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Associations between Digital Literacy and Executive Functions in College Undergraduates

Asociaciones entre Competencia Lectora Digital y Funciones Ejecutivas en Estudiantes Universitarios

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Digital literacy can be defined as a set of skills for searching, accessing, navigating, integrating, and evaluating the reliability of information on the internet, mainly in written form. The present study aimed to examine the contribution of executive function skills (inhibition, cognitive flexibility and working memory) to performance on a digital literacy assessment tool in college undergraduates. Eighty-five Argentinean university undergraduates (56 female, mean age 20.34 ± 4.6 years) completed a digital literacy test and a computerized executive functions battery. After controlling for vocabulary scores and sociodemographic factors, cognitive flexibility was the main predictor of digital literacy scores. In particular, it was associated with information search and integration task performances. Visuospatial working memory predicted information search scores and inhibition correlated positively with reliability evaluation tasks. Our results indicated: 1) a general involvement of cognitive flexibility in digital literacy, possibly reflecting the need to shift between multiple documents, reading or navigation strategies; 2) a specific link between visuospatial working memory and information search, which might be indicating a spatial processing load related to hyperlink navigation; and 3) a possible involvement of inhibition in the evaluation of web documents, which may contribute to the suppression of irrelevant information.

Keywords: Digital Literacy, Reading Comprehension, Hypertext, Executive Function

La competencia lectora digital puede definirse como un conjunto de habilidades para acceder, navegar, integrar y evaluar la confiabilidad de la información en Internet, principalmente en formato escrito. El presente estudio tuvo por objetivo examinar la contribución de las funciones ejecutivas (inhibición, flexibilidad cognitiva y memoria de trabajo) al rendimiento en una prueba de evaluación de la competencia lectora digital en estudiantes universitarios. Ochenta y cinco estudiantes universitarios argentinos (56 de género femenino, edad promedio: 20.34 ± 4.6 años) completaron una prueba de competencia lectora digital y una batería computarizada de funcionamiento ejecutivo. Luego de controlar los puntajes de vocabulario y factores sociodemográficos, la flexibilidad cognitiva fue el principal predictor de la competencia lectora. En particular, se asoció al rendimiento en las tareas de búsqueda e integración de la información. La memoria visoespacial predijo los puntajes de búsqueda y la inhibición correlacionó positivamente con las tareas de evaluación de la confiabilidad de la información. Nuestros resultados indicaron: 1) una contribución general de la flexibilidad cognitiva a la competencia lectora digital, posiblemente reflejando la necesidad de alternar entre múltiples documentos y estrategias de lectura y navegación; 2) un vínculo específico entre la memoria de trabajo visoespacial y la búsqueda de información, lo que podría indicar la demanda de procesamiento espacial relacionada con la navegación de hipervínculos; y 3) un posible rol de la inhibición en la evaluación de documentos de la web, la cual podría contribuir a la supresión de información irrelevante.

Palabras clave: Competencia lectora digital, Comprensión de textos, Hipertexto, Funciones Ejecutivas

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Digital Literacy: skills for Reading in a Digital World

Reading on the internet is a complex and dynamic task. Readers need to search, identify, and choose the best link pathways to follow as they navigate the web while keeping track of their reading goals. To build coherent mental representations of the content, they also need to integrate information distributed along several pages, multiple formats (i.e., multimedia), and multiple sources (i.e., the author or any other parameter that identifies a content's origin). In addition, they need to make decisions about the reliability and relevance of the information, so they can find their way through multiple, heterogeneous sources (e.g., List et al., 2020; Salmerón et al., 2018a, 2018b). The term "Internet Reading Literacy" refers to the set of skills and knowledge required to comprehend and use information, mostly in written form, to achieve individuals and collective goals (OECD, 2019). Operationally, reading literacy is studied with tasks that require readers to "select and sequence access to documents and move from one to another (i.e., navigation), comprehend and integrate information from different documents, and evaluate information based on its usefulness and quality" (Salmerón et al., 2018a). In the present work, we will use the term Internet Reading Literacy as a synonym of Digital literacy. However, of note is that the concept of digital reading can also be found with a broader sense in the literature, referring to reading in all kinds of screen-based formats, including linear, single-text reading, even with no internet connection (i.e., PDF versions of linear print texts) (Singer & Alexander, 2017, for a meta-analysis see Delgado et al., 2018). While reading on the internet and traditional linear reading share common processes (e.g., Salmerón et al., 2018b; Coiro, 2011), the former may also place additional cognitive loads, particularly in the domain of executive functions (Wylie et al., 2018).

