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Web-based Real-time Neuropsychological Assessment in Dyslexia

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Background

Although cognitive assessment has become increasingly prevalent and integrated into the lives of users, studies investigating Web-based real-time neuropsychological assessment (NPA) are rare and usability of online NPA is poorly understood. This paper examines the feasibility of online, real-time NPA in a special population with dyslexia. We investigated the influence of dyslexia, language differences and motivation factors on the online NPA performance.

Methods

The discriminant ability of Web-based real-time NPA was investigated in samples from university populations in the Hungary and the Czech Republic. The difference between subgroups were calculated using a series of analyses of covariance (ANCOVAs) and Tukey's post hoc test pairwise comparisons.

Results

The present manuscript reports on the results of Czech and Hungarian students (N = 246) who performed online NPA. Participants with dyslexia performed slower than participants without dyslexia on the measure of motor speed and on tasks which are a measure of capacity to integrate multiple processes in an effortful situation. They perform the task requiring response inhibition with a higher number of commission errors (as the measure of disinhibition). We found a significant main effect of language in most tasks of the NPA. Reliability of online real-time NPA was related to the level of motivation as a result of financial compensation among all participants and close relationship with their caretakers among dyslexia participants.

Conclusions

Web-based real-time NPA among dyslexia participants is feasible. Web-based real-time NPA among dyslexia participants and controls is heavy influenced by language, by the continuous relationship between examinee and caretaker as well as by monetary incentives. All these factors influence quality of performance at home. More research is needed to understand in depth the role of these factors in online, real-time NPA.

Keywords: Online assessment, Dyslexia, Real-Time, Neurocognitive tests, Cognition,

Background

It is estimated that over a quarter of the world's population use the Internet. There is a growing trend for individuals to seek health information from online sources [1] and 75% of Internet users have searched for health or medical information on the Web [2]. In the year 2014, 100 million Internet medical visits were predicted, with a potential cost saving of over $5 billion compared with traditional office visits [3]. It is suggested that Web-related contexts are an open, safe space in which people can examine themselves and promote healthy habits [4]. One domain within the area of health information involves Web-based monitoring of cognitive (dys)function [5].

There is a continuous trend towards an increasing role of cognitive assessment because of the worldwide shift away from physical jobs to occupations with higher cognitive demands [6]. Complaints regarding attention and memory difficulties are an increasing public health concern worldwide [7, 8]. In medicine, subtle cognitive dysfunctions are not readily observable with routine clinical examinations, but can be detected with neuropsychological assessment (NPA), an objective methodology to demonstrate cognitive impairment. In addition, quantifying cognitive performance measures in a way that is easily interpretable for the examinee is of increasing interest because cognitive training programs have experienced a steep rise in popularity [9]. Web-based NPA is a low-cost, effective alternative to traditional face-to-face testing, which is not effective from a time and cost perspective [10-13]. Furthermore, now that studies are scaling up in the number of recruited participants, a demand exists for short, easy-to-use neuropsychological tests [14].

In reviewing the available literature, several issues emerge. The validation of Web-based tests is somewhat difficult [15-22] because online assessment introduces aspects of interaction between the examinee and the Internet-related factors such as user friendliness and user satisfaction that influence test performance [23]. Internet-related factors can influence online NPA in several ways: (i) Extensive computer and Internet experience can enhance test scores [24,25]; Furthermore, the level of a "media literacy" of the user can seriously affect test's results [26-28] (ii) Online behavior is more "disinhibited" because of the anonymity of the participants [29,30] as compared to the face-to-face situation; this, can also, affect test results; (iii) Home background can compromise validity of Web-based assessment because control over the testing environment is lost and therefore the possibility of under-performance and non-serious test-taking attitudes are increased. Studies investigating real-time NPA using Web-based reaction-time results are rare [31-34] and usability of websites for NPA is still poorly understood.

