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Cognitive predictors of self-awareness in patients with acquired brain injury along neuropsychological rehabilitation

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ABSTRACT

Previous research has identified a critical role of executive function and memory in self-awareness, a metacognitive capacity often impaired in acquired brain injury. Through this observational study, we aimed to explore the effect of cognitive rehabilitation on the predictive value of these variables, as also whether any of them can predict the level of self-awareness once the cognitive rehabilitation is completed. 69 patients underwent a neuropsychological assessment, including self-awareness, at admission to and discharge from a cognitive rehabilitation process. Regression analysis was performed at these two moments and a third one was conducted to evaluate whether any of the variables at admission predicted the level of self-awareness at discharge. Verbal fluency was found to be the best predictor of self-awareness, both at admission and discharge. In addition, inhibition and cognitive flexibility, as well as episodic memory, appeared as significant predictors of post-rehabilitation self-awareness. Finally, verbal fluency was revealed as the unique pre-rehabilitation predictor of subsequent level of self-awareness following rehabilitation. While post-acute self-awareness is predicted by non-specific executive measures, the cognitive improvement putatively induced by neuropsychological rehabilitation reveals the contribution of more specific executive and memory functions. Importantly, pre-rehabilitation verbal fluency scores predicted the level of self-awareness after cognitive rehabilitation.

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Introduction

Impaired self-awareness (SA) is a frequent alteration after suffering Acquired Brain Injury (ABI). SA refers to the ability to actively become the object of one's attention, being aware of one's thoughts, feeling and mental states (Keenan et al., 2003; Morin, 2006). Impaired SA can be defined as a lack of ability to reflect on the condition of the disease, its consequences and the implications of such deficits for daily functions (Cheng & Man, 2006). It may involve many different functions, including motor, social judgment, behavioural and overall level of functional competency in everyday life (Prigatano, 2010), problems that also lead to increased caregiver burdens (Prigatano et al., 2005). A main aspect of SA deficits is the lack of awareness regarding cognitive function, which is usually known as "metacognition" (Zimmermann et al., 2017) or metacognitive knowledge (declarative knowledge). This aspect is related with discernment about one's abilities (which incorporates elements of intellectual awareness, considering *The Pyramid Model of SA*) (Crosson et al., 1989), in contrast to the online monitoring of performance during tasks (which relates to emergent awareness and anticipatory awareness) (Toglia & Kirk, 2000). Metacognition can be understood as one's own knowledge, in terms of the ability to monitor and control self-cognitive processing (Fernandez-Duque et al., 2000).

Patients with SA disorders experience difficulties in engaging in rehabilitation. They tend to show low motivation and poor acceptance of compensatory strategies (Winkens et al., 2014) that may finally lead to difficulties in achieving and maintaining productive and independent living (Hurst et al., 2018). Consequently, clinical research has devoted increasing attention to the development of ABI rehabilitation programs which include interventions on SA, with some promising results (Fleming & Ownsworth, 2006; Leung & Liu, 2011; Lucas & Fleming, 2005; Schrijnemaekers et al., 2014; Villalobos et al., 2018; see also Villalobos et al., 2020). Indeed, intervention-induced enhancements in SA have been associated with improvement in patients' functionality in daily activities (Engel et al., 2017; Villalobos et al., 2019).

Recent research has focused on exploring relationships between SA and specific cognitive functions. Metacognition is assumed to involve both knowledge and regulation of cognitive activity, including monitoring and cognitive control processes (O'Leary & Sloutsky, 2019). Thus metacognition implies knowledge from the present and the past, allowing planning about the future, with evident contributions from episodic memory. An adequate metacognitive functioning requires precise and adjusted memory skills that keep the information about past experiences and capabilities updated. A few studies have explored the relationship between SA and episodic memory, suggesting a positive association between SA and the amount of words remembered in a verbal learning task in a delayed free recall (Noé et al., 2005; Zimmermann et al., 2017).

