external canthi to detect horizontal eye movement, and the vertical EOG was recorded from an electrode beneath the left eye to detect blinks and vertical eye movements. The single-ended voltage was recorded between each electrode site and a common mode sense electrode (CMS/DRL). Data was digitized at 256 Hz. Off-line signal processing and analysis was performed using the EEGLAB Toolbox (Delorme & Makeig, 2004), ERPLAB Toolbox (erpinfo.org/erplab), and custom MATLAB scripts. All electrodes were referenced to the average of the left and right mastoids. Artifact detection was performed using a peak-to-peak analysis, based on a sliding window 200 ms wide with a step of 100 ms. Trials containing activity exceeding 80 µv at the EOG electrodes, due to ocular artifacts, or 100 µv at the analyzed electrodes (P7, P8, PO7, PO8, PO3, and PO4), due to other artifacts, were excluded from the averaged ERP waveforms (Balaban & Luria, 2015). This procedure resulted in a mean rejection rate of 8.1% (which did not differ between the Facebook and general filtering groups, $p = .57$). The continuous data was segmented into epochs from −200 ms relative to onset of the memory array to +1,300 ms representing the end of retention interval. The epoched data was then low-pass filtered using a noncausal Butterworth filter (12 dB/oct) with a half-amplitude cutoff point at 30 Hz. Only trials with a correct response emitted after at least 200 ms and at most 2,000 ms were included in the analysis. Final analysis for each participant contained at least 150 trials per condition.

CDA analysis. Following convention (Vogel et al., 2005), in order to analyze the CDA component, for each study group, separate average waveforms for each condition were generated, and difference waves were constructed by subtracting the average activity recorded from the electrodes ipsilateral to the memorized array from the average activity recorded from electrodes contralateral to the memorized array. Since the present study used distractors that are real complex objects (i.e., Facebook icons), and congruent with some evidence that complex items (e.g., polygons, faces, real-world objects) require more processing time that is accompanied with later developing CDAs (e.g., Balaban & Luria, 2015; Brady, Stormer, & Alvarez, 2016; Meconi et al., 2014; Stout et al., 2013), the measurement window of the CDA in our study started only 500 ms after the onset of the memory array. Additionally, and consistent with many studies (e.g., Duarte et al., 2013; Kang & Woodman, 2014; Kundu, Sutterer, Emrich, & Postle, 2013; Störmer, Li, Heekeren, & Lindenberger, 2013; Zaehle et al., 2013) the duration of the CDA window was set to 500 ms. In addition, based on a recent review that summarizes 10 years of CDA research showing that averaging the CDA amplitudes across relevant electrodes is a typical procedure (Luria et al., 2016), we followed the standard procedure in our lab and quantified the CDA using average activity from the PO7/PO8, P7/P8 and PO3/PO4 electrodes (Allon, Balaban, & Luria, 2014; Balaban, Drew, & Luria, 2018; Balaban & Luria, 2015, 2017), where the CDA amplitude is clearly evident (see Fig. 2). To compute filtering-ability scores, we measured the amplitude of the CDA in the different experimental conditions and used the

[2] Data on nondeprived, at-home Facebook activities and actual Facebook usage time were collected during the week after participants got back access to their Facebook accounts. The amount of Facebook activities made by participants during this week was coded using the Facebook activity log, and the amount of time participants spent on Facebook via their PCs was measured using "timeStats" application. The application was running in the background and continuously measured Facebook usage without the need to prompt and prime participants, minimally interfering with participants' natural Facebook usage.