Executive Functions and Reading Comprehension

The term "executive functions" (hereinafter, "EF") refers to a set of cognitive processes involved in planning, executing, monitoring and adapting goal-directed behaviors (Follmer, 2018; Miyake, 2000). The most influential EF model for reading comprehension literature (Miyake et al., 2000) conceptualizes them as three distinct but connected sets of processes: 1) working memory (hereinafter, "WM") updating, 2) shifting (also known as "cognitive flexibility", hereinafter "CF") and 3) inhibition. WM is a short-term system for retention and active manipulation of verbal and visuospatial information, deploying memory and controlled attention resources. WM updating refers to the ability of monitoring, adding or removing contents from this system. Shifting (or CF) can be defined as the ability to switch between mental processes and sets to generate appropriate behavioral responses. Inhibition is the ability to suppress interference to achieve a goal. It encompasses the control of interference generated by distracting or task-irrelevant external stimuli, and response inhibition, which suppresses automatic or prepotent, but task-irrelevant responses (Dajani & Uddin, 2015; Diamond, 2013).

Many theoretical models of reading comprehension, such as the Construction-Integration model (Kintsch, 1988), the Landscape model (van den Broek et al., 1999), or the Reading Systems Framework (Perfetti & Stafura, 2014) imply or explicitly describe the role of EFs (for a more detailed review, see Butterfuss & Kendeou, 2018). When comprehending text, WM provides a cognitive workspace to maintain information from the incoming input, integrate it with the unfolding text representation and prior knowledge. In this way, WM allows (and constrains) model construction and inference generation (Daneman & Merikle, 1996). Shifting also plays an important role by supporting the switch from mental sets and the formation of new concepts, integration of new and sometimes unexpected input with the unfolding text representation, adequate forward inference-making processes (by selecting and alternating between relevant pieces of information), switching between reading strategies, and engaging in metacognitive processing, such as monitoring one's comprehension (Butterfuss & Kendeou, 2018). Finally, inhibition helps readers to avoid the activation of irrelevant information, be it from environmental stimuli or long-term memory systems supporting relevant text representation construction and preventing WM overload (Butterfuss & Kendeou, 2018). In the following sections, we will describe how these executive functions apply to the particular demands of digital literacy.

Executive Functions and Digital Literacy

Whereas the contribution of EF to traditional text comprehension is well established (e.g., Butterfuss & Kendeou, 2018; Chang, 2020; Follmer, 2018), its role in digital literacy has been less studied. To complete a printed text comprehension assignment, readers follow a self-regulation cycle where they plan what to read according to their goals and make predictions about the content before going to the text, monitor their understanding during reading and evaluate their responses during and after reading. Reading texts on the Internet involve similar strategies, but their hypertext structure requires readers to repeat this cognitive cycle every time they are faced with a new series of hyperlinks, to create the best navigational pathway to fit their needs (Coiro, 2015 Wylie et al., 2018). Therefore, reading in the web requires "purposeful, critical and flexible mindsets from learners" (Coiro, 2015). Also, internet literacy is not just about comprehending text, it includes reading lists of results, accessing very specific information, and making reflected decisions on the trustworthiness and the origin of several, many times poorly cohered, contents.

Regarding CF, reading on the internet requires allocating cognitive resources for planning information searches, selecting, and prioritizing relevant sources (and avoiding others), monitoring, and adapting reading strategies according to the results. Since reading environments are constantly changing, readers need to flexibly switch reading strategies, alternating from "reading-to-locate" (for instance, scanning search results to find the best link) and deeper semantic processing (when finding target-relevant information), among other proficient strategies. Flexibility is also required when alternating between reading several short texts from different pages and longer passages of a single document. In addition, the diversity of online reading environments (search engines, portals, websites, etc.) demands flexible attention allocation to contextual cues, to identify the best reading strategy for a particular context. The reader also engages inhibition to resist distracters, such as irrelevant information (be it text or multimedia) and advertising, e.g., Wylie et al., 2018). Regarding WM, DeStefano and Lefevre (2007) have suggested that hypertext navigation is likely to place additional demands on WM than traditional linear reading. Hyperlink navigation may interrupt the reading flow, making it harder to build a coherent text representation and resulting in increased WM loads. In addition, visuospatial WM might have a specific role in navigation efficiency by supporting to process the spatial relations between pages (Salmerón et al., 2018b; Wylie et al., 2018). To sum, as digital environments extend the notion of reading to a problem-solving, context-oriented, and iterative task (Britt et al., 2018), the role of EF becomes more ostensible.

