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The criterion-related validity of the *IADL Profile* with measures of executive functions, indices of trauma severity and sociodemographic characteristics

CAROLINA BOTTARI[1,2], CLÉMENT DASSA[3,4], CONSTANT RAINVILLE[2,5], & ÉLISABETH DUTIL[1,2]

[1]*École de réadaptation, Université de Montréal, Montréal, Canada,* [2]*Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain (CRIR), Montréal, Canada,* [3]*Département de Médecine sociale et préventive, Université de Montréal, Montréal, Canada,* [4]*Groupe de recherche interdisciplinaire en santé, Montréal, Canada, and* [5]*Département de psychologie, Université de Montréal, Montréal, Canada*

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Abstract

Primary objective: To examine relationships between classical measures of executive functions (EF) and indices of traumatic brain injury (TBI) severity with the *IADL Profile*, a new performance-based measure of independence in instrumental activities of daily living (IADL) based on EF. This study hypothesized the presence of correlations between classical tests of EF and the *IADL Profile*, as the latter aims to establish whether the subject's main difficulties pertain to goal formulation, planning, carrying out the task and/or attaining the initial task goal; all important components of EF.

Methods and procedures: One hundred subjects with a moderate/severe TBI aged 16–65 years (convenience sample) were recruited. Subjects were tested with the *IADL Profile* and three measures of EF within their home environment. Data was analysed using Pearson correlations, *t*-tests and multiple stepwise regressions.

Results: Post-traumatic amnesia and working memory emerged as the major determinants of *IADL Profile* scores. Together, indices of injury severity, measures of EF, education, age and environmental factors accounted for 12–28% of the variance in *IADL Profile* scores.

Conclusions: This study has shown that the *IADL Profile*'s non-structured approach permits the observation of a broad range of behaviours related to EF deficits and thus provides a closer approximation of the person's independence in IADL. Further study is required to demonstrate the *IADL Profile*'s ability to inform more targeted treatment interventions.

Keywords: *Brain injuries, activities of daily living, psychometrics, home visits, executive processes*

Introduction

Up to 80% of individuals having sustained a moderate or severe traumatic brain injury (TBI) require long-term assistance in one or more tasks of everyday living [1]. Executive function (EF) deficits are thought to be an important cause of this need for assistance [2–5]. However, little is known about exactly how cognitive deficits and especially EF deficits interact to cause dysfunctions in instrumental activities of daily living (IADL). EF deficits are known to be more severe in novel and complex tasks [6], in poorly structured tasks [7] and in the presence of distracting stimuli in complex and dynamic environments (natural contexts) [8, 9]. Lezak et al. [4], based on the seminal work of Luria [10], suggests that EF can be conceptualized as consisting of four main components: (1) volition; (2) planning; (3) purposive action and (4)

Correspondence: Carolina Bottari, PhD, OT, McGill University, Department of Neurology and Neurosurgery, Neuropsychology, Cognitive Neuroscience Unit, Montreal Neurological Institute and Hospital, Room 276, 3801 University, Montreal, Quebec, Canada H3A 2B4. Tel: 514-398-2993. E-mail: carolina.bottari@mcgill.ca

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effective performance. EF deficits are at times overtly apparent (e.g. defective self-control or self-direction such as rigidity or difficulty in making shifts in ongoing behaviour) or more subtle (e.g. impaired capacity to initiate activity or to plan the activity sequences related to goal-directed behaviour) [4]. Identifying the stage at which breakdown in executive behaviour occurs (e.g. goal formulation, planning, purposive action, effective performance) during task performance is crucial for the identification of targeted treatment interventions [4, 11, 12]. However, most IADL assessments have serious limitations, as they outrightly fail to consider EF deficits, despite the latter's fundamental importance to IADL independence [13].

The present study expands on previous work on the *ADL Profile* [14, 15], an analytic measure of independence in activities of daily living (ADL) that also documents the repercussions of EF deficits on ADL and IADL, as the criterion-related validity of an alternate version of this test, the *IADL Profile* [16, 17] was examined. The *IADL Profile* is a performance-based test of IADL independence administered in a subject's home and community environment that aims to establish whether the subject's main difficulties pertain to goal formulation, planning, carrying out the task and/or attaining the initial task goal; all important components of EF. It is not explicitly the goal of the *IADL Profile* to measure EF. At best, through its observational measure of independence in consideration of EF, it contributes to the understanding of the impact of EF deficits on independence.

The *IADL Profile* [17] includes eight tasks with elements of complexity and novelty, six of which are linked to the overarching goal of receiving guests for a meal (putting on outdoor clothing, going to the grocery store, shopping for groceries, preparing a hot meal for guests, having a meal with guests, cleaning up after the meal) and two of which are single complex tasks (obtaining information and making a budget). In order to maximize the possibility of observing EF deficits and their repercussion on task performance, examinees receive minimally-structured instructions, i.e. examinees are largely left to formulate goals and sub-goals and plan and initiate relevant tasks. It was expected that this approach would permit the observation of a broader range of behaviours related to EF deficits than that which has been previously reported, as in most similar studies (see [8]) the examiner formulates task goals, provides task material and thus removes the possibility of observing deficits that are of crucial importance to the individual's independence. Task performance is analysed according to four underlying operations related to EF, i.e. goal formulation, planning, carrying out the task and verifying attainment of the initial goal. Each operation is then scored using a five-level ordinal scale of independence (dependence, verbal and physical assistance, verbal or physical assistance, independence with difficulty and independence). According to an international multidisciplinary group of experts (content validity), the tool was judged to be clear and pertinent to its intended goal [18]. A high percentage of generalizability coefficients of item scores (80%) indicated acceptable agreement between raters [16]. Internal consistency of the total scale was very high ($\alpha = 0.95$). Exploratory and confirmatory factor analyses ($n = 100$) disclosed six correlated factors linked to the tasks of the tool (going to the grocery store/shopping for groceries; having a meal/cleaning up; putting on outdoor clothing; obtaining information; making a budget; preparing a hot meal for unexpected guests). The total explained variance was 73.6% [19].