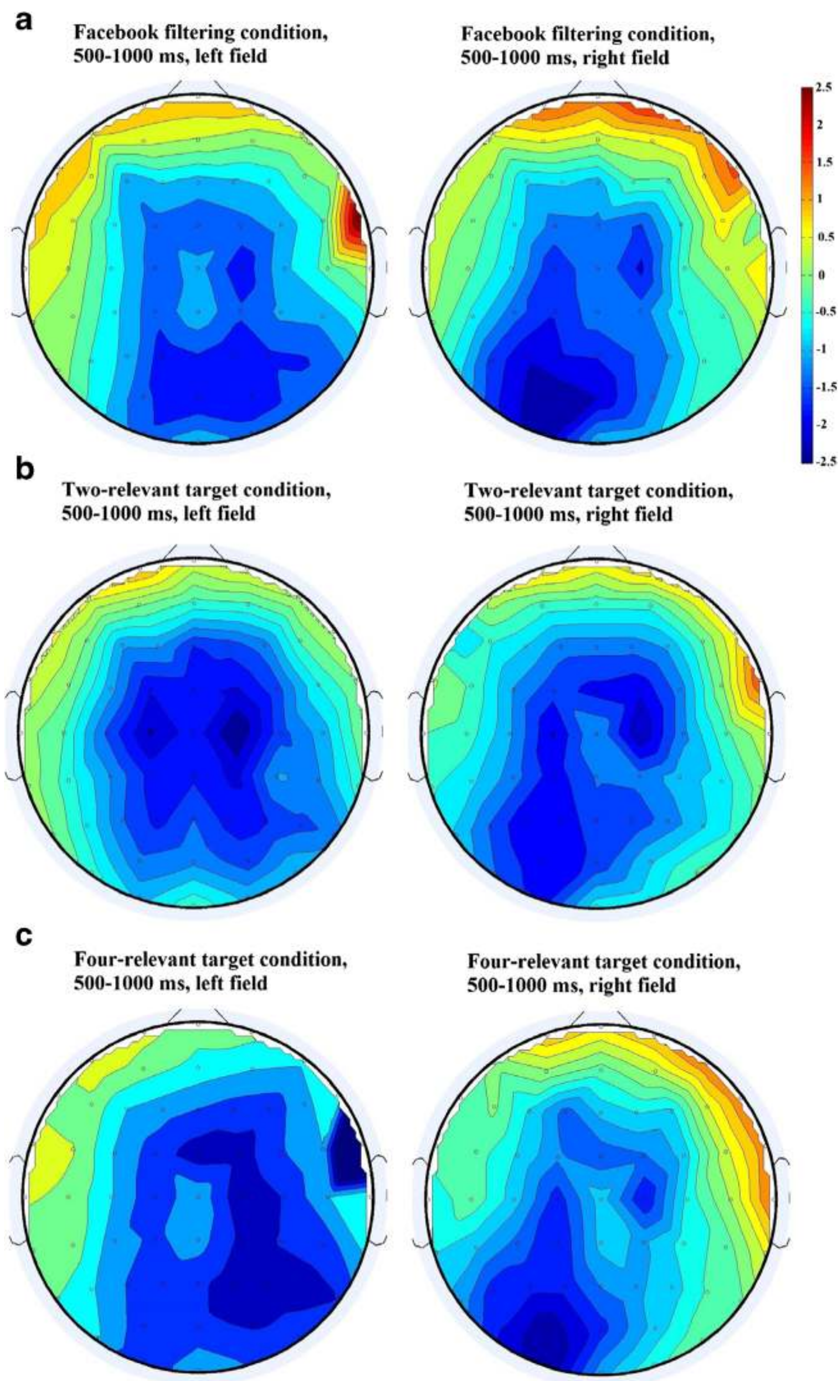


Fig. 2 Scalp distributions of the CDA component. Facebook filtering group scalp distribution in (**a**) Facebook filtering condition; (**b**) two-relevant target condition; and (**c**) four-relevant target condition. Since the subtraction computation of the CDA waveforms takes into account the average activity of both ipsilateral and contralateral electrodes, we present separate scalp maps for the left and right memory arrays. Note that when participants attend the left memory array, large negative voltage amplitudes (drawn in the blue shaded regions) are expected to be seen across the right posterior areas, and when participants attend the right memory array, large negative voltage amplitudes are expected to be seen across the left posterior areas. (Color figure online)

following conventional formula for both study groups: $\frac{(\text{four}-\text{target condition})-(\text{filtering condition})}{(\text{four}-\text{target condition})-(\text{two}-\text{target condition})}$ (Vogel et al., 2005). The nominator indicates the extent of distractor irrelevant information being held in VWM relative to target relevant information in VWM (matched for total number of stimuli). The denominator represents a reference point to the filtering condition as it includes only task relevant information.

General neural filtering-ability task The general filtering task and the ERPs analysis in the general filtering-ability task were identical to the Facebook filtering-ability task except for sole difference pertaining to the nature of the distractors in the filtering condition. Specifically, for the general neural filtering group, the Facebook icons that were presented in the Facebook filtering condition were scrambled and their colors were changed (i.e., blue, red and white Facebook colors were changed to yellow, orange, and pink colors) using a custom MATLAB script

Maladaptive psychological aspects In order to examine maladaptive psychological aspects, we concentrated on two well-established questionnaires measuring depressive and anxious symptoms that were previously associated with social media usage (Acar, 2008; Feinstein et al., 2015; Verduyn et al., 2015). Specifically, we administered the Spielberger Trait Anxiety Inventory (STAI-T ((Spielberger, 1989) consisting of 20 items that assess the intensity of anxious symptoms ($M = 42.14$, $SD = 11.24$, Cronbach $\alpha = .92$). We also administered the Beck Depression Inventory–II (BDI-II) (Beck, Steer, & Brown, 1996)—consisting of 21 items that assess the intensity of depressive symptoms, and omitting the one item pertaining to suicidality ($M = 5.03$, $SD = 5.47$, Cronbach $\alpha = .84$).[3]

Control measure: VWM capacity To further isolate the role of specific filtering ability, we wished to control for general VWM capacity. Accordingly, participants completed a VWM capacity task where they were instructed to memorize four or eight colored squares presented for 100 ms, followed by a retention interval of 1,000 ms, followed by the test array. In the test array a colored square presented in one of the locations where stimuli presented in the memory array, and participants' task was to respond whether this colored square in the test array had changed color or not. Participants completed a total of 120 trials. In order to calculate VWM capacity scores, we used the conventional formula: K = S(H − F), where K is the memory capacity, S is the size of the array (four or eight colored squares), H is the observed hit rate, and F is the false-alarm rate (the probability of a "different" response for "same" trials; Cowan, 2001).