Despite these theoretical claims, most of the evidence on the association between EF and university students' performance on digital reading comes mostly from the WM domain (e.g., Burin et al., 2018; Salmerón et al., 2018a; for a review, see: Wylie et al., 2018), and studies on the subject are rather scarce (Tarchi et al., 2021). Recent studies suggest, however, a more complex contribution of EF to digital literacy. For example, college students who performed better in an e-learning environment also self-reported using specific metacognitive skills, such as keeping the reading goal in mind, re-reading, or varying the amount of attention as a function of information relevance and difficulty (Burin et al., 2020). In another study, undergraduates with lower attentional inhibition scores showed poorer comprehension of a science hypertext with irrelevant pictures, suggesting they were more easily seduced by the images during navigation (González et al., 2019). Inhibition differences may also play a role when readers revise misconceptions (Butterfuss & Kendeou, 2020), a skill crucial to reduce the impact of inaccurate and/or misleading information (e.g., Rapp & Salovich, 2018). Finally, a recent study (Caccia et al, 2019) analyzed how cognitive functions predicted high school students' performances on the Online Research and Comprehension Assesment (ORCA), a tool designed to measure online search and comprehension skills by solving reading tasks in Internet-like scenarios. A regression analysis showed that self-report and objective performance measures of WM and inhibition were significant predictors of ORCA scores. However, this study did not consider objective measures of cognitive flexibility or visuospatial WM. To date, no other work has attempted to examine the association of these three aspects of EF with the performance in a digital literacy assessment test.

Taking this into consideration, we aimed to further analyze the contribution of Miyake's (2000) components of EFs to digital literacy. Digital literacy was assessed through the WebLEC test (Salmerón et al, 2018a), a closed digital environment emulating Internet reading scenarios in Spanish (see the Instruments' section for details). The present study examined the associations between college undergraduates' WebLEC performances and their EF skills (inhibition, cognitive flexibility, working memory), measured by a computerized battery of neuropsychological tests.

Methods

Design

El párrafo posterior a un título de nivel 3 tiene un espaciado anterior de 10 puntos y usa una sangría de primera línea de 0,63 cm con interlineado sencillo.

Participants

Eighty-five university students (66% female; Age M=20.34 ± 4.6 years) from a large south American university, currently at the first (n=35) or third (n=50) year of their psychology degree studies, volunteered to take part anonymously in the study. All participants were Spanish native speakers. All participants gave their informed consent, according to the terms of the Helsinki Declaration and local regulations.

Instruments

Digital Literacy Test

Digital literacy was assessed through the WebLEC test (Salmerón et al., 2018a). Originally aimed to high school students, the test presents 28 items (26 multiple-choice and 2 open-ended) on different general world knowledge domains, distributed across four scenarios (an online Q&A Forum, a Wikipedia environment, "Youth Web", a services' web portal, and a Google-like search engine). The Forum scenario presents two different conversations about daily life topics: "I'm going on a trip. What can I do with my pet?" and "Planting a Christmas tree in my garden." In each case, three more or less reliable users give advice on these topics. After reading the forum, participants are asked questions about the users' advice. The Wikipedia scenario includes two articles on the topics "The French Revolution" and "Pollution". It follows the structure of the pages in Wikipedia, with a table of contents and different subsections. The student can access additional information by clicking on the hyperlinks. Participants are required to navigate these sections to locate and retrieve the answers to a series of questions about the articles' contents. The Youth Web scenario consists of a Web environment directed to young people and structured in five large topics (environment, technology, health, sports, and courses) with three subsections each. The student must navigate through the menus to answer a series of questions about the website's information and services. Finally, the Google scenario includes two modules on "Effects of transgenic foods" and "Solutions for climate change". Participants are given fictional assignments on these topics (for instance: "You're writing a paper on transgenic food. You need to find information about its effects on health. What would you write on a search engine?"). Participants need to write search terms to look for relevant Web pages, interpret pages of results with different sources of varying reliability, and integrate contradictory information found on two Web pages.