Our previous work, employing the same sample as used in the current study, focused on Web-based real-time tests of Learning Abilities (i.e. phonological awareness, spelling, reading speed, auditory memory, sequential and parallel visual memory; 35). We found that students with dyslexia were significantly more impaired than non-dyslexia participants. Dyslexia is defined as "a brain-based type of learning disability that specifically impairs a person's ability to read” [36]. Although, dyslexia is primarily expressed in reading difficulties, reading is a complex information processing activity. Therefore, impaired reading may be the result of multiple deficits [37-39] including a number of cognitive factors ranging from low-level sensory to high-level cognitive processes. Non-linguistic cognitive functions such as attention, working memory, motion perception and motor abilities should also be considered [40, 41]. Furthermore, it has long been observed that learning disorders, especially reading difficulties, occur in combination with attention-deficit/hyperactivity disorder (ADD/ADHD). Given the greater than expected co-occurrence of difficulty with reading and ADHD [42], the need to accurately diagnose ADHD among dyslexia subjects requires assessment of cognitive impairment beyond learning and reading abilities.

In the current study we examined the differences in cognitive performance between students with and without dyslexia using Web-based real-time NPA. This is important because of the increasing number of students with dyslexia entering higher education [43] and the need for easy to administer, inexpensive, assessment techniques. It is important because use of the internet can be impaired by dyslexia [44]. In this light, previous research found close associations between reading difficulties and online literacy [45,46]. Therefore an easy and convenient online assessment of NPA is important in dyslexia populations.

Conceptual and psychometric measurement equivalence of tests is a fundamental requirement for valid cross-cultural use when assessing linguistically diverse individuals [47,48]. Cross-cultural differences in linguistically diverse individuals, in their test-taking behaviors, in skills of different demographic subgroups are important for diagnostic sensitivity of tests [49]. Language-specific factors are especially important in populations with deficits in academic (reading, math, and writing), language, and motor skills [50]. Dyslexia is thought to affect between 5 and 10 percent of a given population [51]. However, the vast majority of studies on NPA in dyslexia have been conducted among children in English speaking countries. Studies of NPA of non-reading cognitive function among non-English speaking adults are rare [52].

Very little is known about the impact of Web-based NPA administration on real-time formats in dyslexia research, which routinely uses a face-to-face procedure. Thus, it is clear that the ability of students with learning disability to perform Web-based NPA (without external control of examiner) should be investigated. The goals of the present work were threefold. First, we aimed to characterize the neuropsychological profile of students with reading difficulties in two non-English speaking countries (Czech Republic and Hungary) using Web-based real-time assessment. Second, we sought to obtain preliminary insights into the influence of language on Web-based real-time NPA. The last question was whether different factors are associated with motivation during online real-time NPA. To our knowledge, this is the first study to examine online NPA in dyslexia students with non-English languages.

Methods

Study Population

We recruited a total of 246 adults for the study, 146 in the Adolescent and Adult Dyslexia Center in Budapest, Hungary, in collaboration with the Institute of Cognitive Neuroscience and Psychology of the Research Centre for Natural Sciences, Hungarian Academy of Sciences and 100 at the Pedagogical and Psychological Counseling Center Brno, Czech Republic in collaboration with at Masaryk University, Faculty of Education. Volunteers were recruited by means of advertisements posted at universities; through personal contacts and via social networks to take part in a research project investigating reading problems. Czech participants were entitled to receive financial compensation for their time and reimbursement of travel costs. Hungarian participants received a document on their official assessment in return for their participation. Otherwise the assessment would have cost them at least 30 Euros. Czech participants were recruited by caretakers with whom they had an ongoing relationship. This was not the case for Hungarian participants.

Inclusion criteria were: age 18-30, education 12 -18 years and previously diagnosed dyslexia or non-dyslexia. Exclusion criteria were history of significant brain trauma with episodes of amnesia, neurological disorder, alcohol and substance use (other than tobacco smoking and coffee consumption), major psychiatric disorders and treatment with any psychiatric medication in the month before the screening interview.

Instruments of evaluation

A screening interview was administered which covers the following areas: age, gender, education, employment, medical (including neurological) history, alcohol or substance use, history of treatment with psychiatric medication and self-assessment of dyslexia.