The potential contribution of IADL task performance analysis as a means of better understanding the repercussions of EF deficits on everyday activities in TBI has gained recent attention in the literature. For instance, results obtained by Chevignard et al. (2000) confirmed that script execution (or observation of task performance when shopping for groceries, cooking and answering a letter and finding the way to post the reply) in individuals with a dysexecutive syndrome ($n = 11$) is a valid ecological approach to estimate the severity of planning deficits in daily life activities [20]. Similarly, Fortin et al. [21] confirmed that individuals with mild-to-severe TBI ($n = 10$) with frontal lobe lesions manifested marked anomalies during the performance of a meal preparation task; the latter were deemed indicative of an outstanding deficit in strategic planning and prospective memory, important underpinnings of reduced IADL performance. However, these studies failed to use validated tests of IADL with evidence of satisfactory psychometric properties. Information is therefore lacking regarding the stability of the tool over time (test–re-test reliability), its stability over different raters (inter-rater reliability) and its ability to measure that which it purports to measure (validity).

Studies examining the relationships between ecological measures of EF and classical tests of EF have largely failed to show significant correlations between the two types of measures in individuals with a TBI. For instance, studies with the Multiple Errands test (MET) [5], an IADL type task used to measure planning deficits whose psychometric properties have recently begun to be established, failed to find significant correlations between the Tower of London (ToL), a classical measure of planning, and a hospital version of the MET [22]. Le Thiec et al. [7], based on 12 severe TBI, found six to be impaired

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on both neuropsychological measures of EF and the MET, five to be impaired on the MET but not on neuropsychological measures of EF and only one to be impaired on neuropsychological measures of EF and not on the MET. Overall, significantly more errors were evident in the MET than in the ToL, suggesting that an ecological measure of performance in complex IADL tasks may provide a more precise indication of executive deficits in everyday activities. The current study was intended to examine similar relationships between classical measures of EF and the *IADL Profile* with a much larger ($n = 100$) sample of subjects.

The goal of the present study was to investigate the *IADL Profile*'s criterion validity in relation to classical measures of EF. It examined the relationship between *IADL Profile* scores and three measures of EF that were selected to better capture unique EF related to planning, inhibition and working memory, i.e. ToL [23], Stroop [24, 25] and Working Memory Index (WMI) of the Weschler Memory Scale-III (WMS III) [26]. As the *IADL Profile* is a new tool that uses a testing approach which differs from classical tests of EF (classical tests use a directive approach to measurement in a controlled environmental setting, where as the *IADL Profile* is administered within a real-world environment using a non-structured approach), the hypotheses regarding expected correlations with measures of EF were modest.

Though EF deficits are expected to contribute to loss of IADL independence in brain-lesioned patients, a number of other variables also needed to be considered. For instance, a number of studies have shown injury severity, pre- and post-injury level of education and various environmental factors to influence outcome. Duration of post-traumatic amnesia (PTA) [27–30], Glasgow Coma Scale (GCS) score and length of coma [27–29, 31, 32] have been linked to reduced levels of independence; coma duration alone was shown to be a good predictor for more severe injuries only [33]. Increasing age [34] and the female gender [29] have been associated to generally poorer outcomes [31], though age has been shown to not be independently predictive [35]. Environmental factors, such as needing a special bus to take short trips or needing aids to enter or leave their residence have also been associated with lower levels of participation in IADL [21]. Hence, an alternate goal of the present study was to investigate the *IADL Profile*'s criterion validity in relation to measures of injury severity (GCS score, duration of PTA, coma duration), age, sex and environmental factors such as rural vs urban living environment and distance between the subject's home and the nearest grocery store. It was hypothesized that more severe TBI would be associated to a greater need of assistance in IADL tasks, that more years of education would be linked to greater independence and that living at a greater distance from the grocery store would be associated to a greater need of assistance in a task such as shopping.

Overall, in consideration of all the variables included in this study, it was hypothesized that independence in IADL would be best explained by injury severity (PTA, GCS score and coma duration), followed by measures of EF (ToL, WMI and Stroop), socio-demographic characteristics (education, age) and, finally, by environmental factors (distance between the subject's home and the nearest grocery store).

Methods

Participants

One-hundred subjects were recruited from 12 post-acute TBI programmes in the province of Quebec. Inclusion criteria were: patient age between 16–65 years, moderate or severe TBI and proficiency in French. The severity of the TBI was estimated with the Glasgow Coma Scale (GCS) (GCS score ≤ 8 = severe; GCS score 9–12 = moderate) [35] and duration of post-traumatic amnesia (1–14 days = moderate; several weeks = severe). Although subjects with a GCS score between 13–15 are generally considered to have had a mild TBI, those with a confirmed cerebral lesion were considered to have had a moderate TBI. Exclusion criteria were: disorientation (i.e. score of 65 or less on the Galveston Orientation and Amnesia Test [36]), severe mobility deficits (score <3 on the transfer item of the Functional Independence Measure, FIM [37]), severe language deficits (score <4 on the communication item of the FIM) and history of hospitalization for psychiatric disorders. Prior to the evaluation, subjects were given verbal and written information on the study and signed statements of informed consent. Subjects were informed that they were free to withdraw from the study at any time. The study was approved by the institutional review boards of participating centres.