Following the PISA framework (OECD, 2019), each item of the test proposes a short question requiring either to access or retrieve information (12 items, hereinafter search tasks), to interpret and integrate information from different paragraphs and pages (12 items, hereinafter integration tasks), or to reflect on and evaluate the reliability of the information (4 items, hereinafter evaluation tasks). A search task, for example, could require the participant to locate a specific citation from Rousseau regarding the French Revolution (Wiki scenario). An integration task could require finding what the advices from different Forum users have in common. An evaluation task would require deciding what is best forum advice, and why. As a result, the test provides a digital literacy index, calculated as the sum of correct responses to the 28 items, and two navigation indexes that were not considered in the current study. In addition, although the digital literacy index works a single factor, we also considered each of the component task types (i.e., search, integration, and evaluation) during our analyses, to gain a deeper insight of the potential associations with EF. The test used in this study consisted of a validated, local adaptation of the original (reference blinded for revision). The test exhibited good internal consistency in the original study (α=0.,79) and the local adaptation (α=0,75).

Vocabulary

As an indicator of more basic reading abilities, a vocabulary test (BAIRES-A; Cortada de Kohan, 2003) was included. The test has exhibited good internal consistency (Cronbach's alpha: 0.7) and it has previously correlated with digital reading tasks (González et al., 2017). Within an eight minutes limit, participants are required to choose the correct definition (part A of the test) or the synonym (part B of the test) for a target word among four options (max. 34 items). The score is computed as the sum of correct responses.

Executive Functions Battery

The Cognitive Self-Regulation Test Battery (Richard's et al., 2018) is a computer platform designed for the evaluation of inhibition, WM and CF across a wide age range. It has shown adequate internal and external validity in a variety of children (Richard's et al., 2018) and adult (Richard's et al, 2019; Comesaña et al., 2017) studies. The following tasks were included in the present study (see Richards et al., 2018 for details). A) Perceptual Inhibition (hereinafter, "PI") task: participants must detect the presence of target stimuli among a varying number of perceptually similar distracters (the number of distracters varies between 4-32 among trials). Performance was measured as accuracy and response latency difference between the conditions with the highest and lowest cognitive load (32 and 4 distracters, respectively) (α=.60). B) Visuospatial Working Memory (hereinafter: "VSWM"). Participants are asked to remember and recall the location of a series of X in a square matrix as a primary task, while also indicating the color of the stimuli in a palette in a secondary, interference task, interposed between the encoding and recall stages of the trial. Performance is measured as the maximum number of elements recalled before committing two consecutive mistakes (α=.60). C) CF task: The task presents "congruent" trials (where participants must respond pressing a key ipsilateral to target stimuli) and "incongruent" trials (where participants must respond contralaterally). Target stimulus is a hand with a finger pointing straight down (congruent trials) or diagonally to the other side (incongruent trials), as a cue for each trial type, respectively. After some training, congruent and incongruent trials are presented in a mixed block which requires switching between responses. In the context of the CF task, three Inverse Efficiency indexes (IE=RT/(1–Error proportion); Christie & Klein, 1995) were calculated: IE total switch (IETS), which is calculated from those trials where both response types (ipsi and contralateral to stimulus location) and response site (left key or right key) change with respect to the previous one; IE response type switch (IERTS, different response, same site than previous trial); IE response site switch (IERSS, same response, different site than previous trail). All these indexes were considered as performance measures for the CF task (α=.93).

Verbal Working Memory Test

The Running Memory Span (Barreyro et al., 2015) assesses storage capacity and concurrent processing of verbal information within WM. The task has shown good internal consistency (α=.78) and external validity, being a good predictor of expository text comprehension in undergraduates (Barreyro et al., 2019). Participants must retain and recall the last n letters ($2 \leq n \leq 6$) of a series (of unknown and varying length) presented in rapid succession. Performance is calculated as the longest sequence of letters the participant can recall before committing two consecutive mistakes within a series.

Procedure

Data collection was carried out virtually during 2020 COVID-19 lockdown. Participants completed all tasks from their homes, through three synchronic online sessions conducted on small groups. In the first session (30 minutes), participants gave their consent and completed a sociodemographic questionnaire plus the vocabulary test. In the second session, they completed the digital literacy test (45 minutes). Finally, they completed the EF tests in a third session (20 minutes). Although all tests were self-administered, the research team assisted data collection during all sessions to ensure good comprehension of the instructions and the normal development of the protocol.

Data Analysis

Associations between Digital literacy, vocabulary and executive function scores were examined through Pearson correlations. Factorial ANCOVA and MANCOVA were applied to examine the effect of categorical variables such as gender, course year and age (as covariate) over the WebLEC global index and task scores, respectively. ANCOVA was applied to analyze the WebLEC global score, while MANCOVA was applied to include all three WebLEC task scores (search, integration, evaluation) in the same analysis. Effect sizes were estimated through partial eta squared coefficients.