Evaluation of cognitive status was performed using real-time tasks from the CogScan Computerized Cognitive Test Battery (Anima Scan Ltd. Ashdod, Israel) that were adapted for online use by Anima Scan Ltd in the context of the Literacy Project (http://www.literacyproject.eu). The tasks were translated into Hungarian and Czech. Further information on the neuropsychological test battery is provided at: http://www.literacyproject.eu/pdf/Literacy_Cognitive_Assessment-20130729.pdf. The test battery can be accessed online and is available free of charge to users as part of the assessment provided on the Literacy Portal (http://www.literacyportal.eu/)

The test battery consists of 10 online tasks. The system retains participants' reaction times and accuracy of responses across subtests. The tasks are all self-administered. They were chosen to assess attentional, motor, inhibition, and working memory problems. At present, there is no universally accepted standard battery of neurocognitive tests, but most examiners include selected tests of attention, memory, psychomotor abilities, and speed of information processing:

1a.Continuous Performance Task (CPT) is a measure of sustained attention or vigilance and reflects an ability to maintain goal-directed behavior over time [53]. A classical measure of failures of sustained attention is the number of omission errors [53].

1b.The Go/NoGo task is a measure of impulse control by the ability to withhold “prepotent” response [53]. The number of commission errors is a classical measure of failures of motor inhibition control [53].

The whole experimental task lasts for 10 min, and each condition [either a) CPT or b) Go/NoGo] continues for 5 min without a pause between them (for details see [54]. Accuracy was calculated with the following algorithm: [1 - ((number of commissions + number of omissions)/total possible correct)] X 100.

2. Stroop Task is a measure of both selectivity of attention and "interference inhibition" of overlearned responses [55]. Selective attention is the ability to focus on relevant stimuli and ignore competing stimuli as well as to shift the course of ongoing mental activity. Problems with this task are associated with distractibility (for details see [56].

3. Digit Running (DR) task is a measure of the degree of mental effort required, an index of cognitive load and capacity to integrate multiple processes in complex performance including divided attention, working memory and sustained attention when dealing with an effortful situation. The increased amounts of information in the DR task relate to numerical processing. Two numbers are displayed on each screen. The examinee is asked to press a key each time the two numbers are identical. Numbers in the first trial are of one digit; numbers in the second trial are of two digits, and numbers in the third trial are of three digits. Reduced level of accuracy in the DR is greater in participants with impaired capacity to compare number-pairs accurately during performance (as can be seen according to DR accuracy percentages over time from one digit to three digits conditions) (for details see [57].

4. N-Back Task is a measure of semantic working load of 0, 1, and 2 items. We use a sequential-number memory task as variant of the N-back task [58, 59]. To accomplish this task, the subject needs to both maintain and manipulate information in working memory. Accuracy scores reflect the subject's ability to hold information in memory without forgetting. Response time reflects the time it takes to retrieve information from working memory.

5. Inspection Time Task (IT) is a measure of the capacity to quickly detect the identity of a stimulus (perceptual speed). IT is the best single index of information input and it is not contaminated with factors related to motor speed and differences in speed-accuracy tradeoff strategies [60].

6. Motion Perception Task (MPT) is measures motion-processing ability [61] an important task for identifying individuals who have a specific deficit in the magnocellular pathway, physiological pathways of the visual system important for reading ability.

7. Finger Tapping Test (FTT) is measure of integrity of the neuromuscular system and examines motor control - fine movement functioning (e.g. motor speed) [62].

8. Digit Symbol Substitution Task (DSST) is a measure of visual attention, information-processing speed and efficiency in translating phonemic codes into suitable visual counterparts and a measure of the efficiency of paired-association learning [63]. The test is 120 seconds long, and the total score equals the sum of all correct symbols copied completed within 120 sec.

9. Matched Familiar Figures Test (MFFT [64**])** is a measure of visual search accuracy and speed accuracy tradeoff (for details see [65]. Even small difficulties in discriminating details of the whole picture can slow down reading and make comprehension more difficult. Impulsive subjects tend to quickly choose an answer without thinking, and therefore their performance is associated with short latencies and high numbers of errors. This type of behavior can be detected by the short first response time and high total number of errors in the MFFT.

For each response of each participant, RTs were calculated from the onset of the stimulus until the onset of the response via a computer algorithm. Only RTs of correct responses were used to calculate the RT means.

Procedure

Participants at the Hungarian and Czech Republic Centers (with and without reading difficulties) performed the Web-based versions of the neuropsychological tasks at home via the Internet. They were able to take breaks in performing the tasks and to complete them in more than one session.