[3] Participants additionally completed two other questionnaires for pilot purposes. Specifically, given that we wished to explore the future possibility of repeating the present design with specialized populations suffering from Internet addiction and OSN addiction, participants completed Young's Internet Addiction Scale (Young, 1998), and The Bergen Facebook Addiction Scale (Andreassen, Torsheim, Brunborg, & Pallesen, 2012). Since these questionnaires were administered in the same session together with the anxiety and depression questionnaires, we cannot rule out the possibility that participants' responses to anxiety/depression scales may have been affected by responses to Internet/Facebook addiction scales. However, we believe that the anxiety scores, which are central to our investigation, are unaffected by the two central independent variables (Facebook usage and neural filtering of Facebook information) that comprise our moderation model, since these two performance-based measures entailed assessments of behavioral and neural activity, and because they were measured in a different session.

Results

Does neural Facebook filtering ability moderate the relationship between Facebook usage and maladaptive psychological aspects?

Prior to turning to the main analyses, we report zero-order correlations between all measures in Table 1. Relevant to the present focus and consistent with some (but not other) prior findings (Feinstein et al., 2015; Koc & Gulyagci, 2013; Pantic et al., 2012; Toseeb & Inkster, 2015; Zaffar et al., 2015), we found a positive correlation between actual Facebook usage in the laboratory and anxious and depressive symptoms.

The main analyses tested our hypothesis that enhanced Facebook usage (activity and time) is associated with enhanced symptoms of anxiety and depression among individuals with low (but not high) ability to filter irrelevant Facebook distractors. In order to test our main prediction, we conducted moderation analyses using Hayes PROCESS Model 1 (Hayes, 2012), with bias-corrected bootstrap 95% confidence interval based on 5000 bootstrap samples. In these analyses we entered Facebook Usage (activity or time in separate analyses) as independent variable, VWM capacity as a control variable, neural Facebook filtering ability as moderator, and psychological symptoms (anxiety or depression scores in separate analyses) as outcome variable. The main findings and their significance levels are presented in Table 2.

Table 2 Moderation analysis with Facebook activities as the independent variable, VWM capacity as a control variable, Facebook filtering ability as moderator and anxiety scores as outcome

Variable	*B*	*SE*	*T* value	*p* value	95% CI Low limit	95% CI High limit
Facebook activity	.21	.29	.71	.48	−.38	.79
Facebook filtering ability	−1.77	1.58	−1.12	.27	−5.01	1.47
Facebook Activity × Facebook Filtering Ability	−.55	.22	−2.53*	.02	−1.00	−.11
VWM capacity (control variable)	−3.94	2.57	−1.53	.14	−9.20	1.32

Note. Estimated coefficients, standard errors (*SE*s), and 95% confidence intervals (CIs) for control, independent, and moderator variables in the model predicting anxious symptoms—Facebook filtering group. *B* = unstandardized estimated coefficient

Anxious symptoms outcome Consistent with our predictions, the PROCESS model that examined anxious symptoms as an outcome revealed a significant interaction between Facebook activity and neural Facebook filtering ability, $t(33) = -2.53$,