Metacognition is also assumed to be closely linked to executive functions, to such an extent that some authors have considered the "metacognitive" aspect of executive functions different from the "emotional" aspect of them (Ardila, 2008; Stuss, 2011). In this view, metacognitive executive functions are those related with the ability to monitor and control the information processing required for voluntary and goal-directed behaviour (Tate et al., 2014). Hart et al. (2005) found a significant correlation between the level of SA and a global measure of executive functions (a composite score which included attentional control, working memory updating, set shifting, response inhibition and generativity/fluency) in patients with traumatic brain injury. Similar results have been reported when considering key executive measures (i.e., *number of categories completed* and *perseverative responses*) provided by the Wisconsin Card Sorting Test (WCST) (Bivona et al., 2008, 2019; Ciurli et al., 2010) or abstract reasoning, measured trough the Matrix Reasoning subtest from the Wechsler Adult Intelligence Scale-III and the Abstraction subtest from the Shipley's Institute of Living Scale (Chiou et al., 2011).

Finally, some studies have used regression analysis to characterize the predictive value of both executive functions and episodic memory to SA. In an early study, Bogod et al. (2003) identified working memory and inhibition, as measured by Go/no-go and Stroop tasks, as good predictors of the level of SA. More recent research looking at a wider range of executive functions has only found cognitive flexibility and inhibition (Noé et al., 2005), working memory (Morton & Barker, 2010) and verbal fluency (Zimmermann et al., 2017) as significant predictors of SA.

In addition to cognitive functions, other variables such as demographic and clinical characteristics have been proposed as important contributors to the level of SA. Patients in whose case more time has elapsed after injury (Caldwell et al., 2014), those with less severe lesion (Morton & Barker, 2010; Zimmermann et al., 2017), as well as older patients (Zimmermann et al., 2017), have been reported to exhibit higher levels of SA. Notwithstanding, these, other reports have failed to find any cognitive or clinical measure as significant predictor of SA, though the high severity and chronicity of participants in that study might have affected the predictive capacity of the analyses (Belchev et al., 2017).

All in all, studies looking at potential contributors to SA have identified episodic memory and, particularly, executive functions as key predictors of SA in patients who have suffered an ABI. Yet, whether cognitive rehabilitation may be associated with changes in the predictive value of some of these variables, is an issue that remains unexplored. Indeed, variations at the moment of assessment of patients (i.e., at admission versus discharge from the rehabilitation process) may account for some of the inconsistencies in the literature reviewed here. But more important from an applied point of view is the question of whether certain cognitive and clinical variables, measured at the time of admission of the patient, may predict their level of SA at discharge. If this were to be the case, identifying these factors may contribute to the development of more precise interventions on SA, for the benefit of the patient.

Consequently, the purpose of this study is two-fold. First, we aimed to replicate previous findings showing the predictive value of episodic memory and executive functions to the level of SA. Moreover, we attempted to characterize potential changes in the predictive value of these functions to SA, from the moment of admission to discharge, putatively induced by cognitive rehabilitation. And second, we aimed to identify those executive and memory measures at admission that, along with demographic and clinical factors, best predict the level of SA following the cognitive rehabilitation process.

Methods

Participants

The sample in the study consisted of 69 patients (44 men and 25 women) over 16 years old (mean age: 42.3 years, standard deviation: 11.57, range from 17 to 56 years), and a mean educational level of 12.6 years (standard deviation: 3.79), admitted on a residential basis in the National Center for Brain Injury Treatment in Madrid, Spain, from January 2018 to July 2019. Their time since injury ranged from 53 to 379 days, with a mean of 173.9 days (standard deviation: 71.3). Patients were recruited according to the following inclusion criteria: (a) Age older than 16; (b) Diagnosis of moderate/severe ABI. Although in some cases the Glasgow Coma Scale (GCS) score was not available, all patients manifested important deficits and difficulties at motor, cognitive, behavioural or emotional levels during their initial assessment; (c) medically stable; (d) absence of relevant speech disturbances; (e) ability to actively participate in an integrative rehabilitation process.

The etiology of brain injury included traumatic brain injury ($n = 18$), stroke ($n = 38$), brain tumour ($n = 7$), encephalitis ($n = 5$) and other causes ($n = 1$). The centre research committee approved the study and all participants gave informed consent prior to participation.