Ethical aspects

Participation was voluntary. Written and oral information about the study was provided before recruitment. All participants gave informed consent indicating their willingness to participate in the study, which includes the questions covering background information and the cognitive assessment. The study was conducted in accordance with the Helsinki Declaration and was approved by the local Research Ethics Committees and authorized by the local Data Protection Agency.

Data analysis

Data were analyzed using SAS (v. 9.01) software for windows. For each participant, means and standard deviations of RTs for correct responses were computed for each task. Because demographic characteristics could influence the group differently, the difference between groups in age, education and gender was examined. T-test was used to analyze numerical variables (age and education) and a chi-square ($\chi 2$) test for the categorical variable (sex). To analyze the difference in tests' performance measures series of analyses of covariance (ANCOVAs) were conducted with performance measures (response time, variability of response time, numbers of commission, omission errors as well as "accuracy") as dependent measures, Group (Dyslexia vs. Control), Language (Czech vs. Hungarian) as between-subject factor and demographic variables (age, education and gender) as covariates.

Instead of presenting a long list of all tests results (main effects and interactions), we present only statistically significant results. Results of each test were analyzed separately. The difference between subgroups was calculated using Tukey's post hoc test pairwise comparisons. The full set of test results can be provided on request. Chi square test was applied to participants with incomplete or erratic test results (unreliable) among Czech and Hungarian samples (Table 4). Incomplete results were definited as an interruptions of the test performance before completion. Erratic results were definited as an number of random, or otherwise unreliable responses **(**for example, more responses than that the number of stimuli in CPT (wich include both stimuli of the Go and of the NoGo), or exessive slowness of responses or variability of responses more than 5 standart deviation see table 1). After that, prior to analysis, performance measures of each test were examined for outliers [66]. Participants with extreme RTs (defined as greater or less than 3.29 standard deviations, calculated per participant, per condition) were excluded from further analyses [66].

Results

2.1. Demographic characteristics

246 participants were recruited in the two centers, 146 participants in Budapest and 100 participants in Brno. 70 Budapest and 14 Brno participants were excluded from the data analysis because of incomplete or erratic test results (Table 4). In both centers excluded

participants were equally distributed between the participants with reading difficulties and dyslexia groups.

Table 1: Distribution of demographic features of Hungarian and Czech groups with and without dyslexia

Population	Variables		Dyslexia (N=80)	Non-Dyslexia (N=82)
	Age	Mean	22.9	24.7
		SD	3.1	3.8
Czech	Education	Mean	14.5	16.2
		SD	2.3	3.0
	Gender	Male:Female	26:17	29:14
	Age	Mean	19.4	23.0
		SD	3.6	7.3
Hungarian	Education	Mean	12.2	13.2
		SD	2.6	3.1
	Gender	Male:Female	25:12	16:23

Table 1 shows the age, education and gender distributions of the samples with and without dyslexia in the present study. In the Czech sample participants with dyslexia were significantly younger than controls (t=2.36, p=0.02). They were also significantly less educated (t=2.85, p=0.006). No significant between groups differences were found for gender (χ^2 =0.45, p=0.50).

In the Hungarian sample participants with dyslexia were also significantly younger than controls (t=2.70, p=0.009). No significant between groups differences were found for education (t=1.47, p=0.15). A significant difference was found for gender (χ^2 =5.38, p=0.02) with an excess of males in the dyslexia group.

Given the significant differences caused by age, education and sex, these variables were included as covariates in an analysis of covariance (ANCOVA) between the students with dyslexia and controls.

2.2 Neuropsychological Tests

The presentation of the results is organized into two sections, which correspond to the main questions of the study: (1) Are there differences in performance of online neuropsychological tests between participants with dyslexia and non-dyslexic participants?

(2) Are there online differences in performance of online neuropsychological tests between participants with dyslexia and non-dyslexic participants across languages?

Table 2. Comparison of participants with and without dyslexia on the Web-based real-time neurocognitive tasks.