Trauma severity

- *The Glasgow Coma Scale (GCS)* [36] is an internationally recognized criterion measurement of TBI injury severity [38]. The GCS is a measure of level of consciousness. Three indicators of level of consciousness have been retained: eye opening, best motor response and verbal response. The

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total score varies from 3–15, with a score of 3 being associated to the most severe injuries.

- *Coma length*: According to Jennett and Teasdale [39], altered consciousness is the most consistent indicator of brain damage. These authors define coma as 'not obeying commands, not uttering words, and not opening eyes' (p. 80). A patient who fails to meet anyone of these three components is regarded as not being in a coma. Coma has also been defined as a pathological state of profound and sustained unconsciousness [40]. According to Levin et al. [41] and cited in Lezak et al. [4], coma has been defined as occurring when the GCS score is less than or equal to 8 in patients without spontaneous eye opening, ability to obey commands or comprehensible speech.
- *Post-traumatic amnesia* (PTA) is a criterion for severity of brain injury [42]. It is defined by some as the time of injury to when the patient resumes 'continuous memory' [43], including the time in which the person is in a coma. Others suggest that the beginning of PTA should only be considered once the person is out of a coma [44]. PTA varies from minutes to months, typically lasts about four times the length of coma [45] and is considered one of the best predictors of outcome following TBI [42, 46]. PTA is frequently documented using prospective measures such as the Galveston Orientation and Amnesia Test [36]. Based on this measure of orientation, a client who obtains three consecutive daily scores of 75 or greater is considered to be out of PTA.

Executive functions

Although a wide variety of measures of EF are present in the literature, three measures were selected for use in this study: the Stroop, the ToL and the WMI. These measures were carefully selected to better capture unique EF (inhibition, planning and working memory). All three measures are gold standards in the literature and have been extensively used to measure different aspects of EF [47–52]. Strong evidence of psychometric properties has been documented and validated French translations were available at the time of the study [4, 5, 23, 53, 54].

Stroop colour and word test. The Stroop [25, 53], more specifically the Stroop interference measure, is used as a measure of inhibition, i.e. it documents the extent to which a person can inhibit the strongly ingrained habitual response of reading in order to name the colour in which a word is written. This deliberate, controlled suppression of prepotent responses is commonly labelled as an EF linked to the frontal lobes [55]. In the present study, a French translation and adaptation of the Golden version of the test was used [56] as it is one of the versions with the most thoroughly documented psychometric properties [57]. This version of the Stroop consists of three sub-tasks; a word reading test, a colour naming test and a colour word naming test. The person is instructed to read as many words or to say as many colours as possible within a time limit of 45 seconds. The Golden version produces an interference score that measures the inhibition component. According to MacLeod [48] the interference score is the most prevalent manner in which this test is scored.

Tower of London. The Tower of London (ToL) test [23] was developed to identify deficits of planning in individuals with frontal lobe lesions. The test consists of 12 problems (reproduction of a model according to specific rules) of graded difficulty ranging from two to five moves. The task requires that the subject look ahead to determine the order of moves necessary to rearrange three coloured balls from their initial position on three pegs of different heights, to a new set of pre-determined positions on the three pegs. A problem is scored correct if the solution is achieved within the minimum number of moves necessary, rules are not broken and the solution is attained within 60 seconds. Results are summarized in terms of the number of problems correctly answered on the first trial.

The Working Memory Index of the Weschler Memory Scale–III. The Weschler Memory Scale (WMS) is said to be the most widely used and most recognizable memory battery [4]. The Weschler Memory Scale–III (WMS III) [26] consists of eight indexes, only one of which, the Working Memory Index (WMI), was used in the present study as a measure of working memory. The WMI is made up of two primary sub-tests, the Letter-Number Sequencing and the Spatial Span sub-tests. In the Letter-Number Sequencing sub-test, subjects hear lists of randomized numbers and letters (in alternating order) of increasing lengths (from two to eight units). Subjects are then asked to separately repeat numbers and letters from the lowest to the highest in each series; numbers must always be given first. In the Spatial Span sub-test, subjects must reproduce a sequence of blocks identified by the examiner, first in a direct order and then in a reverse order. Raw scores of the Letter-Number Sequencing sub-test range between 0–21 and between 0–32 for the Spatial Span sub-test. These scores are then

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transformed into scaled scores corrected for age, which are then converted into a WMI score. These scores range from 49–155.

Procedure

Research assistants trained and supervized by a qualified neuropsychologist administered three measures of EF to the subjects ($n = 100$). Neuropsychological testing lasted between 45 minutes and 1 hour and took place in subjects' homes. The order of testing was constant in all cases with the neuropsychological tests administered first, immediately followed by the *IADL Profile*. All tests were administered on the same day. The occupational therapist who administered the *IADL Profile* was blind to neuropsychological testing results. Information regarding trauma severity was extracted from health records at the time of injury.

Data analysis

Criterion-related validation is defined as the study of the relationship between test scores and a practical performance criterion [58]. To address the objective of criterion-related validation, measures of relationships (Pearson's correlations) and comparison of means (*t*-tests) were examined between scores obtained on the *IADL Profile* (factor and total scores) and concomitant variables related to injury severity (GCS, PTA and coma length), demographic characteristics (age, gender, level of education) and evaluation environment (distance to grocery store, urban/rural).