Measures

Self-awareness measurement

We used a SA scale developed in a semi-structured interview format for a former study (Villalobos et al., 2018). According to previous studies that have raised the importance of separately assessing the awareness of the deficits and the awareness of the functional implications of such deficits (Giacino & Cicerone, 1998), this scale consisted of three main areas of assessment: Awareness of Injury, Awareness of Deficit and Awareness of Disability. The Awareness of Injury dimension (ranges from 0 to 6) is based on the clinician score on whether the patient is able to acknowledge having suffered a brain injury or not, either spontaneously or in response to the clinician's questions. The Awareness of Deficit dimension scores (ranges from 0 to 12) depends on whether the patient spontaneously refers suffering from physical, sensory and cognitive deficits, requires help or examples to recognize them or, by contrast, ignores their deficits. Finally, the Awareness of Disability dimension (ranges from 0 to 12), explores the patient's ability to currently perform a series of activities (driving, cooking dinner or lunch, doing house chores, looking after a young child, working or studying and living alone). It is scored based on whether their answers are aligned with their actual ability or not. The final score in the scale ranges from 0 to 30, the maximum score indicating full awareness of having a sustained brain injury, of its consequences and about the disability it causes (see the complete ad-hoc scale in the Supplementary Material, Annex 1). Although the scale has not yet been formally validated, a previous study has shown a high correlation with the scores provided by the Self-Awareness of Deficits Interview (SADI) (Fleming et al., 1996). This agreement with a standardized and recognized instrument for the assessment of SA suggests that the scale used in the study is able to provide a valid measure for SA in a sample of patients with ABI (Villalobos et al., 2018). Nevertheless, to further confirm a high correlation between the SA scale and the SADI in the current study, the latter was also administered during the discharge assessment of participants (see results of this correlation analysis at the corresponding section below).

Cognitive measurement

A neuropsychological battery containing the following memory and executive function tests was administered to all participants in the study:

- Hopkins Verbal Learning Test. It consists of three free-recall trials of a 12-word, semantically categorized list, followed by delayed recall (20 min) and a yes/no recognition (Brandt & Benedict, 2001). Two measures from this test were taken into account: the sum of the three trials recall (*total recall*) and the *delayed recall*.
- Digit forward, backward and sequencing span test (from the Wechsler Adult Intelligence Scale – Fourth Edition, WAIS-IV) (Wechsler, 2009). The first part provides a measure of attentional span while the second and third parts are considered related with working memory capacity.
- Verbal fluency task: phonemic (letters "f", "a" and "s") and semantic ("animals") verbal fluency. It is a traditional executive function measure related with flexibility and cognitive control processes (Lezak et al., 2012).
- Wisconsin Card Sorting Test (WCST) (Grant & Berg, 1948; Heaton et al., 1993) is one of the most widely used tests to assess executive functioning, specifically inhibition and cognitive flexibility. Specifically, we considered three measures from the brief WCST-64 version (Greve, 2003): *number of categories completed*, *percentage of errors* and *percentage of perseverative responses*.

Procedure

The patients were assessed twice. The first assessment took place upon admission to the centre and before the beginning of the rehabilitation process. The average time since injury was 164 days. The second assessment was administered days following discharge from the centre, once the rehabilitation process was over. The average length of the rehabilitation was 199 days. The neuro-rehabilitation programme was tailored to each patient's requirements and conducted in individual and group sessions/workshops, according to patients' therapeutic goals, so that an intensive neuropsychological-based rehabilitation could be offered. Sessions of 2–3 h length in total were provided 3–5 days per week, depending on patient's needs and rehabilitation goals (see Methods section in Villalobos 2018 for more details for the SA intervention programme). This cognitive intervention was coupled with other neuro-rehabilitation therapies (i.e., physiotherapy, speech therapy or occupational therapy) according to the patient's profile. Two different and experienced clinical neuropsychologists conducted the admission and discharge assessments and all tests were administered following the same order in all patients and on both occasions of assessment.

In the admission assessment, three patients were not able to perform the verbal fluency test and six patients the WCST, while in the discharge assessment, three patients did not complete the WCST. These subjects were included in the analysis, if the final adjusted model did not include such variables.