Test		Variable	Dyslexia		Non- Dyslexia			
			Adj. Mean	Adj. SE	Adj. Mean	Adj. SE	F	p
Continuous Performance Test	Q1	SD	80.65	4.14	66.38	4.08	5.83	0.02
		COM	0.85	0.15	0.36	0.14	5.73	0.02
		OM	0.41	0.10	0.11	0.10	4.13	0.04
	Q2	COM	0.87	0.15	0.42	0.15	4.20	0.04
Go/NoGo	Q3	COM	2.53	0.25	1.85	0.24	4.08	0.04
	Q4	COM	3.65	0.29	2.59	0.29	6.34	0.01
Digit Running	1	RT	562.56	6.34	536.74	6.04	8.48	0.004
	2	RT	687.71	8.27	654.25	7.87	8.38	0.004
	3	RT	744.14	9.84	698.33	9.37	11.08	0.001
		OM	2.26	0.22	1.51	0.21	5.70	0.02
Digit Symbol Substitution Test	2	Err	0.62	0.12	0.22	0.12	5.02	0.03
		ACC	0.58	0.02	0.65	0.02	6.52	0.01
Finger Tapping Test	4	Time4	182.20	4.32	168.12	3.74	5.98	0.02

Note: RT – mean reaction time, SD – standard deviation of mean reaction time, COM-commissions, OM – omissions, ACC – accuracy.

Differences in online accuracy and response speed between participants with and without dyslexia

For the first step of the analysis, all participants were grouped on the basis of reading ability**.** Participants with dyslexia performed consistently worse on five of the nine neuropsychological tests as compared with non-dyslexic participants (Table 2). Among participants with dyslexia, we found a significantly higher number of commissions errors, as a measure of disinhibition, during performance of both blocks of the CPT Q1 [F(1, 145)=5.73, p=0.02] and Q2 [F(1,145)=4.20, p=0.04] and both blocks of the Go/NoGo tasks Q3 [F(1,145)=4.08, p=0.045] and Q4 [F(1,145)=6.34, p=0.01] than in non-dyslexic participants (Table 2). Also, the ANCOVA results show that participants with dyslexia had a longer mean reaction time over the all three conditions of the DR task (a measure of capacity to integrate multiple processes in effortful situation) than participants without dyslexia (one digit [F(1,153)=8.48, p=0.004]; two digits [F(1,153)=8.38, p=0.004]; and three digits [F(1,153)=11.08, p=0.001]). In the most effortful condition, which required intensive processing of high amounts of information (three digits), participants with dyslexia made significantly more omission errors on online performance than participants without dyslexia [F(1,153)=5.70, p=0.02].

We find the same learning curve in the DSST in the groups with and without dyslexia. However, the participants with dyslexia made more errors than those without dyslexia in the DSST: [F(1,145)=5.02, p=0.03].

Analysis of motor speed as measured by the FTT (see Table 2) revealed a main effect of group [F(1,140)=5.98, p=0.02]; the participants with dyslexia tapped slower than those without dyslexia.

No significant differences between the participants with and without dyslexia were found on the following tests: Inspection Time Task, Motion Perception Task and N-Back Task, and MFFT.

Differences in online accuracy and response speed between the two language groups.

For the next step of the analysis, all participants were grouped on the basis of language: Czech versus Hungarian participants**.** Results of the ANCOVA demonstrated a significant main effect of Language indicating that the Czech participants were more accurate on the CPT [in terms of omission rate [F(1,145)=4.29, p= 0.04], the DSST [F(1,145)=4.36, p=0.04]; the neutral condition of the Stroop [F(1,131)=9.48, p=0.002]; the MFFT [F(1,149)=4.60, p=0.03]; Motion perception (for omission in the most simple condition (1/2) [F(1,122)=6.09, p=0.01] and for errors in the more complicated conditions (3/4) [F(1,122)=9.48, p=0.002], (4/5) [F(1,122)=5.92, p=0.02] and (5/6) [F(1,122)=19.06, p=<0.0001], respectively) and the N-back task in trail 1 [F(1,134)=14.04, p=0.0003] and trail 2 [F(1,134)=6.39, p=0.01], than the Hungarian participants. There was also a significant Group by Language interaction effect for the accuracy on the N-back task in first trail [F(1,134)=5.33, p=0.02]. Results of the ANCOVA demonstrated a significant main effect of Language indicating that the Czech participants were slower in the CPT[F(1,145)=5.75, p=0.02], the Go/NoGo [F(1,145)=7.49, p=0.007]; in the all DR conditions (one digit [F(1,153) =4.30, p=0.04]; two digits [F(1,153)=5.02, p=0.03]; and three digits [F(1,153)=3.91, p=0.049], respectively) and slower in the MFFT [F(1,149)=6.03, p=0.02] than the Hungarian participants. There was also found significant Group by Language interaction effect and response time during MFFT [(1,149) =5.88, p=0.02].