Concurrent validity, a type of criterion-related validation, refers to the relationship between test scores and a criterion measurement made at the time the test was given [58]. In this study, scores obtained on the *IADL Profile* were compared using Pearson's correlation coefficient for continuous measures, with scores obtained on EF measures of inhibition (Stroop), planning (ToL) and working memory (WMI). Pearson's correlation coefficients are a measure of the degree of linear relationship between two sets of observations. The magnitude of the number represents the strength of the relationship between the two variables and the sign of the number indicates the positive or negative direction of the relationship [58].

Next, for each of the variables of interest (e.g. age, gender, level of education, trauma severity, measures of EF) independent sample *t*-tests were conducted to further validate results obtained with correlations. The mean *IADL Profile* total score of two subgroups, that is the 20 subjects with the highest independence scores and the 20 subjects with the lowest independence scores, were compared with the mean of these same subjects on all variables of interest. As these *t*-tests focused on contrasting the highest and lowest ends of independence with variables of interest, they provided information that was complementary to that obtained with correlations, which are measures of relationship based on whole sample data.

Ultimately, as a final means of verifying the criterion-related validity of *IADL Profile* scores with the independent variables of interest, significantly correlated independent variables ($p \pm 0.05$, two-tailed test) were entered in a stepwise regression analysis with p to enter set at 0.05 and p to exit set at 0.06. Analysis was performed using SPSS regression. The assumptions were checked using SPSS frequencies and SPSS graphs. Results of testing the assumptions led to the identification of outliers that can cause spurious associations, attenuated associations or heteroscedasticity (i.e. non-constant variance of the independent variable around the regression line). Each outlier was analysed on an individual basis and in nearly all cases was removed with theoretical justification. For each dependent variable (six factor scores and one total score), independent variables were entered according to the strength of the correlations with the dependent variable, from the strongest to the weakest correlation. Once stepwise regression was done, for completion, sequential multiple regressions were attempted using a prespecified order of entry of our independent variables, based on the hypotheses. Here, we attempted to enter any significantly correlated trauma severity variables first, followed by measures of EF and then sociodemographic variables. However, due to the large number of missing values for PTA and coma length, this approach resulted in sample size falling below the minimum acceptable number of subjects ($n = 30$) and hence no analysis with this order of variables could be performed. Finally, sequential multiple regressions were done forcing the entry of ToL prior to WMI for Factors 4 (obtaining information), 5 (making a budget) and 6 (preparing a hot meal) as the *IADL Profile* was developed with a particular emphasis on documenting deficits in planning ability. For simplicity, only the best models will be presented.

Results

Participant characteristics

Sociodemographic and clinical characteristics are depicted in Table I. As illustrated, the average age of the subjects was 37.0 years and the majority were male (78%). Sixty-nine per cent had a severe TBI and the average time post-injury was 14.2 months. Although nearly 20% of subjects had GCS scores between 13–15, 96% of all subjects had a

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Table I. Description of sample ($n = 100$).

Variable	Values
Age (years)	37.0 ± 13.7
Gender, % male	78%
Education (years)	11.6 ± 3.4
TBI severity, %	
Severe	69%
Moderate	31%
Glasgow Coma Score at emergency ($n = 96$)	
3–8	63.5%
9–12	16.7%
13–15	19.8%
Positive scan	96.0%
Post-traumatic amnesia (days) ($n = 72$)	29.0 ± 32.0
Less than 1 day	6.8%
Between 1 and 14 days	27.4%
Greater than 14 days	63.0%
Coma duration % ($n = 61$)	
No coma	41.0% (25)
2–7 days	14.8% (9)
8–14 days	16.4% (10)
>14 days	27.9% (17)
Cause of TBI	
Motor vehicle accident	61%
Pedestrian accident	16%
Falls	6%
Work accident	5%
Sports injury	5%
Other	7%
Time post-injury (months)	14.2 ± 13.6
Mobility outdoors, %	
Walked with/without orthosis	78%
Walked with a cane or walker	14%
Used a wheelchair	8%

Note: Values are mean ± standard deviation (SD) unless otherwise indicated.

positive scan. The mean GCS score at emergency was 7.7 (range 3–15). The mean number of days of PTA was 29 ± 32.0 days. The mean duration of coma was 11.2 ± 17.6 days. For variables whose distributions were not normally distributed (PTA, coma score, time post-injury), outliers were removed to examine correlations with other variables so as to reduce the likelihood of spurious correlations. The mean number of years of education was 11.6 (±3.4) years. At the time of the assessment, 41% were on a medical leave of absence from their work, 22% were undergoing a work assessment, 16% had been declared unemployable and 12% were working (either full or part time).

IADL Profile

Results obtained with the *IADL Profile* show that the easiest tasks overall were having a meal, cleaning up and putting on outdoor clothing. The average factor scores associated to these tasks were 3.49 and 3.56 out of a possible 4.0, respectively. The most difficult tasks were obtaining information and making a budget with average factor scores of 2.37 and 1.29 out of a possible 4.0 respectively.

Measures of executive functions

Working memory scaled scores on the WMI ranged from 66–151, with a mean score of 97.1 (SD = 14.8). ToL scores, in terms of the number of problems correctly answered on the first trial, ranged from 1–12, with a mean score of 8.1 (SD = 2.1). Stroop Interference scores based on raw scores ranged from −23.4 to 23.2, with a mean score of 3.2 (SD = 8.0).