Table 1 Zero-order correlations

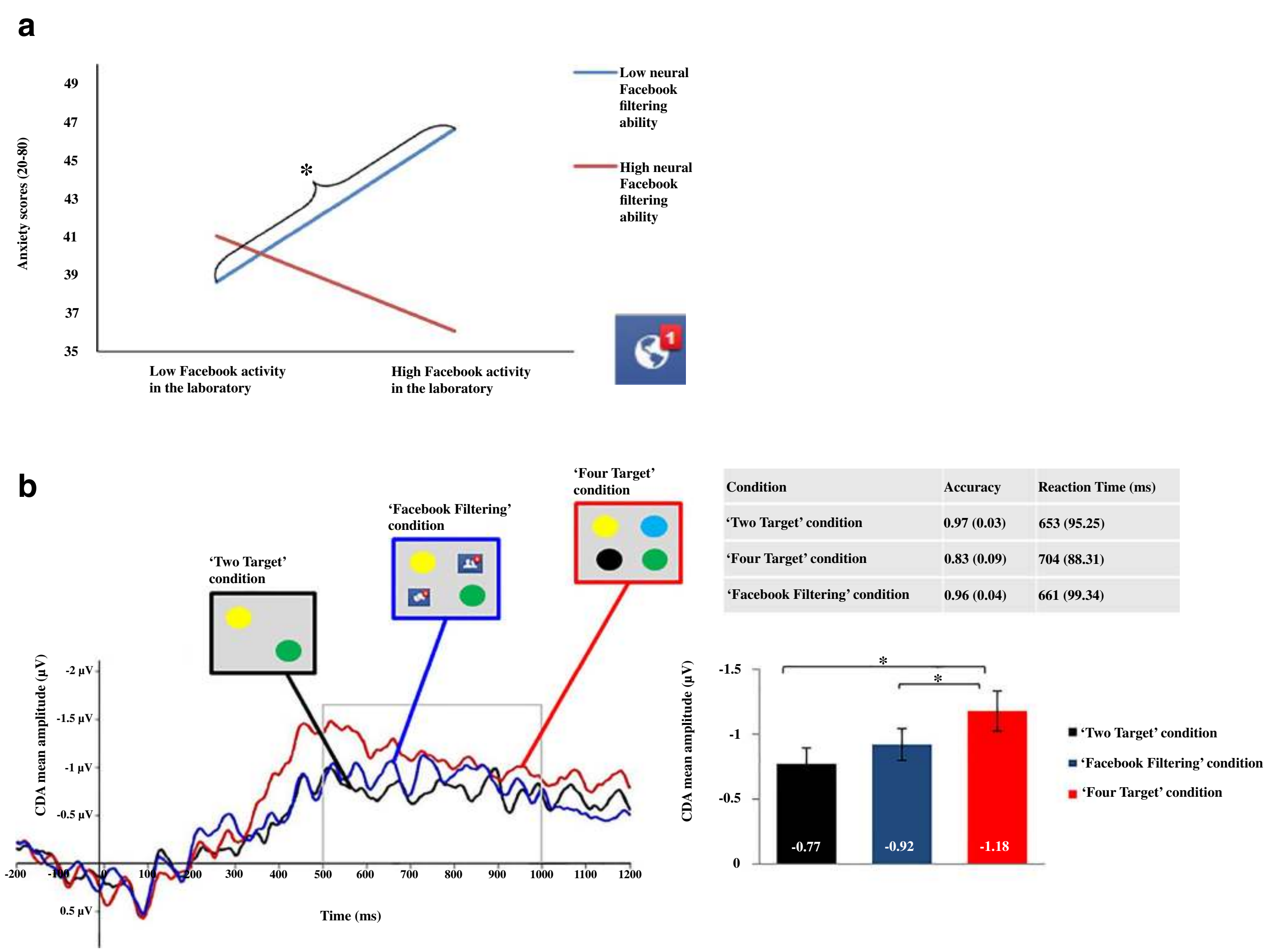
Variable	1	2	3	4	5	6	7
STAI-T (1)							
BDI-II (2)	.69**						
VWM capacity (3)	−.08	−.13					
Facebook activity (4)	.16	.16	.23				
Facebook time (5)	.34*	.38*	−.12	.56**			
Facebook filtering ability (6)	−.27	−.16	−.07	−.15	−.16		
General filtering ability (7)	.15	−.19	−.08	.11	.36*	–	

Note. Zero-order correlations between anxious symptoms, depressive symptoms, VWM capacity, Facebook activity and time, Facebook filtering ability, and general filtering ability. *$p < .05$. **$p < .01$

$p = .02$, CI [−1.00, −.11] that accounted for 16% of the variance above the main effects (see Fig. 3a). It bears noting that the pattern of the interaction remains essentially unchanged when repeating this analysis without the VWM capacity control variable, $t(33) = -2.13$, $p = .04$, CI [−.89, −.02], or when controlling for general number of Facebook friends, $t(33) = -2.59$, $p = .01$, CI [−1.03, −.12].

To further interpret this significant interaction, we conducted a follow-up analysis that tested our hypothesis of a positive relationship between Facebook activity and anxious symptoms for individuals with low (−1 *SD*) but not high (+1 *SD*) Facebook filtering ability. Confirming predictions, an increase in Facebook activities was associated with more anxious symptoms among low Facebook filtering individuals, $t(33) = 2.27$, $p = .03$, $\eta_p^2 = .13$, CI [.08, 1.58] but not among high Facebook filtering individuals, $t(33) = -1.07$, $p = .29$, $\eta_p^2 = .03$, CI [−1.22, .38].

Similar to findings obtained with Facebook *activity* as a predictor, we found a marginally significant interaction (with the same pattern) when we repeated the same aforementioned analysis with Facebook *time* as a predictor, $t(33) = -1.97$, $p = .06$, $\eta_p^2 = .11$, CI [−.75, .01].



Condition	Accuracy	Reaction Time (ms)
'Two Target' condition	0.97 (0.03)	653 (95.25)
'Four Target' condition	0.83 (0.09)	704 (88.31)
'Facebook Filtering' condition	0.96 (0.04)	661 (99.34)

Fig. 3 Facebook filtering analyses. **a** Moderation analyses: The relationship between Facebook activity, high and anxious symptoms as a function of Facebook-filtering ability, while controlling for VWM capacity. Graphs are created using the fitted model's predicted anxious symptoms given values of the independent variables at −1 *SD* and +1 *SD*. **b** Continuous CDA amplitudes; table of mean accuracy and RTs; bar plot of CDA mean amplitudes (from electrodes PO7/PO8, P7/P8, PO3/PO4). Bars displaying the between-subjects standard error. (Color figure online)

Depressive symptoms outcome In contrast to the clear pattern obtained with anxious symptoms, no results were obtained when we repeated the same aforementioned analyses with depressive symptoms as an outcome. Specifically, although in the same direction of anxiety analyses, the Facebook Filtering Ability × Facebook Activity interaction predicting depression scores was not significant, $t(33) = -1.45$, $p = .16$, CI [−.38, .06], $\eta_p^2 = .06$, nor was the Facebook Filtering Ability × Facebook Time interaction predicting depression scores, $t(33) = -.74$, $p = .47$, CI [−.25, .12], $\eta_p^2 = .01$.