The Czech participants demonstrated lower variability of response time in the DR two digits [F(1,153)=9.57, p=0.0023], in the Stroop task (congruent condition: F(1,131) =4.44, p=0.037; and incongruent condition: [F(1,131) =4.64, p=0.03] than the Hungarian participants (Table 3).

Table 3. Comparison of performance variables among Czech versus Hungarian participants on the Web-based real-time neurocognitive tasks (adjusted means and standard errors).

Test	Condition	Variable	Czech		Hungarian			
			Adj. Mean	Adj. SE	Adj. Mean	Adj. SE	F	p
Continuous Performance Test	Q1	OM	0.10	0.11	0.43	0.11	4.29	0.04
	Q2	RT	448.52	8.70	480.04	9.01	5.75	0.02
Go/NoGo Test	Q3	RT	392.85	7.52	423.93	7.78	7.49	0.01
Digit Running	1	RT	540.27	6.12	559.05	6.40	4.30	0.04
	2	RT	657.77	7.97	684.19	8.34	5.02	0.03
		SD	99.65	7.84	135.58	8.21	9.57	0.002
	3	RT	707.34	9.49	735.13	9.93	3.91	0.04
Digit Symbol Substitution Test	4	Er	0.36	0.09	0.65	0.1	4.36	0.04
Stroop Test	C	SD	353.28	30.41	451.59	32.65	4.44	0.04
	NC	SD	471.97	34.97	587.58	37.55	4.64	0.03
		Err	0.07	0.07	0.45	0.08	11.02	0.001
MFFT		RT	17.37	0.84	14.18	0.90	6.03	0.02
		Er	1.46	0.25	2.30	0.27	4.60	0.04

Motion Perception	1/2	Om	0.01	0.03	0.13	0.03	6.09	0.01
	3/4	Er	0.23	0.09	0.52	0.09	5.20	0.02
	4/5	Er	0.39	0.12	0.80	0.11	5.92	0.02
	5/6	Er	0.27	0.11	0.96	0.10	19.06	<0.0001
N-Back	1	Er	0.10	0.28	1.79	0.30	15.89	<0.0001
	2	Er	1.57	0.32	2.74	0.35	5.76	0.02

Note: RT – mean reaction time, SD – standard deviation of mean reaction time, Er-errors, Om- omissions, ACC – accuracy.

Differences in the number of participants with unreliable versus reliable online results between the Czech and Hungarian samples.

Table 4 presents number of participants with incomplete or erratic (unreliable) test results among the Czech and Hungarian samples. Chi square test showed a significant difference ($\chi 2$ = 30.41 and *P* <0.0001, *n*=246), suggesting that there was a significant difference in motivation between the samples. The Czech sample showed more motivation than the Hungarian sample.

Table 4. Comparison of Czech and Hungarian groups by the number of the unreliable versus the reliable results.

Population	Reliable N (%)	Unreliable N (%)	Total
Czech	86 (86)	14 (14)	100
Hungarian	76 (52)	70 (48)	146
Total	162	84	246

Discussion:

In the current study we found that a majority of students with dyslexia suffer from different neurocognitive deficits beyond reading-related difficulties. They performed significantly less effectively than controls on five online real-time NPA tasks such the CPT, the Go/NoGo, the DR, the DSST, and the FTT (Table 2). These results are in accordance to previous findings from standard face-to-face assessment showing that impaired reading can be the result of multiple deficits within visual processing and attention control [37-39, 67-70].