Correlations of indices of injury severity, socio-demographic variables and measures of executive functions with IADL Profile scores

Pearson correlations were calculated between *IADL Profile* scores and measures of injury severity, socio-demographic characteristics and measures of EF. As reported in Table II, all three measures of injury severity (GCS scores, PTA and coma duration) were significantly correlated at $p = 0.05$ with the total score of the *IADL Profile* ($r = 0.248$–0.521). Total scores of the *IADL Profile* correlated highly with coma length ($r = -0.521$; $p = 0.001$), moderately with duration of PTA ($r = -0.361$; $p = 0.002$) and only slightly with GCS scores at emergency ($r = 0.248$; $p = 0.05$). Correlations between these three indices and *IADL Profile* factor scores varied. PTA is the measure that was moderately correlated at $p = 0.01$ with the largest number of factor scores ($r = -0.303$ to -532). The negative correlation indicates that, as expected, when duration of PTA increases, IADL independence scores decrease. Concerning the time of injury to test interval, a slight but significant correlation was noted with Factor score 6, preparing a hot meal ($r = -0.224$; $p = 0.05$), whereas the correlation with the total score ($r = -0.200$) was marginally significant at a $p = 0.051$ level.

Education was the only socio-demographic variable correlated at $p = 0.05$ with the total score of the *IADL Profile* ($r = 0.250$) and with factor scores 2, 4, 5, 6 ($r = 0.221$–0.411) (Table II). Moderate relationships were shown between education and obtaining information (Factor 4) ($r = 0.411$; $p = 0.001$) as well as between education and making a budget (Factor 5) ($r = 0.342$; $p = 0.001$). Weak correlations were shown between education and having a meal/cleaning up (Factor 2) ($r = 0.221$; $p = 0.05$) and with preparing a hot meal (Factor 6) ($r = 0.251$; $p = 0.05$). The correlations between age and Factor 1 scores (going to the grocery store and shopping for groceries) was $r = -0.234$ ($p = 0.05$), indicating a weak significant inverse relationship between age

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Table II. Pearson correlations between *IADL Profile* scores and concomitant variables.

	Variables	*n*	Factor 1 Going to store/ shopping	Factor 2 Having meal/ cleaning up	Factor 3 Putting on outdoor clothing	Factor 4 Obtaining information	Factor 5 Making a budget	Factor 6 Preparing a hot meal	Total score
	Glasgow Coma score at emergency	96	0.155	0.310**	0.168	0.091	0.145	0.293**	0.248*
Indices of injury severity	Post traumatic amnesia	70	−0.432***	−0.303**	−0.532***	−0.308**	−0.22	−0.224	−0.361**
	Coma duration	56	−0.270*	−0.257 ($p=0.052$)	−0.203	−0.100	−0.176	−0.309	−0.521***
	Time of injury to test interval	100	0.002	−0.087	0.037	0.045	−0.112	−0.224*	−0.200 ($p=0.051$)
	Age	98	−0.234*	0.016	−0.080	−0.022	−0.177	0.114	−0.154
Socio-demographic characteristics	Level of education	98	0.040	0.221*	0.011	0.411***	0.342***	0.251*	0.250*
	Distance to grocery store	83	−0.213 ($p=0.055$)	0.038	−1.220	0.088	−0.032	−0.027	−0.136
	Tower of London	98	0.223*	0.274**	0.219*	0.327	0.215 ($p=0.052$)	0.291**	0.366***
Tests of exective functions	Weschler Memory Scale III-working memory index	96	0.209*	0.300**	0.223*	0.425***	0.359***	0.197 ($p=0.052$)	0.376***
	Stroop Interference score	95	0.056	0.017	−0.031	−0.035	−0.019	0.038	0.049

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

Table III. Comparison of TBI groups with highest and lowest *IADL Profile* total scores with *t*-tests on measures of injury severity, sociodemographic variables and measures of executive functions.

	Group				
	Highest *IADL Profile* total score ($n=20$)		Lowest *IADL Profile* total score ($n=20$)		
Concomitant variables	*M*	SD	*M*	SD	*t*
Glasgow Coma Scale	8.632	3.760	6.556	3.502	−1.736
Post-traumatic amnesia	21.250	14.085	53.750	50.583	2.447*
Coma duration	6.000	9.487	25.462	30.021	2.220*
Time of injury to test interval	12.713	10.967	25.663	53.480	1.061
Age	36.150	13.978	41.700	14.797	1.219
Level of education	13.350	3.870	11.211	4.417	−1.611
Tower of London	8.650	1.755	7.100	2.845	−2.073*
WMI of WMSIII	104.600	16.600	89.263	14.521	−3.065**
Stroop Interference score	3.905	8.400	1.520	8.523	−0.869

M = Mean, SD = Standard deviation *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

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and shopping. The low magnitude of the correlation suggests that increased age is only very slightly associated to reduced independence for going to the grocery store and shopping for groceries. Regarding other variables such as gender and evaluation environment (rural/urban), no relation was observed; neither with the total score nor with any of the six factor scores. The correlation between Factor 1 scores (going to the grocery store and shopping for groceries) and the distance from the subject's home to the grocery store ($r=-0.213$) was significant at a 0.055 level. The negative correlation suggests that when distance to the grocery store increases, IADL independence scores decrease. However, the relationship is very small, marginally significant, suggesting that distance and independence are only slightly related.

Two measures of EF were shown to be modestly correlated at $p=0.001$ with the total score of the *IADL Profile*, that is the ToL ($r=0.366$) and the WMI ($r=0.376$) (Table II). These two measures were also correlated with all factor scores of the *IADL Profile*. The greatest number of statistically significant correlations ($p<0.01$) was noted with Factor 4 scores (obtaining information) and the total score. Although the *IADL Profile* was administered within a real-world environment, no correlation was noted with a recognized measure of inhibition (Stroop).