Statistical analysis

Data analysis was carried out using SPSS software (version 22). Descriptive statistics were used to illustrate the characteristics of the sample upon admission and discharge assessments. Pearson's correlation analysis were performed in order to explore the associations between SA and the neuropsychological variables. In order to evaluate the relative contributions of memory and executive measures, as well as clinical and demographic variables in the reduction of the SA level, a stepwise regression analysis was computed using SA as dependent variable and with due consideration of all neuropsychological, demographic and clinical variables (HVLT *total recall*, HVLT *delayed recall*, Digit forward, Digit backward, Digit sequencing, Verbal fluency, WCST *number of categories completed*, WCST *percentage of errors*, WCST *percentage of perseverative responses*, age, years of education and time since lesion). The model was selected on the basis of the highest explained variance (R^2) and highest cross-validity (adjusted R^2) and, when the final regression included more than one predictor, we provide fit index per each step.

This analysis was first performed on the admission measures and then on the scores at discharge. Both analyses considered the same variables so that results might be subsequently compared to in order to examine cognitive rehabilitation-induced changes. A further regression analysis was performed to explore potential variables that, at admission, were able to predict the level of SA at discharge, after the rehabilitation process (variables at admission included were: Self-awareness, HVLT *total recall*, HVLT *delayed recall*, Digit forward, Digit Backward, Digit sequencing, Verbal fluency, WCST *number of categories completed*, WCST *percentage of errors*, WCST *percentage of perseverative responses*, age, years of education and time since lesion). Accordingly, the level of SA at admission was also considered as potential predictor in order to control the individual baseline of each participant. In all the analysis, we ran a final model with the variable holds in the stepwise analysis and reported adjusted R^2. We also checked the assumptions of the model and studied residuals, in order to search for outliers or influential cases (Field, 2013; Pardo Merino & San Martín, 2010). In none of the model presented we find high residual deviations from normality, neither influence values larger than .5, Cook's distances larger than 1, nor Studentized deleted residuals larger than 3. We also checked for collinearity of predictors finding no collinearity problems (max VIF = 1.85; min tolerance = .54).

Results

Descriptive statistics for the sample including SA measurement and the neuropsychological variables of interest at admission and discharge assessment are reported in Table 1. The correlation analyses confirm that scores on the SA scale were strongly associated with scores on the SADI ($n = 69$; $r = -.914$; $p < .001$; note that, unlike SA scale, greater scores on the SADI reflect greater SA impairments).

Correlation analysis performed with measures at admission showed a significant relationship between SA and time since lesion ($r = -.281$, $p = .019$), HVLT *total recall* ($r = .527$, $p < .001$), HVLT *delayed recall* ($r = .504$, $p < .001$), Digit backward ($r = .449$, $p < .001$), verbal fluency ($r = .536$, $p < .001$) and WCST *% of perseverative responses* ($r = -.299$, $p = .017$). Additionally, it also showed a marginally significant correlation with WCST *number of categories completed* ($r = .252$, p

Table 1. Self-awareness and neuropsychological variables at admission and discharge.

	Admission		Discharge	
Variable	Mean	Standard deviation	Mean	Standard deviation
Self-awareness	21.8	6.9	25.0	5.9
HVLT *total recall*	18.3	5.9	22.4	6.7
HVLT *delayed recall*	4.6	3.5	6.6	3.8
Digit forward	9.1	2.7	8.6	1.8
Digit backward	6.9	2.3	7.4	1.6
Digit sequencing	5.9	2.2	7.4	1.7
Verbal fluency	41.6	14.9	50.1	17.0
WCST *number of categories completed*	2.3	0.9	2.5	0.9
WCST *% of errors*	33.5	16.8	26.3	16.4
WCST *% of perseverative responses*	23.6	18.0	18.5	15.6

= .047). No significant relationship emerged between SA and the other variables (see Table 2 for full information on the correlation analysis).