More specifically, the dyslexia group had sustained attention deficit expressed by a higher number of omissions and a higher variability of responses (inconsistency in reaction time) in performance on the CPT than participants without dyslexia (Table 2). Abnormal attention is not a 'core' feature of dyslexia. Thus, in some of the participants with dyslexia attention impairment may be a consequence attention deficit/hyperactivity disorder (ADD/ADHD) comorbidity [71, 72]. In addition, participants with dyslexia had a higher number of commission errors in both the CPT and Go/NoGo tasks that are consistent with impaired inhibition ability as the test progressed (Table 2). "Behavioral" inhibition represents impulsivity in terms of inability to inhibit prepotent actions is measured by the numbers of commission or slow response time on the Go/NoGo task (see for details [54]. Another conceptualization of impulsivity is known as "reflexive" inhibition and refers to an individual's inability to gather information before responding in a situation with several highly plausible alternatives, when only one of them is correct, as measured by the numbers of errors in the MFFT [65]. Thus, it was expected that dyslexia participants would respond in a disinhibited manner in the MFFT (evidenced by shorter first response time and mirrored by increasing of errors rate) than participant without dyslexia. In contrast to our expectation, we did not find significant differences between the two groups in the MFFT performance (Table 3). Current results showed that dyslexia participant have not express inhibition impairments in situations without time pressure such MFFT. However, in situations when they have to perform under time pressure (such a Go/NoGo task performance) they expressed the "response" inhibition impairments. We did not find significant differences between dyslexia and non-dyslexia participants for inhibition tests administered, with the exception of the Go/NoGo task (slower responses).

Participants with dyslexia were significantly more impaired on measures of complex information processing (as measured by the DSST) as compared to those without dyslexia. Reading ability is linked to processing speed and typically defined as speed of completion of a task with reasonable accuracy [73]. DSST is a classical processing speed task and includes quick association between numbers and symbols and searching for and responding to specific targets [63]. Thus, processing speed is a more fundamental cognitive process that underlies the efficiency with which one can read and write [70]. Slowed processing speed has been described as a sensitive but not specific characteristic of reading disability [74]. Our results support the hypothesis that individuals with dyslexia are characterized by a generalized difficulty in rapidly processing sequential information [75].

Individuals differ in their processing capacity [76]. Effortful tasks such DR requires a lot of divided attention, working memory, and sustained attention. Capacity to integrate multiple sub-processes in complex performance is highly dependent on the degree to which participant can exert effort. It was expected that participants with dyslexia would be less effective in the performance on the DR task as a measure of the degree of mental effort. In accordance, the group differences in the DR task increased rapidly with the increase of stimulus complexity (Table 2). This suggests that processing speed deficits in participants with dyslexia deteriorate as the complexity of the stimulus increases [77, 78].

Participants with dyslexia were significantly more impaired on measures of motor speed (as measured by the FTT) as compared with those without dyslexia. In fact, individuals' with dyslexia are reported to be clumsy, with poor handwriting, suggesting that there may be a motor deficit in dyslexia [79]. Our results are consistent with a previous suggestion that a motor speed deficit in dyslexia may not simply be a sign of developmental delay, but may persist into adulthood and it may be related to the speed at which literacy information is processed [80]. Furthermore, some individuals with dyslexia may suffer from an implicit motor learning deficit, which could generalize to non-motor learning [81].

The group with dyslexia did not show significant impairment in selective attention (Stroop), N-Back task, tasks measuring speed of information input (IT) and motion perception (MP) capacities (Table 2). The participants with and without dyslexia did not differ in their accuracy and reaction times in the N-Back conditions, in accordance with previous studies [82]. Why do participants with dyslexia perform at the same level of accuracy and with the same speed of responses as controls on the N-Back task? One possible explanation is that N-Back is a measure of semantic working memory and correlates well with IQ. IQ is preserved among dyslexic individuals' [83]. As reported previously, participants with and without dyslexia in this sample did not differ in performance on a Reasoning task [63]. Motion perception is a key task for identifying individuals with dyslexia who have a specific deficit in the magnocellular pathways of the visual system [84]. However, in our dyslexia sample the percent of participants with impaired motion perception was small and differences between dyslexia and controls were absent.