An incompatibility between the software used to run the digital reading task and the operating system on the participant's machine (typically observed with MAC users) affected the registration of log files in 43.5% of the sample. Importantly, this problem only affected log files' recording (i.e., the navigation indexes), not the participants' responses to the test items (i.e., the digital literacy global index), which was registered normally. Consequently, navigation indexes were not considered for the study.

Hierarchical regression models were conducted to analyze the differential contribution of predictor variables to performance in the digital literacy test. The first step included participant's age, gender, course year and vocabulary as control variables. In the second step, EF variables that showed significant associations in the correlation analysis were included. In the case of CF, only the most highly correlated index was included, to avoid potential collinearity issues with the rest. Casewise diagnostics were applied to deal with outliers (standardized residuals above 3 or below -3). Since no outliers were found, all data were included in the regression analysis.

Assumptions of normality, homoscedasticity and linearity were checked by visual inspection of normal quantile plots of residuals, standardized residuals scatterplots and observed versus predicted values, respectively. No signs of heteroscedasticity were found. Independence of errors was checked through the Durbin-Watson coefficient, which fell under the acceptable range for all models (1.760<DW<2.234). Multicollinearity issues were analyzed with collinearity statistics. Both inflation of variance (VIF<1.287) and tolerance (>.777) fell within the acceptable range for all models.

Results

Descriptive Statistics

A complete list of descriptive statistics can be found on Table 1. The mean global score in digital literacy was 78.64 ± 12.52%. Significant effects of Course year ($F(1,73)=6.321$, $p=.014$, $\eta_p^2=0.08$) and Gender ($F(1,73)=6.321$, $p=.014$, $\eta_p^2=0.148$) were observed. Performance was better for third year students (74,98 ± 13,18% vs 67,79 ± 15,23%) and men (78,64 ± 12,52% vs 68,37 ± 13,44%). MANCOVA analysis of task scores (search, integration, evaluation) indicated significant multivariate effects of Course year (Pillai's trace:.105, $F(3,71)=2.772$, $p=.048$, $\eta_p^2=0.105$) and Gender (Pillai's trace:.162, $F(3,71)=4.559$, $p=.006$, $\eta_p^2=0.162$). Performance was better for third year students in integration scores ($F(1,73)=7.768$, p=.007, $\eta_p^2=0.096$) and for men in all scores ($F>5.033$, $p<0.028$, $\eta_p^2>0.065$).

Table 1
Descriptive Statistics of Measure Variables

Variables	*M* (*SD*) (*n*=85)
Sociodemographic data	
Age (in years)	20.34 (4.6)
Gender	
Male	34.12%
Female	65.88%
University year	
First	41.18%
Second	58.92%
Digital Literacy (WebLEC)	
Global reading score	70.75 (14.77) %
Search	70.11 (17.89) %
Integration	75.44 (16.42) %
Evaluation	58.62 (27.15) %
Vocabulary	56.30 (12.15) %
Executive Functions	
PI Accuracy (32 vs 4 distractors)	4.48 (7.02) %
PI Response time (32 vs 4 distractors)	587.33 (389.63) ms
CF IETS	8.59 (2.17) ms
CF IERTS	10.51 (3.73) ms
CF IERSS	8.70 (2.71) ms
VSWM	3.81 (1.73)
VWM	5.47 (2.05)

Note. PI = perceptual inhibition; CF = cognitive flexibility; IETS = Inverse efficiency total switch; IERTS = Inverse efficiency response type switch; IERSS = Inverse efficiency response site switch; VSWM = visuospatial working memory; VWM = verbal working memory.

Associations between Digital Literacy and Executive Functions

Pearson correlation coefficients were calculated to explore the associations between the digital literacy and navigation scores, vocabulary, and EF performance. A complete list of correlation coefficients is provided on Table 2. Vocabulary correlated with digital literacy, $r>.234$, $p<.034$.). Regarding EF, digital reading scores improved with PI ($r=-.286$, $p=.013$), CF ($r<-.343$, $p<.004$) and VSWM ($r=.353$, $p=.003$), but not with VWM. To delve into the nature of the relationship, the different task types composing the digital literacy score (i.e., search, integration, and evaluation) were considered separately. Both integration and search scores increased with CF ($r<-.265$, $p<.027$). Evaluation was specifically associated with PI ($r=.420$, $p<.001$), and search with VSWM ($r=-.269$, $p=.020$).