Correlation analysis at discharged showed a significant relationship between SA and years of education ($r = .252$, $p = .037$) and all the neuropsychological variables: HVLT *total recall* ($r = .657$, $p < .001$), HVLT *delayed recall* ($r = .658$, $p < .001$), Digit forward ($r = .376$, $p = .001$), Digit backward ($r = .414$, $p < .001$) Digit sequencing ($r = .72$, $p < .001$), verbal fluency ($r = .715$, $p < .001$), WCS *number of categories completed* ($r = .500$, $p < .001$), WCST *% of errors* ($r = -.384$, $p = .001$) and WCST *% of perseverative responses* ($r = -.536$, $p < .001$) (see Table 2). Correlation analysis performed between SA at discharge and demographic, clinical and neuropsychological variables at admission, showed a significant relationship between SA and years of education ($r = .252$, $p = .037$), time since lesion ($r = -.294$, $p = .014$), HVLT total recall ($r = .478$, $p < .001$), HVLT delayed recall ($r = .483$, $p < .001$), digit backward ($r = .424$, $p < .001$) and verbal fluency ($r = .631$, $p < .001$). No significant relation emerged between SA at discharge and the other demographic, clinical and neuropsychological variables at admission (see Table 2).

Regression analyses: neuropsychological performance and demographic and clinical variables, as predictors of self-awareness at admission and discharge

Regression model significantly predicted SA at admission and discharge. In the first case, only verbal fluency has significant contribution, F (1, 64) = 25.758; $p < .001$; adjusted $R^2 = .276$. However, for SA at discharge, apart from verbal fluency, also HVLT *delayed recall* and WCST *number of categories completed* gave significant contribution, F (3, 62) = 33.700; $p < .001$; adjusted $R^2 = .601$ (see Table 3).

Regression analyses: neuropsychological performance, demographic and clinical variables, and self-awareness at admission, as predictors of self-awareness at discharge

Regression model significantly predicted SA at discharge, considering variables at admission. SA at admission and verbal fluency made significant contributions, F (3, 63) = 58.298; $p < .001$; adjusted $R^2 = .638$ (see Table 4).

Discussion

This study examined the relationship between SA and cognitive processes, specifically episodic memory and executive functions, in patients with ABI given the association previously reported between measures of these cognitive skills and SA. In particular, we aimed to explore whether the predictive value of these cognitive variables could change across the cognitive rehabilitation process.

Table 2. Correlation analysis between self-awareness and neuropsychological variables.

Variable		Age	Years of education	Time since lesion	HVLT *total recall*	HVLT *delayed recall*	Digit forward	Digit backward	Digit sequencing	Verbal fluency	WCST *number of categories completed*	WCST *% of errors*	WCST *% of perseverative responses*
Admission													
Self-awareness	*R*	.226	.170	−.281	.527	.504	.038	.449	.192	.536	.252	−.241	−.299
	p	.061	.162	.019	<.001	<.001	.754	<.001	.123	<.001	.047	.057	.017
Discharge													
Self-awareness	*R*	.166	.252	−.158	.657	.658	.376	.414	.472	.715	.500	−.384	−.536
	p	.172	.037	.196	<.001	<.001	.001	<.001	<.001	<.001	<.001	.001	<.001
Admission													
Self-awareness (*at discharge*)	*R*	.165	.252	−.294	.478	.483	.205	.424	.154	.631	.182	−.155	−.174
	p	.175	.037	.014	<.001	<.001	.091	<.001	.216	<.001	.155	.227	.173

Table 3. Regression model statistics for self-awareness at admission and discharge.

Variable	B_0	SE	Standardized coefficients	*p*-value	Part correlation
Admission					
(Constant)	10.912	2.26		<.001	
Verbal fluency	0.261	0.05	.536	<.001	.536
Discharge*					
(Constant)	10.406	1.68		<.001	
Verbal fluency	0.144	0.037	.411	<.001	.302
HVLT *delayed recall*	0.502	0.163	.317	.003	.241
WCST *number of categories completed*	1.601	0.572	.240	.007	.219

*Models' fit information: Verbal fluency (VF): $AIC = 200.85$; $R^2 = .506$; adjusted $R^2 = .498$; VF + HVLT: $AIC = 193.32$; $R^2 = .572$; adjusted $R^2 = .558$; VF + HVLT + WCST $AIC = 184.74$; $R^2 = .620$; adjusted $R^2 = .601$.