Also, t tests confirmed the previous findings as individuals with higher IADL independence (Table III), as documented by higher IADL Profile scores, had less severe TBIs (shorter PTA and shorter comas), better planning abilities (higher scores on ToL) and better working memory (higher scores on WMI). *T*-tests also confirmed that IADL independence was not associated to gender or to whether the test was administered within a rural or urban setting.

Regression analyses

Due to the fact that the instrument under study is new, a series of stepwise multiple regression analyses between *IADL Profile* scores as dependent variables and statistically significant independent variables were first performed. Independent variables most strongly correlated with each of the dependent variables were entered first into each equation, followed by progressively less highly correlated variables. Next, for completion, the order of entry of the independent variables was specified and a sequential regression analysis completed. Here, planning (ToL) was entered, before working memory (WMI), for Factors 4, 5 and 6. This didn't change the results; explained variance in the dependent variables was highest secondary to the stepwise regression analysis.

The *IADL Profile* total score was best explained by PTA and working memory when the WMI, the ToL and PTA were entered into the equation (Table IV). These two variables explained 27.7% of the variance in total scores. Three of the independent variables contributed significantly to the prediction of Factor 1 scores (going to the grocery store/shopping for groceries): PTA, distance to the grocery store and age. Once those three variables were considered in the regression, the ToL and WMI did not add significant information in determining Factor 1 scores. These three variables explained 26% of the variance in Factor 1 scores. Total variance in Factor 2 scores (putting on outdoor clothing) was best explained by PTA and the ToL. Once those two variables were considered in the regression, the GCS scores and WMI did not add significant information in determining Factor 2 scores. These two variables explained 18% of the variance. Total variance in Factor 3 scores (putting on outdoor clothing) was best explained by PTA. Once this variable was entered into the equation, WMI and ToL did not

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Table IV. Results of stepwise regression analysis for prediction of *IADL Profile* scores.

			Unstandardized coefficients		Standardized coefficients			
		n	B	SE	β	*t*	Sig.	R^2
Total score	(Constant)	69	61.719	17.635		3.50	0.001	27.7
	Post-traumatic amnesia		−0.304	0.076	−0.431	−3.984	0.000	
	Working Memory Index		0.360	0.169	0.231	2.133	0.037	
Factor 1 (grocery)	(Constant)	56	4.661	0.552		8.448	0.000	26.0
	Post-traumatic amnesia		−0.021	0.006	−0.420	−3.492	0.001	
	Distance to grocery store		−0.122	0.058	−0.250	−2.104	0.040	
	Age		−0.027	0.013	−0.249	−2.076	0.043	
Factor 2 (having meal/cleaning)	(Constant)	71	2.915	0.349		8.362	0.000	18.0
	Post-traumatic amnesia		−0.008	0.003	−0.340	−3.090	0.003	
	Tower of London		0.097	0.039	0.275	2.498	0.015	
Factor 3 (outdoor clothing)	(Constant)	72	4.063	0.172		23.59	0.000	27.3
	Post-traumatic amnesia		−0.021	0.004	−0.533	−5.228	0.000	
Factor 4 (obtaining info)	(Constant)	95	−1.036	0.782		−1.325	0.188	
	Working Memory Index		0.025	0.009	0.289	2.714	0.008	
	Education		0.090	0.041	0.232	2.180	0.032	18.5
Factor 5 (making budget)	(Constant)	96	−1.598	0.802		−1.993	0.049	
	Working Memory Index		0.030	0.008	0.359	3.687	0.000	11.9
Factor 6 (preparing hot meal)	(Constant)	94	2.372	0.306		7.746	0.000	
	GCS emergency		0.053	0.019	0.264	2.780	0.007	17.6
	Education		0.060	0.022	0.265	2.791	0.006	
	Time since injury		−0.014	0.005	−0.258	−2.712	0.008	

add significant information in determining Factor 3 scores. This one factor explained 27.3% of the variance. Total variance in Factor 4 scores (obtaining information) was best explained by the WMI and education when the WMI, education and ToL were entered into the equation. These two variables explained 18.5% of the variance. Total variance in Factor 5 scores (making a budget) was best explained by the WMI when the WMI, education and the ToL were entered into the equation. This variable explained 11.9% of the variance. Total variance in Factor 6 scores (preparing a hot meal for guests) was best explained by the GCS scores, education and time since injury when these three variables plus the ToL were entered into the equation.

Discussion

In developing the *IADL Profile*, it was hypothesized that a measure of IADL independence structured to consider the role of EF would better reflect an individual's level of functioning in the community. To this end, particular attention was given to including task complexity and novelty, elements of known importance to tests of IADL independence in consideration of executive functioning [6, 10, 59, 60]. A non-structured approach [4, 60] and real-world environments [62, 63] were also judged important and included in the basic structure of the test. The *IADL Profile* integrates these elements into one complex and long lasting multitask IADL, linked to the overarching goal of receiving guests for a meal in their home. Use of this test should provide a new perspective on IADL independence, as independence scores will reflect a much more extensive understanding of that which is required to perform IADL tasks in the context of living independently in one's home and community environment. Independence in IADL must be understood as resulting from the competence of individuals, not only to act, but also to decide what they want to do, to choose from available options and plan a course of action, to implement the plan in day-to-day activities and to assess the outcomes [64]. It is suggested that use of an analytical measurement instrument such as the *IADL Profile* that provides some information regarding the repercussion of executive deficits on IADL independence will be a valuable addition to treatment planning for this population of individuals. Furthermore, identifying the impact of task performance errors on independence and safety is an important contribution of this measurement tool.