Does neural general filtering ability moderate the relationship between Facebook usage and maladaptive psychological aspects?

Prior to turning to the main analyses, Table 3 shows that the two filtering groups (Facebook, general) did not differ in any of the background measures.

In order to provide a first step toward specificity of OSN filtering-ability moderation, we repeated the same aforementioned main analyses conducted with the Facebook filtering group with the general filtering group. Specifically, we repeated the aforementioned significant moderation analysis with Facebook activity as the independent variable, VWM capacity as a control variable, general filtering ability as moderator, and anxiety scores as outcome (see Table 4). In this analysis, we found no signs for a general Filtering Ability × Facebook Activity interaction, $t(33) = -.31$, $p = .75$ (see Fig. 4a). All other analyses for the general filtering group were also not significant. Specifically, the General Filtering Ability × Facebook Time interaction predicting anxiety scores was not significant, $t(33) = -1.35$, $p = .19$, CI [−.50, .10], $\eta_p^2 = .05$, nor was the General Filtering Ability × Facebook Activity interaction predicting depressive symptoms, $t(33) = -1.63$, $p = .11$, CI [−.26, .03], $\eta_p^2 = .07$, or the General Filtering Ability × Facebook Time interaction predicting depressive symptoms, $t(33) = -1.50$, $p = .14$, CI [−.26, .04], $\eta_p^2 = .06$.

Importantly, to rule out that perceptual or symbolic differences between the Facebook and general distractors explain the aforementioned differential moderation effects between the two groups, we report that there were no differences in CDA amplitudes in any of the conditions between groups (all *t*s < 1.35, all *p*s > .18). Mirroring these null differences, there were no differences between Facebook filtering ability and general filtering ability in the behavioral measurements: accuracy, $t(67) = -0.006$, $p = .95$; RTs, $t(67) = -0.17$, $p = .86$. These results show that on average filtering requirements (as manifested in CDA amplitudes), were the same in the Facebook and general filtering groups. Considered together, our results provide the first step toward specificity by suggesting that a deficit in the ability to filter out Facebook (but not general) distractors moderates the relationship between OSN usage and maladaptive psychological anxiety. However, these results should be treated with caution given that we did not find signs for a three-way interaction between Group (Facebook or general) × Filtering Ability × Facebook Activity, $F(1, 60) = 2.13$, $p = 0.15$, $\eta_p^2 = .03$.

Table 3 Between-group differences

Variable	Facebook filtering group *M* (*SD*)	General filtering group *M* (*SD*)	*p* value
STAI-T	41.06 (10.91)	42.97 (11.38)	.43
BDI-II	4.65 (4.96)	5.53 (5.58)	.57
VWM capacity	2.63 (0.72)	2.61 (1.01)	.93
Facebook activity	4.79 (6.27)	4.79 (8.30)	.96
Facebook time	13.66 (10.80)	11.52 (9.44)	.36

Note. Characteristics of the Facebook filtering group and general filtering group

Secondary CDA analyses

Facebook filtering group The CDA waveforms of all conditions, means, and standard deviations are presented in Fig. 3b. We first aimed to replicate prior findings showcasing that CDA amplitudes are sensitive to the number of VWM representations (Luria, Sessa, Gotler, Jolicœur, & Dell'Acqua, 2010; Luria & Vogel, 2014; Vogel et al., 2005). A one-way analysis of variance (ANOVA) with condition (two targets, four targets, and Facebook filtering) as a within-subject variable on the CDA and mean amplitude as a dependent variable revealed a significant effect of condition, $F(2, 66) = 10.05$, $p < .001$, $\eta_p^2 = .23$. As expected, findings showed higher CDA amplitudes in the four-target condition relative to two-target condition, $F(1, 33) = 18.58$, $p < .001$, $\eta_p^2 = .36$. Complimentary to this analysis, we also examined our prediction that, on average, distractor-irrelevant information would be represented in VWM to some extent, demonstrating partial filtering success (Vogel et al., 2005). As expected, findings showed that the CDA amplitudes in the Facebook filtering condition were lower than the four-target condition, $F(1, 33) = 7.20$, $p < .05$, $\eta_p^2 = .18$, but marginally higher than those in the two-target condition, $F(1, 33) = 3.08$, $p = .08$, $\eta_p^2 = .08$.