Table 4. Regression model statistics for Self-Awareness at discharge, considering all variables at admission.

Variable	B_0	SE	Standardized coefficients	*p*-value	Part correlation
Admission					
(Constant)	8.486	1.558		.05	
Self-Awareness	0.505	0.075	.593	<.001	.501
Verbal fluency	0.130	0.037	.313	.001	.265

Models' fit information: SA: $AIC = 192.37$; $R^2 = .606$; adjusted $R^2 = .599$; SA + VF: $AIC = 182.34$; $R^2 = .648$; adjusted $R^2 = .636$.

Results from the regression analysis at admission showed a strong relation between verbal fluency, a general measure of executive function, and SA. Strikingly, this measure was identified as the only predictor of SA in patients with ABI, before engaging in a cognitive rehabilitation process. Verbal fluency is a complex task which, apart from language, involves a number of processes related to executive functioning (Kavé et al., 2011). First, appropriate words need to be activated, which requires intact lexical knowledge and retrieval mechanisms. Thereafter, executive control abilities, such as those involved in initiating responses, monitoring prior responses and inhibiting non-appropriate responses, are required for selecting words from the activated set of items (Fischer-Baum et al., 2016). Thus verbal fluency is commonly considered a global task, which assesses a wide range of different executive function processes.

The regression analysis on data from the same set of patients at the moment of discharge from the rehabilitation process also identified verbal fluency as the most important predictor of SA. Interestingly, other cognitive measures such as *number of categories completed* in the WCST and *delayed recall* in the HVLT also appear as relevant predictors. The *number of categories completed* in the WCST is considered a good measure of executive function, especially cognitive flexibility, which has been previously reported as strongly related to SA (Bivona et al., 2008, 2019; Ciurli et al., 2010; Noé et al., 2005). On the other hand, *delayed recall* in the HVLT provides a measure of the ability to store and retrieve information in long-term memory. Previous studies have found memory skills related to the level of SA (Noé et al., 2005; Zimmermann et al., 2017). Indeed, the ability to hold episodic information has been proposed to play a major role in achieving a functional level of SA (Mograbi et al., 2009). In this view, patients who display difficulties at consolidating and recalling recent information about themselves, would experience problems in updating and maintaining knowledge regarding physical and functional changes that follow ABI. These problems would in turn affect the patients' ability to achieve and maintain an adjusted representation of their deficits and capacities (see Morris & Mograbi, 2013, for a review).

Previous studies have identified either executive function as the sole cognitive process related to SA (Bivona et al., 2008, 2019; Bogod et al., 2003; Ciurli et al., 2010; Hart et al., 2005; Morton & Barker, 2010) or both executive function and episodic memory as key predictors of SA in patients with ABI (Noé et al., 2005; Zimmermann et al., 2017). Still, Zimmermann et al. (2017) found these two predictors in independent regression analyses, considering only either executive function or mnemonic predictors. Therefore, only one study has identified both executive function and episodic memory in the same analysis, as significant predictors of SA. A closer look at the samples' characteristics in these previous studies suggests that these discrepancies may be related to the moment at which patients were assessed. While some studies were conducted based on data from patients who did not receive cognitive rehabilitation (or it was not specified) (Hart et al., 2005; Morton & Barker, 2010; Zimmermann et al., 2017), others considered samples that were at different stages of a cognitive rehabilitation program at the moment of assessment (Bivona et al., 2008, 2019; Bogod et al., 2003; Ciurli et al., 2010; Noé et al., 2005). According to this rationale, results from our regression analysis on the neuropsychological data before rehabilitation only showed a non-specific executive measure, verbal fluency, as a significant predictor. The same analysis on the post-rehabilitation data from the same patients revealed also the contribution of a more specific executive measure, which reflects cognitive flexibility, as well as episodic memory to a lesser extent (Noé et al., 2005).