Table 2
Associations between CDI. Home literacy. Media exposure. Educational institution. and sociodemographic variables

Measure	1	2	3	4	5	6	7	8	9	10	11	12
1. WebLEC GRS	1	.837***	.848***	.616***	.234*	-.286*	.086	-.343**	-.503***	-.374**	.353**	.082
2. WebLEC access		1	.505***	.297**	.149	-.207	.007	-.398**	-.444***	-.317**	.420**	-.023
3. WebLEC integration			1	.419**	.242*	-.224	.092	-.265*	-.441***	-.353**	.205	.153
4. WebLEC evaluation				1	.165	-.269*	.146	-.024	-.218	-.143	.134	.081
5. Vocabulary					1	-.250*	.064	.063	-.146	-.115	.148	.389**
6. PI accuracy						1	-.210	.072	.190	.180	-.155	-.008
7. PI RT							1	.012	-.173	-.116	-.166	-.112
8. CF IETS								1	.679***	.641	-.409***	.188
9. CF IERTS									1	.801	-.239*	-.021
10. CF IERSS										1	-.161	-.053
11. VSWM											1	.044
12. VWM												1

Note. GRS = Global reading score; PI: Perceptual Inhibition; RT = Response times; CF = Cognitive Flexibility; IETS = Inverse efficiency total switch; IERTS = Inverse efficiency response type switch; IERSS = Inverse efficacy response site switch; VSWM = Visuospatial working memory; VWM = verbal working memory.
*p<.05; **p<.01; ***p<.001.

Digital Literacy predictors

Hierarchical regression models were carried out to analyze the contribution of executive functions to performance on the digital literacy test, while controlling for demographic factors. Considering that PI response times and accuracy scores and the different CF scores were highly correlated with each other (see Table 2), only scores with the highest correlations in the exploratory analysis (PI accuracy and CF IERTS, see Table 2) were included to avoid collinearity issues. The digital literacy global score model accounted for 40% of the variance. After controlling for age, gender, university year, and vocabulary the addition of EF scores increased the proportion of explained variance significantly ($\Delta r2$=0.196, p=0.001, F(7,84)=6.863, p<.001). Global reading scores increased with CF (β=-0.301; p=.002). In addition, they were higher for men (β=-0.206; p=.038) and third year students (β=0.204; p=.031) (see Table 3). Vocabulary was a significant predictor in the first step (β=0.247; p=.021), but not in the final model.

A similar analysis was fitted for the three task types composing the digital literacy score (i.e., search, integration, and evaluation). The final model predicted 23% of the search scores' variance and indicated CF (β=-0.284; p=.007) and VSWM (β=0.292; p=.006) as predictors. In the case of integration scores, the model explained 26.5% of the variance, and CF was the only significant cognitive predictor (β=-0.277; p=.007). Once again, the vocabulary effect was significant in the first step (β=0.259; p=.015), but only marginally significant on the final model (β=0.259; p=.066). Finally, no significant effects of EF were found for evaluation scores (see Table 4).

Table 3
Regression analysis of WebLEC scores

Step	Predictor	WebLEC GRS					
		B	S.E.	L.L.	U.L.	std ß	T
1	U. year	7.874	2.945	2.014	13.734	0.264	2.674**
	Gender	-10.125	3.492	-17.074	-3.177	-0.297	-2.900**
	Age	-0.858	0.352	-1.559	-0.158	-0.256	-2.440*
	Vocabulary	0.898	0.382	0.139	1.658	0.247	2.354*
1	Model Statistics			Adj.R²=0.196 F=6.104***			
2	U. year	-7.014	3.318			0.204	2.196*
	gender	-0.506	0.333			-0.206	-2.114*
	Age	0.525	0.366			-0.151	-1.518
	Vocabulary	-0.259	0.215			0.144	1.432
	PI	-1.325	0.422			-0.115	-1.202
	CF	1.591	0.892			-0.301	-3.141**
	VSWM	-7.014	3.318			0.170	1.783
2	Model Statistics			ΔR²=0.150** Adj.R²=0.328 F=6.863***			

Note. U. year = University year; GSR = Global reading score; PI = Perceptual Inhibition; CF = Cognitive Flexibility; VSWM = Visuospatial working memory; U.L. = confidence interval upper limit; L.L. = confidence interval lower limit; std ß = standardized beta coefficient.
*p<.05; **p<.01; ***p<.001.