General filtering group The CDA waveforms of all conditions, means, and standard deviations are presented in Fig. 4b. Repeating the same analyses obtained the same trend of results. Specifically, a similar one-way ANOVA also revealed the expected effect of condition, $F(2, 68) = 17.89$, $p < .001$, $\eta_p^2 = .34$. As expected, findings showed higher CDA amplitudes in the four-target condition

Table 4 Moderation analysis with Facebook activities as the independent variable, VWM capacity as a control variable, general filtering ability as moderator and anxiety scores as outcome

					95% CI	
Variable	*B*	*SE*	*T* value	*p* value	Low limit	High limit
Facebook activity	.22	.26	.84	.40	−.31	.74
General filtering ability	.71	.99	.72	.48	−1.32	2.74
Facebook Activity × General Filtering Ability	−.05	.15	−.31	.75	−.36	.26
VWM capacity (control variable)	.72	2.15	.34	.74	−3.68	5.13

Note. Estimated coefficients, standard errors (*SE*s), and 95% confidence intervals (CIs) for control, independent, and moderator variables in the model predicting anxious symptoms—general filtering group

relative to two-target condition, $F(1, 34) = 36.77$, $p < .01$, $\eta_p^2 = .56$. In addition, findings showed that the CDA amplitudes in the general filtering condition were lower than in the four-target condition, $F(1, 34) = 9.11$, $p < .01$, $\eta_p^2 = .21$, but higher than those in the two-target condition, $F(1, 34) = 8.54$, $p < .01$, $\eta_p^2 = .20$.

Discussion

While there is no doubt that OSN usage is steeply increasing worldwide, links between OSN usage and maladaptive psychological aspects are mixed (Acar, 2008; Feinstein et al., 2015; Koc & Gulyagci, 2013; Shaw et al., 2015; Zaffar et