Post-acute phases of ABI are accompanied by a severe impairment that globally affects the cognitive status of the patient. This overall impairment affects those executive and memory capacities involved in SA, as suggested by the correlation analysis, and seems to limit their contribution to the latter, at these early stages, so that only the one with higher correlation can predict the level of SA. Cognitive rehabilitation is able to alleviate this global impairment by putatively enhancing the executive and memory capacities of the patient (Miller & Radford, 2014; Spikman et al., 2010; for a review, see Cicerone et al., 2019). Our results suggest that once these capacities have raised an adequate level of functioning, its contribution to SA would become observable. Indeed, neuropsychological data at discharge not only showed an executive and mnemonic improvement but also an enhancement in the level of SA. Still, our results are inconclusive on supporting the idea that cognitive rehabilitation is the key factor for improving those capacities to the level of making their contribution observable. Instead, it is also possible that the mere passage of time between assessments, and an associated spontaneous recovery to some extent, would better explain these changes. Despite of this caution, applied research has demonstrated that cognitive rehabilitation in ABI patients can induce cognitive improvements as well as functional reorganization of brain networks. Indeed, these two levels of change correlate one to each other, suggesting that they are actually related and influenced by cognitive rehabilitation (Castellanos et al., 2010; Turner-Stokes, 2008). Of importance for our results, one of those studies (Castellanos et al., 2010) has shown that verbal fluency improvements after rehabilitation negatively correlate with decrements in delta band-based functional connectivity, which is considered a sign of brain pathology (Murias et al., 2007; Stam et al., 2006). Furthermore, it also showed that increases in beta band-based connectivity following cognitive rehabilitation, along with reductions on connectivity in the theta band, are associated with higher independency in daily living activities, a very good index of cognitive and functional recovery. At the light of this previous evidence, it seems reasonable to think that cognitive rehabilitation is likely to play an important role on the change of executive function and episodic memory as contributors to the level of SA.

But one of the main objectives in this study was to identify the cognitive and psychological variables, measured at admission, which are able to predict the level of SA, once the cognitive rehabilitation process had been completed. Predictably, SA at admission clearly predicted the level of SA at discharge, so that patients with better SA were those who showed higher levels of SA at discharge. More interestingly, our results confirmed that, in addition to it, a concrete cognitive measure was able to predict the level of SA after the rehabilitation process. In particular, and in accordance with results from our regression analysis on data at admission, verbal fluency appeared to be a significant predictor. As previously commented, verbal fluency may be considered a not very specific measure of executive function. Nevertheless, it offers a good impression of the global cognitive status of patients with ABI. Verbal fluency (phonemic and semantic) is extensively used since it provides a sensitive measure in ABI population (Henry & Crawford, 2004; Zakzanis et al., 2013), as well as it does in other neurological disorders (McDonnell et al., 2019). It is sub-served by different cognitive strategies, including word clustering that reflects the semantic organization of memory and an executive component that allows the strategic search of those semantic/phonological clusters, its monitoring and the flexible switch from one to other clusters (Kavé et al., 2011).

Our results suggest that before rehabilitation, best predictors of post-rehabilitation SA, apart from the baseline level of SA, are non-specific executive measures (i.e., verbal fluency) that however are representative of the general cognitive status of the patient. This finding is particularly interesting from an applied point of view, since it suggests that an accessible and easy-to-administer neuropsychological measure is informative of the cognitive status of the patient. Also important, this measure may provide information about the outcome of the rehabilitation process in terms of metacognition. However, information extracted from verbal fluency performance needs to be taken with caution since, like most of cognitive measures, is influenced by other factors such as education (Olabarrieta-Landa et al., 2015) or even genetics (Taporoski et al., 2019). Also in this regard, the relatively limited sample size (although fairly large in the context of acquired brain injury) might have made difficult to identify smaller potential contributions from other variables included in the analysis (Field, 2013). Nevertheless, previous studies exploring the predictive value of neuropsychological variables to SA have identified only large or moderate effects (Bogod et al., 2003; Zimmermann et al., 2017), suggesting that the present sample size may be appropriate to the objectives of the study. Also in this vein it is important to consider that only few executive and episodic memory measures have been included in the analysis and that subsequent studies might contribute to potentially identify differential contributions of specific executive and/or episodic memory abilities by including a more not an extensive assessment.