In this study, level of independence was modestly associated with TBI injury severity, particularly with PTA, as well as with education, planning and working memory. No relations were shown between *IADL Profile* scores and gender. Correlations between going to the grocery store/shopping for groceries and distance to the grocery store was shown to be marginally significant, suggesting that individuals who live at a greater distance from the grocery store show a tendency of being slightly less independent in this task than individuals who live closer.

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Measures of executive functions

It was shown in this study that correlations between *IADL Profile* scores and measures of EF (planning, working memory) were modest, suggesting that a certain portion of both sets of measures documents similar aspects of functioning. This is a positive finding as previous studies in this area have largely failed to show relations between IADL tasks and traditional measures of EF [20]. The authors would argue that these results provide some preliminary evidence that inferences about the repercussions of executive functioning deficits on IADL independence can be drawn from the *IADL Profile*. Of equal interest is the demonstrated ecological validity of both the ToL and the WMI in a large relatively homogeneous sample.

However, correlations that varied between slight and moderate were found between both the ToL and the WMI and *IADL Profile* factor scores related not only to complex tasks but also to more automatic and familiar ones. According to the literature, planning is required in more complex tasks and less so in more automatic and familiar ones [65]. It is expected that correlations with tasks generally considered as requiring less planning such as having a meal and putting on outdoor clothing may have been significant because of the manner in which the *IADL Profile* was administered. More precisely, subjects were evaluated on these tasks not as single tasks but as part of a sequence of tasks where the subject formulates goals and plans the sequence. This may account for the greater than expected correlations between these tasks and planning and working memory.

Failure to find significant correlations between the selected inhibition task used in this study (Stroop) and the *IADL Profile* administered in a real-world environment with large numbers of distracters is particularly difficult to explain. Bush et al. [67] showed inhibition, an important component of EF, to be impaired subsequent to a TBI. However, Stroop Interference scores have previously been shown to not differentiate between individuals with TBI who required assistance with ADL and those who did not [66]. The hypothesis put forth by Leahy and Lam [66] is that overall impaired performance on all sub-tests can lead to Interference scores in the normal range. With these results, one may either question the ecological validity of scores obtained on the Stroop, the sensitivity of the *IADL Profile* to inhibition errors or the likelihood that inhibition errors, though present, did not widely alter the subjects' level of independence. These and other hypotheses will require further investigation.

Measures of injury severity, sociodemographic characteristics and environmental factors

This study showed small-to-moderate correlations between *IADL Profile* scores and indicators of injury severity such as duration of PTA, GCS scores and length of coma, known predictors of functional outcome [29, 32, 34]. These results provide some evidence for the criterion-related validity of the tool with injury severity. Inclusion criteria used in this study may have had the effect of weakening these correlations as individuals with very severe injuries were excluded, reducing the variance of the data. However, similar expected relationships were not found with time of injury to test interval, i.e. subjects at a greater time post-injury were not found to be more independent. This can most probably be explained by the cross-sectional design of the study and the method used for recruiting subjects. As the majority of subjects in this sample were receiving active rehabilitation services, those at a greater time post-injury were likely to have persistent and severe disabilities. This explained their continued need for services years after their injury. Individuals with good recovery several years post-injury were not solicited for participation in this study.

Age was significantly correlated with going to the grocery store and shopping for groceries, with higher age shown to be very slightly associated to lesser independence. For individuals of all ages, planning to get to places more or less out of walking distance, such as the grocery store, is more complex when confronted with the reality of not having resumed driving subsequent to their TBI. These results may suggest that permanent or temporary loss of driving ability subsequent to a TBI may affect older people more than younger people. As older subjects in this study had milder injuries overall, severity of injury does not explain these results. Due to the slight correlations that were found between these two variables, further studies would be required to further examine these findings.

As the *IADL Profile* largely revolves around a meal preparation task, one could have expected to see gender differences favouring women. However, the sheer absence of significant relations between gender and any *IADL Profile* scores suggests that the test is pertinent for both men and women and, moreover, that neither gender is either advantaged or disadvantaged in this test.

Level of education was the sociodemographic variable that was related to the largest number of *IADL Profile* scores. These findings provide added support to the presence of the desired degree of task complexity within the test, with task complexity being a criterion for measures interested in documenting the repercussions of EF deficits.

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The highest correlations were observed with two factors: obtaining information and making a budget. These are possibly the two most systematically complex tasks of the test. These results provide some evidence regarding the criterion-related validity of the *IADL Profile* with education.

No differences were found in IADL independence between subjects living in rural and those living in urban environments when the confounding variable of driving ability was not considered. However, the distance subjects had to travel to go to the grocery store was nearly statistically correlated ($p = 0.055$) with independence on the tasks of going to the grocery store and shopping. Hence, there is an unconfirmed slight tendency for individuals living a greater distance from a grocery store to be less independent on this task. This finding is of particular interest as it contributes data that supports the importance of assessments in home and community environments. It is important to note, however, that had examiners systematically pre-selected the grocery store at which errands were to be made and directly brought subjects to this pre-selected store, they would have failed to capture the importance of the variable 'distance to the grocery store' in relation to the individual's independence on this task. Greater distances between the individual's home and the grocery store contribute to increasing the degree of task complexity, particularly in terms of planning. Moreover, planning complexity was at it's peak when long distances to the grocery store were accompanied by subjects not having resumed driving subsequent to their injury. These results, although modest, are consistent with previous studies that have highlighted that independence decreases with increased environmental demands [68].