Table 4
Regression analysis of WebLEC Task scores

Step	Predictor	**WebLEC Search**						**WebLEC Integration**						**WebLEC Evaluation**					
		B	S.E.	L.L.	U.L.	std β	T	B	S.E.	L.L.	U.L.	std β	T	B	S.E.	L.L.	U.L.	std β	T
1	**U. year**	6.334	3.855	-1.338	14.007	0.175	1.643	9.708	3.250	3.239	16.176	0.293	2.987**	6.993	5.866	-4.680	18.666	0.127	1.192
	Gender	-8.331	4.571	-17.428	0.766	-0.202	-1.823	-10.558	3.854	-18.228	-2.888	-0.279	-2.739**	-14.208	6.955	-28.048	-0.367	-0.227	-2.043*
	Age	-0.719	0.461	-1.636	0.198	-0.177	-1.561	-0.961	0.388	-1.734	-0.188	-0.258	-2.475*	-0.968	0.701	-2.362	0.427	-0.157	-1.381
	Vocabulary	0.698	0.500	-0.296	1.692	0.158	1.397	1.049	0.421	0.211	1.887	0.259	2.490*	1.048	0.760	-0.465	2.560	0.157	1.378
1	**Model Statistics**	Adj.R^2=0.059 F=2.327						Adj.R^2=0.206 F=6.449***						Adj.R^2=0.054 F=2.208					
2	**U. year**	4.705	3.594	-2.451	11.861	0.130	1.309	8.105	3.222	1.688	14.521	0.244	2.515*	4.188	6.002	-7.763	16.139	0.076	0.698
	Gender	-3.623	4.301	-12.187	4.941	-0.088	-0.842	-8.203	3.856	-15.881	-0.524	-0.217	-2.127*	-13.621	7.183	-27.923	0.682	-0.218	-1.896
	Age	-0.215	0.432	-1.074	0.645	-0.053	-0.497	-0.719	0.387	-1.490	0.051	-0.193	-1.859	-0.737	0.721	-2.172	0.698	-0.120	-1.023
	Vocabulary	0.239	0.475	-0.706	1.185	0.054	0.504	0.793	0.426	-0.055	1.640	0.196	1.862	0.577	0.793	-1.002	2.156	0.086	0.727
	PI	-0.171	0.279	-0.727	0.384	-0.063	-0.615	-0.163	0.250	-0.662	0.335	-0.066	-0.653	-0.806	0.466	-1.734	0.122	-0.196	-1.730
	CF	-1.513	0.547	-2.602	-0.424	-0.284	-2.766**	-1.351	0.490	-2.327	-0.374	-0.277	-2.754**	-0.688	0.913	-2.507	1.131	-0.085	-0.753
	VSWM	3.301	1.156	0.998	5.604	0.292	2.855**	0.359	1.037	-1.705	2.424	0.035	0.346	0.156	1.931	-3.690	4.001	0.009	0.081
2	**Model Statistics**	ΔR^2=0.190** Adj.R^2=0.230 F=4.585***						ΔR^2=0.082** Adj.R^2=0.265 F=5.326***						ΔR^2=0.067 Adj.R^2=0.046 F=1.866					

Note. U. year = University year; GSR = Global reading score; PI = Perceptual Inhibition; CF = Cognitive Flexibility; VSWM = Visuospatial working memory; U.L. = confidence interval upper limit; L.L. = confidence interval lower limit; std β = standardized beta coefficient.
**p*<.05; ***p*<.01; ****p*<.001.

Discussion

This study is one of the firsts to examine the associations between objective measures of Miyake's (2000) executive function components and performance in a digital literacy assessment tool in college students. Our participants exhibited good digital literacy skills (considering the task was originally designed for high school students), which were better in more advanced university students (integration scores) and males but were not associated with age. An advantage for hypertext reading on males had already been observed among adolescents (Rasmusson & Åberg-Bengtsson. 2015). A previous study on a similar population showed better comprehension of linear texts (i.e., non-hyperlinked) in more advanced, but not in older, university students (Tabullo et al., 2021). Considering the effect was specific for WebLEC integration scores in this case, it might be reflecting an improvement in multiple source comprehension skills (Goldman et al., 2012) due to the sustained practice of studying throughout university courses.

Digital Literacy and Executive Functions

Regarding our main objective, we found a link between undergraduates' performance on EF and digital literacy tasks. The contribution among EF components to this association, however, was not homogenous. Our results suggest a contribution of CF to general task performance, a specific role of VSWM in search skills and a possible association between PI and evaluation skills. These findings are discussed in detail below.