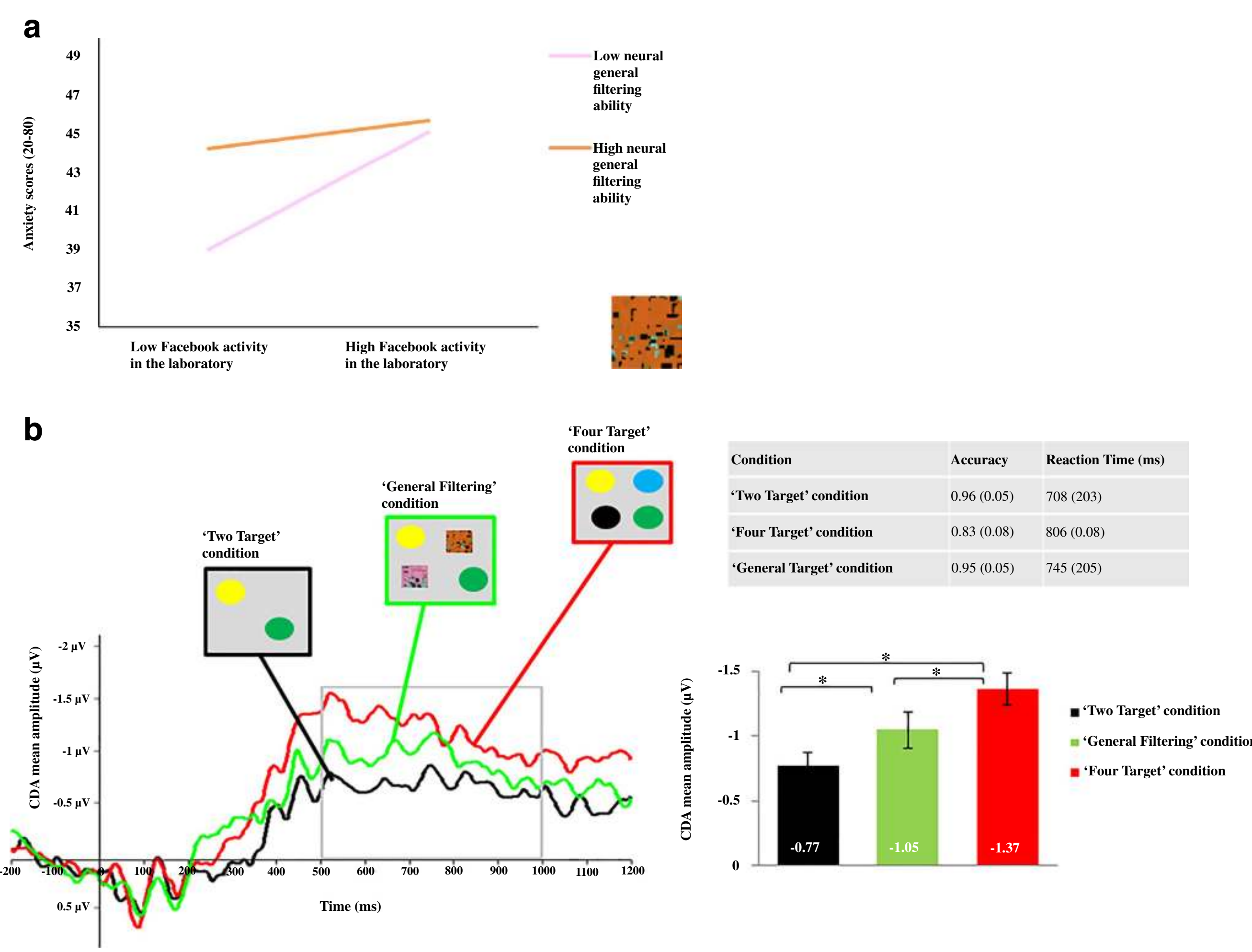


Fig. 4 General filtering analyses. **a** Moderation analyses: Relationship between Facebook activity and anxious symptoms as a function of general filtering ability, while controlling for VWM capacity. Graphs are created using the fitted model's predicted anxious symptoms given values of the independent variables at −1 *SD* and +1 *SD*. **b** Continuous CDA amplitudes; table of mean accuracy and RTs; bar plot of CDA mean amplitudes (from electrodes PO7/PO8, P7/P8, PO3/PO4). Bars displaying the between-subjects standard error. (Color figure online)

al., 2015). The present study helps clarify these contradictions by providing the first evidence for an important moderator, namely, neural OSN filtering ability, that can shed light on for whom increased OSN usage may be associated with maladaptive psychological aspects.

In the present study, we employed a novel EEG paradigm that can assess the online neural representation of Facebook distractors in VWM. We predicted and found that enhanced Facebook usage was related to enhanced symptoms of anxiety among individuals with low (but not high) ability to filter irrelevant Facebook distractors. Furthermore, we provided a first step toward specificity, by showing that our results are not better explained by a general filtering deficit can explain the moderation between Facebook usage and anxiety.

The present results demonstrating a neural Facebook filtering-ability moderator extend prior findings. Specifically, while previous studies only examined direct relationships between pairs of variables that constitute our moderation account, the present study provides empirical support for the moderating role of OSN filtering ability in the relationship between OSN usage and maladaptive psychological aspects. Moreover, the development of a novel paradigm that isolates the online neural mechanism of filtering irrelevant OSN information transcends prior findings that focused on behavioral filtering ability that is remotely associated with an underlying neural filtering process (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Ophir et al., 2009). In addition, the present study, which measured actual immediate OSN usage in the laboratory, transcends most prior studies that relied on subjective OSN usage measures that are prone to multiple reporting biases (Ryan & Xenos, 2011; Steers, Wickham, & Acitelli, 2014).

While we found that enhanced Facebook *activity* was related to enhanced symptoms of anxiety among individuals with low (but not high) ability to filter irrelevant Facebook distractors, we only found a marginally significant interaction (with the same pattern) when we repeated the same analysis with Facebook *time* as a predictor. Recent studies indicate that social networks activities can be classified into two broad categories: active and passive usage (Verduyn et al., 2015; Verduyn, et al., 2017). Active usage refers to activities that facilitate direct exchanges with others, while passive usage refers to the monitoring of other people's lives without engaging in direct exchanges with others. Adopting this distinction (in retrospect) in the current study, it is possible that the differential results we obtained are partially driven by the notion that our Facebook activities variable is a "pure" measure of active Facebook usage, while the Facebook time measure is more complex since it sums both active and passive categories. Therefore, the present findings contribute to this active–passive categorization. Specifically, while studies consistently find a negative relationship between passive usage and aspects of well-being (Verduyn et al., 2015; Verduyn et al., 2017), the nature of the relationship between active usage and well-being is mixed (Verduyn et al., 2017). Accordingly, our moderation findings suggest that the direction of influence between active Facebook usage and anxiety is related to individual differences in neural filtering ability.

Our model that explains maladaptive OSN usage via impairments in neural OSN filtering ability accords well with recent advancements in clinical science that move from categorizations that are symptom focused (e.g., ICD or DSM) to categorizations that highlight deficits in basic underlying mechanisms (Research Domain Criteria, RDoC; Insel et al., 2010). Specifically, the neural OSN filtering mechanism is part of the working memory psychological construct under the broader umbrella of cognitive systems. In addition, our ERP methodology, and particularly the CDA component, provides a clear physiological unit of analysis.

The notion that OSN filtering impairments constitute a basic transdiagnostic dimension of functioning suggests possible relations to other "addiction"-like clinical conditions involving enhanced engagement in rewarding stimuli despite negative consequences. This view is congruent with recent empirical efforts that try to determine whether and when excessive Internet and technology usage can be labeled as a form of "addiction" (Griffiths & Kuss, 2015; Marcial, 2013; Turel, He, Xue, Xiao, & Bechara, 2014). Importantly, the transdiagnostic nature of OSN filtering impairments suggests it may have neural overlap with other addiction-like conditions. One central way to examine whether excessive OSN usage may share addiction-like symptoms involves searching for underlying similarities with classic addictions. For example, a prominent feature of addiction is poor inhibitory control (Noël, Brevers, & Bechara, 2013; Turel et al., 2014), defined as the inability to suppress responses to irrelevant stimuli while pursuing cognitively represented goals (Carlson & Moses, 2001; Rothbart & Posner, 1985). One manifestation of impaired inhibitory control involves a compromised ability to filter task-irrelevant information (Owens et al., 2012). While somewhat speculative, it may be that excessive maladaptive Facebook usage that involves a filtering deficit may have some neural overlap with other addiction-like conditions.