Results of the multiple-regression analysis provide new insights into the variables that best account for the cross-sectional variance in independence in IADLs. However, overall, independent variables documented within this study explained less than a third of the variability in independence in IADL as measured by the *IADL Profile* in subject's home and community environments. Altogether, 28% of the variance in IADL independence, as measured by the *IADL Profile* total score, was predicted by knowing scores on PTA and working memory. The size and direction of the relationships suggests that individuals with lesser IADL independence have had a more severe TBI, as indicated by longer PTA and poorer working memory. Twenty-six per cent of the variance in individual's independence in going to the grocery store and shopping for groceries (Factor 2) was predicted by knowing scores on PTA, distance to the grocery store and age. The size and direction of the relationship suggests that individuals with lesser independence in these tasks have had a more severe TBI, as indicated by longer PTA. They also tended to live further from the grocery store and were generally older. Overall, lesser independence on five of the six tasks included within the complex sequence of tasks related to the goal of receiving guests (putting on outdoor clothing, going to the grocery store, shopping for groceries, having a meal and cleaning up) was at least partly predicted by knowing scores on PTA. However, the predictive power of PTA remains limited, as explained variance in IADL independence did not exceed 27.3% for any one of these tasks. The GCS score was a somewhat important determinant exclusively on Factor 6 (preparing a hot meal for guests). The size and direction of the relationship suggests that individuals with lesser independence in this task have had a more severe TBI, as indicated by lower GCS scores. However, combined with education and time since injury, only 17.6% of the variance in independence for preparing a hot meal was explained by these variables. This is a small proportion of explained variance. As a growing number of studies are suggesting that PTA is a stronger predictor of outcome than GCS scores [28, 69–71] these results remain congruent with the known contribution of these indicators of TBI severity to functional outcome. The results do however suggest caution when predicting outcome with these early indicators of injury severity. Alternately, knowing that EF have been shown to control the sequence and execution of complex goal-directed activities such as cooking, dressing, shopping and doing housework [72], it is very surprising that EF was not shown to be a major determinant of independence in these IADL tasks. These results are not entirely congruent with the initial hypotheses and will require further investigation. Working memory was a major determinant for Factors 4 (obtaining information) and 5 (making a budget), both single complex tasks. However, explained variance in these scores remained inferior to 20%. These results are nonetheless coherent with the initial hypotheses as in both of these tasks subjects are required to retain a set of task demands as they carry out the task over an extended period of time. Planning, as measured by the ToL, was shown to be a major determinant of a single factor, that is Factor 2 (having a meal and cleaning up) contributing to a total explained variance of 18%. These are not the results that were expected as it had been assumed that minimal planning was required for the realization of both of these tasks and that more planning would have been required for more complex tasks such as going to the grocery store and shopping for groceries (Factor 1), obtaining information (Factor 4) and making a budget (Factor 5). Moreover, when the order of entry of the variables

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within the regression equations was modified to force the earlier entry of the planning variable, this did not change the results. Overall, use of a larger number of measures of EF, documenting more dimensions of the concept, may have been beneficial to explain a larger proportion of the variance.

These results thus provide support for the importance of EF deficits in relation to IADL independence, while at the same time suggesting that other variables further contribute to IADL independence secondary to a TBI. These results may partly be explained by the multidimensional nature of IADLs. For instance, math skills are likely to explain some of the variance involved in 'making a budget' and spatial orientation is likely to explain some of the variance in 'going to the grocery store'. This will necessarily require further investigation as the nature and complexity of IADL independence, as measured an individual's home and community environment, is only starting to be grasped.

One of the limitations of the study is the proportion of missing data regarding coma length and PTA. As these data were extracted from medical files, the number of incomplete files from which information was extrapolated for this study highlights a problem with the systematic documentation of trauma severity in the health care system. Hence, findings of the criterion validity study of the *IADL Profile* with measures of injury severity related to coma duration and PTA must be interpreted with caution. Also, these missing data prevented the verification of the study's initial hypotheses through theoretically-driven sequential multiple regressions. To attain this goal, these analyses would need to be attempted anew on a larger sample size. Secondly, criterion validity with measures of EF was limited to three neuropsychological tests, although many more could theoretically have been used. TBI subjects' problems with fatigue imposed time limits on overall neuropsychological testing and did not allow for the use of a greater number of tests beyond the three that were used. Testing had to be completed within a 1-day session due also to the vast distances that had to be travelled to attain this study's sample size. As a more comprehensive neuropsychological assessment might have yielded a different pattern of findings, it would be important to replicate these findings with additional neuropsychological measures.

Conclusions

This study presented the criterion-related validity of the *IADL Profile*, a new analytical measure of IADL independence that documents whether a subject's main difficulties pertain to goal formulation, planning, carrying out the task or attaining the initial task goal; all important components of EF. It is suggested that the contribution of the *IADL Profile* towards understanding some of the repercussions of executive deficits on IADL independence, its use of novel and complex tasks, its semi-structured approach and administration within a real world environment provides a closer approximation of a subject's true independence in his or her home and community environment. It is considered that the *IADL Profile*'s identification of underlying causes of persisting need for assistance in IADL tasks will be shown to be invaluable for targeted treatment interventions.

This study has now documented the criterion-related validity of the *IADL Profile* with relation to TBI injury severity, education and EF measures of planning and working memory. The results showed slight-to-modest correlations between *IADL Profile* scores and measures of EF. These results provide some preliminary evidence that inferences about the repercussions of EF deficits on IADL independence can be drawn from the *IADL Profile*.

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