In any case, our results are consistent with the Dynamic Comprehensive Model of Awareness proposed by Toglia and Kirk (2000), which considers metacognition and awareness as a dynamic process, rather than as a result of a series of hierarchical levels. Thus, monitoring and flexibility (executive functions), and recalling knowledge regarding physical and functional changes that follow ABI (episodic memory) would contribute to SA to a different extent.

Strikingly, although some of the demographic or clinical variable included in the analysis (age, years of education and time since injury) showed a significant correlation with SA level, they did not predict post-rehabilitation SA. In this sense, our results differed from previous studies which have related SA with time elapsed since injury (Caldwell et al., 2014), lesion severity (Morton & Barker, 2010; Zimmermann et al., 2017) and age (Zimmermann et al., 2017). Still, they are in line with the findings from a recent study by (Belchev et al., 2017), who did not find this predictive relation either. Again, these discrepancies may be associated with whether the participants were undergoing a cognitive rehabilitation or not (Caldwell et al., 2014; Morton & Barker, 2010; Zimmermann et al., 2017), and even the stage of the rehabilitation they were assessed at. For our particular sample though, we did not find age, years of education or time elapsed since injury predicting the level of SA, even when we performed these analyses before and following the rehabilitation processes. Despite this, the finding requires to be explored more in-depth in further studies by extending the clinical and demographic assessment to include mood state measures of social support features that might potentially has a contribution. Nevertheless, if confirmed, these results would suggest that variables that cannot be affected by rehabilitation have limited impact on the potential SA improvement. Rather, the executive function (as measured by verbal fluency), which may actually improve by cognitive rehabilitation (Poulin et al., 2017; Tornås et al., 2019), would be the one that plays the most critical role in the SA status of a patient with ABI.

The inclusion of a variety of brain injury etiologies should be pondered when considering these results. On the one hand, including most frequent etiologies (e.g., traumatic brain injury or stroke) may make the results more generalizable to the most common profiles of patients who receive cognitive rehabilitation; on the other, a mixed sample prevents us from investigating whether different etiologies may present different profiles in the predictive measures for the level of SA. Thus further research should seek to explore predictors of SA in homogeneous samples with different etiologies of ABI. In a similar vein, our sample consisted of ABI patients with different degrees of injury severity (severe and moderate). Although this allows to derive more general conclusions, it would be very interesting to investigate whether different levels of severity are related to differences in the predictive value of cognitive variables to SA. Also important, the precise contribution of cognitive rehabilitation to the change observed in the cognitive predictors of SA cannot be completely unraveled without the inclusion of a control group. This approach would have required to enroll ABI patients who would have not received any sort of rehabilitation for about 72–400 days. Even though this procedure would have provided substantial information on the precise effect of cognitive rehabilitation, it would have also prevented those patients from participating in a treatment that has been proven beneficial, purely for experimental reason, which undoubtedly raises ethical concerns (World Medical Association, 2013). A final limitation is in regard with the SA dimension considered in the study, namely, the metacognitive or intellectual dimension. Consider the emergent and anticipatory dimensions (Crosson et al., 1989), more related with the online awareness (Toglia & Kirk, 2000), could offer in subsequent research a more comprehensive view of the predictive value of cognitive status in SA level of ABI patients. Taking into account these limitations, as well as previous evidence on the effect of cognitive rehabilitation on brain functional reorganization and on cognitive improvements, our results are still informative at considering the putative role of cognitive rehabilitation on the reported changes.

In conclusion, this study replicates previous findings that highlighted the predictive value of executive functions to the level of SA, with minor contribution of episodic memory. More importantly, performing regression analysis in the same group of patients at two different moments, at admission and after the cognitive rehabilitation, shed light on the differential contribution between these two sets of cognitive measures to the level of SA at different stages of the patient with ABI. In addition, this study shows that a global executive measure (i.e., verbal fluency) at admission is able to predict the level of SA at discharge, once the cognitive rehabilitation is over.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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