A further main finding of the current study is that performance on online NPA in the Czech and the Hungarian participants was different. Over and above dyslexia status, Hungarian students made a greater number of errors and had slower responses than Czech participants (Table 3). One possible explanation is that the difference between these samples may go beyond language differences and include also motivational variables. Dealing with an increasing volume of information requires the use of cognitive resources available for processing. Cognitive resources are limited and individuals differ in motivation to adjust their cognitive capacity to dealing with a demanding volume of information. Methods to evaluate degree of motivational involvement or level of effort have recently become an important part of NPA, because about 50% of the variance in scores on any test may be explained by effort and co-operation [85]. We tested motivation-related sampling bias using the number of random, interrupted or otherwise unreliable responses. Real-time documentation of performance is very sensitive to low participant motivation and non-serious responses ["sub-optimal performance" and "non-interpretable results related to unmotivated responses" **[**86, 87], especially during assessment of attention [88]. If Hungarian students performed less seriously, the number of participants excluded from the statistical analysis because of low motivation should be higher than in the Czech sample. In fact, the number of unreliable responses was significantly higher in Hungarian sample (Table 4), providing evidence that motivation-related sampling bias did adversely affect the results. As compared with our previous work, the motivational factors have a more demanding nature on the NPA performance than on the learning tasks [35], because participants were recruited for a study focused on the reading ability.

The significant differences in percent of reliable results between two samples were most likely related to differences in recruitment in the two counties. Czech dyslexic participants were in a continuous personal relationship with their caretakers from the Pedagogical and Psychological Counseling Center, but Hungarian participants did not have a continuous personal relationship with their caretakers. A one-to-one relationship between participant and caregiver in the past can influence the effort of examinee during home performance. In addition, Czech participants received financial compensation for their time and reimbursement of travel costs in contrast to Hungarian participants who got the document on the assessment for free. Previously it was found that monetary incentive can enhance performance in terms of both speed and accuracy [89, 90]. However, it should be noted that the percent of reliable results we observed was nearly the same as previously reported for completing an Internet-based questionnaire [91].

Another noteworthy aspect of current study is related to association between Web-based real-time NPA performance and online disinhibition effect. Online disinhibition effect is a loosening during interactions with others on the Internet of social inhibitions that would otherwise be present in normal face-to-face interaction [30]. We can to expect the online disinhibition effect to impair tests results in Web-based online performance of a participant at home. We see that "behavioral", "reflexive" and "cognitive" types of the disinhibition (Go/NoGo task, MFFT and Stroop task) are more expressed among the less motivated Hungarian participants than in Czech students (see Table 3). In our study this difference was not related to dyslexia (Table 2).

Limitations

The present study has two key strengths. (i) The study implemented a comprehensive NPA battery of cognitive tasks using a Web setting. (ii) Data were obtained from two student samples in two European countries thus allowing the impact of population to be taken into account and increasing generalizability. However, our results should be interpreted in the light of possible limitations. (i) The study included only a defined age group, from 18 to 30 years. This age limitation was implemented in order to limit variability due to age effects and thus allow results to be more definitive. Therefore generalization of the results to all age groups is not possible. However, data will be accumulated over time from the Literacy Portal (www.literacyportal.eu) allowing this limitation to be addressed. (ii) We excluded from the analysis participants with unreliable or poorly motivated responses. Thus, it is possible that the discriminant power of the online tasks may be less pronounced than could be expected in comparison with laboratory situations in which drop-out would have been the significantly lower. (iii) Factors that could have influenced the quality of online real-time performance such as "media literacy", personality traits, comorbidity with ADHD as a clinical diagnosis, motor difficulties and daily dose of psychostimulants such as nicotine [92] and caffeine were not controlled in the present study. Therefore, results based on these measures should be interpreted with caution. It would be useful for future studies to administer multiple measures of key neuropsychological domains to facilitate the creation of shorter and reliable Web-based screening battery of dyslexia.

Conclusion

The results of the present research support the conclusion that Web-based real-time NPA is sufficient in terms of its power to discriminate students with dyslexia from non-dyslexic students including participants from different language groups. It was found that participants with dyslexia have a distinct profile of cognitive impairment compared to participants without dyslexia. Future calibration of tasks used for online real-time NPA should focus on understanding of trans-cultural differences across individuals, regions, and language. Performance on the tasks should be then compared across countries after standardizing performance within each country. Future research should also use specific tasks useful for qualification of motivational involvement during real-time NPA in Web-based tasks, given that monetary incentive and a relationship between participants and caretaker were important factors influencing online performance in the current study.

Further studies are needed to replicate the present findings, and aggregation of the present findings with future work will further clarify the utility of real-time, online NPA.

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