A more precise understanding of the importance of underlying filtering impairments may also allow identifying individuals who are susceptible to maladaptive usage of OSNs. While currently hypothetical, identifying a clear psychological dimension can facilitate future intervention efforts targeting the enhancement of filtering ability (Owens et al., 2013) in at-risk OSN users.

Despite the novel features of the study, several limitations warrant comment. First, while we replicated the positive correlation between actual Facebook usage and depressive symptoms, contrary to our prediction and to our findings with anxious symptoms, we did not find that neural Facebook filtering ability moderated this association. Although anxiety and depression are highly correlated, dissociations between these two constructs and media usage have been documented (Harwood, Dooley, Scott, & Joiner, 2014; Shaw et al., 2015), with at least one prior study showing that Facebook usage was related to aspects of anxiety but not to depression (Shaw et al., 2015). Future studies should examine whether, in contexts that require goal-directed behavior, the inability to filter Facebook cues may be associated with anxious symptoms such as tension and worry and less associated with general withdrawal that is more associated with depression. In addition, differential measurement method characteristics that include anxiety symptoms measured as a trait and depression symptoms as a state could have also contributed to divergent results.

Second, despite significant correlations between lab and home Facebook usage measures, when we reconducted the above moderation analyses with Facebook home usage (weekly activity or weekly time) no consistent findings emerged. The two measures (laboratory and at-home Facebook usage) only share some of the variability, thus potentially tapping on different aspects of Facebook usage. It may be that aspects unique to laboratory Facebook usage (which are not shared with home usage) interact with neural Facebook filtering ability in the association with anxiety. Accordingly, our findings are restricted to a controlled lab context and future studies should examine more long-term influences in natural settings.

A third limitation relates to the cross-sectional design of our study. Such a design does not allow testing whether Facebook filtering ability functions as an antecedent or consequence of anxious symptoms. Therefore, we cannot rule out an alternative model predicting that the relationship between anxious symptoms and Facebook usage is moderated by filtering ability. Congruent with this view, there are several studies that highlighted a reversed directionality, arguing that high trait-anxious individuals have impaired filtering ability of task-irrelevant information (Qi et al., 2014; Stout et al., 2015; Stout et al., 2013). While clearly important, these prior studies were also cross-sectional, and thus are equally inconclusive regarding the true directionality of the relationship between these two constructs. To overcome this limitation, future studies should provide direct casual evidence for this relationship or employ a longitudinal design. Despite this limitation, our study can be seen as providing an important proof of concept that neural Facebook filtering ability is an important variable in the relationship between Facebook usage and anxious symptoms.

A fourth limitation relates to the nature of the general filtering condition in our paradigm. Specifically, although the general filtering distractors are similar to distractors used in the conventional filtering paradigms (Vogel et al., 2005), and although the general distractors are perceptually similar to the Facebook distractors, the general distractors have no semantic meaning, whereas Facebook distractors do. Therefore, it is possible that differences between the ability to filter the distractors are not related to the potency of Facebook icons; rather, they would evince for any stimulus with meaning. Although we cannot fully rule out this possibility, the fact that the average CDA amplitudes were similar in the general and Facebook filtering conditions (all *t*s < -1.35, all *p*s $> .18$; see Results section) suggests that potential differences between distractor types did not manifest in the main measure that constitutes the moderator of this investigation.

Relatedly, although it was important to show that the specific Facebook filtering deficit, is not better explained by a general filtering deficit, this result is tentative because the three-way interaction between group (Facebook/general filtering), filtering ability, and Facebook usage was not significant. Accordingly, and despite the notion that we provided an important first step toward specificity above and beyond previous studies (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Ophir et al., 2009), future research should further isolate the uniqueness of the OSN filtering deficit.

Finally, although our sample size is larger than prior relevant studies, we cannot rule out the possibility that past inconsistent findings may be related to power issues, and that our study was also underpowered. Specifically, although the major finding of our moderation model produced a medium-sized effect ($R^2 = .16$), future resembling studies that expect a similar effect size, would require a larger sample ($n = 44$) to obtain adequate power. However, it is important to note that the present study was sensitive enough to replicate prior findings between Facebook usage and anxiety (Koc & Gulyagci, 2013; Zaffar et al., 2015) and prior neural CDA filtering findings (Luria et al., 2010; Luria & Vogel, 2014; Vogel et al., 2005).

Acknowledgements We wish to thank Lee-mor Zucker for research assistance.

This study was funded by the Blavatnik Interdisciplinary Cyber Research Center (Grant #2017117)

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