CF was our most robust predictor of digital literacy. This association might reflect the demands of adaptive switching between different reading goals, tasks, strategies, and sources, which characterize digital literacy in general (i.e., Britt et al., 2018) and our test in particular (Salmerón et al., 2018b). Participants were required to optimize their reading and navigation strategies to search relevant information, adapting to scenarios with varying structures, text types and styles, all of which may likely engage CF processes. The subsidiary analyses by task types suggest that the switching skills required by our CF task may have played a role in information search. In addition, the kind of integration skills required by the digital test (e.g., to coherently gather different pieces of information, multiple sources, and multiple representation formats) may also tax on CF abilities, for example, when building multi-text or multi-perspective models that require forging connections between the mental representations and the incoming contents, or deploying strategies to facilitate coherence processes in scenarios that require building complex representations (Follmer & Sperling, 2020; Guajardo & Cartwright, 2016).

As with CF, digital environments also tend to increase WM demands with respect to linear formats (DeStefano & Lefvre, 2007). WM differences predict digital text comprehension (Burin et al., 2015) after controlling for linear reading (Hahnel et al., 2016), and more demanding hypertext navigation requirements particularly affect low WM participants (e.g., Lee & Tedder, 2003; Naumann et al., 2008). Specifically, the visuospatial component of WM may contribute to efficient hypertext navigation, as indicated by prior research (e.g., Kornmann et al., 2016). In our study, visuospatial WM was a specific predictor of search scores (i.e., tasks that required accessing and searching specific pieces of information across a variable number of links). This effect might be reflecting the demand of spatial information processing posed by browsing through hypertexts. In fact, previous studies have reported difficulties to recall networked digital documents and to keep track of link hierarchies in low visuospatial WM undergraduates (Rouet et al., 2012). In sum, our results concerning the contribution of VSWM to digital literacy are in line with prior research, suggesting additional demands, not only on semantic integration processes, but also on the creation of spatial relations between pages and sections, which characterize hypertext navigation (Salmerón et al., 2018a).

Finally, we observed a correlation between the ability to inhibit visual distracters (i.e., the PI task) and performance in the evaluation tasks of the digital literacy test. Inhibition might contribute to comprehension, in general, by reducing the effects of distracting, outdated, or irrelevant information (Butterfuss & Kendeou, 2018). It might be possible that perceptual inhibition becomes more important when navigating through stimuli-saturated hypertexts, designed to capture and redirect reader's attention. Considering that the evaluation tasks in the digital literacy test required judging web site parameters and content reliability, participants with lower PI ability might have been more easily misled by superficial visual clues (for instance, highlighted search keywords on irrelevant search results), leading to suboptimal judgment or information choices.

Previous studies (González et al., 2019) showed that irrelevant information (decorative pictures) distracted low PI participants, affecting their hypertext comprehension performance. However, because this correlation was not supported by our regression analysis, it should be interpreted with caution and warrant further studies.

Study limitations

One of the main limitations of the study is its relatively small sample size. Replications on larger samples are required to verify our results and further support our claims. Similarly, the neuropsychological battery from which the EF tests were taken, while implemented in an online platform and previously validated was originally designed for face-to-face, in situ evaluation. Therefore, further studies are required to guarantee internal and convergent validity of the collected measures. In addition, we were not able to analyze navigation behaviors directly; therefore, further research is required to examine how EFs contribute to efficient hypertext navigation. Future studies also include measures of traditional text comprehension to further discriminate the specific contribution of EF to digital reading, while controlling for common comprehension processes. In this type of contrasts, however, equivalence among reading tests (digital and linear) across several parameters (length, content, prior knowledge, difficulty level, etc.) should be warranted. Finally, any generalization of our results to other online reading environments (such as mobile apps) warrants additional empirical testing because cognitive load is expected to vary as a function of device, design, and affordances' differences.

Conclusion

As the characterization of digital literacy gravitates towards problem solution modelling (e.g., Britt et al., 2018), the participation of executive functions (control and regulatory processes required by tasks involving uncertainty and flexible behavior) becomes more apparent. Since few studies have examined this relationship (Tarchi et al., 2021), we analyzed and compared the contribution of different EF subcomponents to digital reading literacy, finding: 1) a general involvement of CF (particularly in integration and search tasks), probably reflecting the need to shift between multiple task, reading, and navigation demands, 2) a specific engagement of VSWM in information search and retrieval processes, probably reflecting the spatial processing demands of navigating and keeping track of hyperlink structures, 3) a possible role of PI in the evaluation of the reliability of web documents, that might reflect the advantage of filtering out irrelevant or distracting information when validating information online.

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