NeuroRegulation

Validation and Application of a Factorial Model of Attention in Attention-Deficit/Hyperactivity Disorder

María Agudo Juan[1], Rubén Pérez-Elvira[1,2], Marina Wobbeking[2], and Bogdan Neamtu[3,4,5]*

[1]Laboratory of Neuropsychophysiology, NEPSA Rehabilitación Neurológica, Salamanca, Spain
[2] Pontifical University of Salamanca, Salamanca, Spain
[3] Medicine Faculty, Lucian Blaga University, Sibiu, Romania
[4] Research Department (Ceforaten), Sibiu Pediatric Hospital, Sibiu, Romania
[5] Faculty of Engineering, Lucian Blaga University, Sibiu, Romania

Abstract

Background. Attentional processes and executive functions have been essential elements in the study of attention-deficit/hyperactivity disorder (ADHD). This research aims to validate Ríos Lago and Muñoz-Céspedes (2004) factorial model of attention in ADHD and to investigate the attentional and executive alterations that occur in ADHD according to this model. **Method**. A total of 40 participants, aged between 7 and 16 years, took part in the study. The sample included 20 ADHD patients and 20 control subjects who participated as volunteers. **Results**. The factors identified through principal component analysis accounted for 78.81% of the variance in the data. Four factors were found, consistent with Ríos Lago and Muñoz-Céspedes' model, based on the factor loadings and following neuropsychological criteria. **Conclusions**. The results supported the replicability of the proposed attentional model in ADHD. They demonstrated the presence of specific alterations in individuals with ADHD, as predicted by the model.

Keywords: ADHD; factorial model of attention; neuropsychological testing

Citation: Agudo Juan, M., Pérez-Elvira, R., Wobbeking, M., & Neamtu, B. (2024). Validation and application of a factorial model of attention in attention-deficit/hyperactivity disorder. *NeuroRegulation, 11*(1), 53–61. https://doi.org/10.15540/nr.11.1.53

***Address correspondence to:** Marina Wobbeking, Facultad de Psicología, Universidad Pontificia de Salamanca, C/ Compañía, 5 37002, Salamanca, Spain. Email: mwobbekingsa@upsa.es

Edited by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA

Reviewed by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA
Mark S. Jones, DMin, University of Texas at San Antonio, San Antonio, Texas, USA

Attention-deficit/hyperactivity disorder (ADHD) has been associated with deficits in attentional processes and executive functions. This disorder begins in childhood and has been defined as a sustained pattern of inattention, hyperactivity, and impulsivity behaviors that must be maintained for a sufficient period of time and usually appears before the age of 12 years (Piñón et al., 2019). ADHD has been considered a problem of behavioral self-regulation. In contrast, in the past decades it was defined not only as a behavioral disorder but also as a learning disorder, explained as deficits in cognitive functions that manifest themselves in disruptive behaviors (García-Nonell & Rigau-Ratera, 2015). According to the *Diagnostic and Statistical Manual of Mental Disorders*, it shows three clinical presentations: inattentive, hyperactive/impulsive, and combined inattentive and hyperactive-impulsive (5th ed.; DSM-5; American Psychiatric Association [APA], 2013).

As noted, one of the affected processes in ADHD is attention. Mellado et al. (2013) state that attention is understood as a control mechanism, which activates the necessary processes to perfect the processing of information and inhibit stimuli that could create interference, ensuring perceptual processing of sensory messages relevant to the goal set and an equally adequate execution of relevant actions to achieve it, in addition to being linked to motivational mechanisms. Therefore, it is a precondition for cognition and indispensable for affective behavior and the survival of the human being itself (Sales, 2016). Attention is composed of different types of processes and systems, within which are situated processes aimed at creating and maintaining an adequate state of alertness, guidance systems aimed at the selection of relevant information from sensory input, and processes that are to a greater extent related to the control and monitoring of attentional resources (Fan, et al., 2002; Rodríguez-Blanco et al., 2017; Stuss, 2006). One of the most interesting attentional models is the one developed by Ríos, Periáñez and Muñoz-Céspedes (2004), who have based their model on a series of response patterns in different psychometric tests and factor analysis to elucidate the underlying attentional mechanisms for performance in these tests. Factor analysis represents a strong, satisfactory, and relatively common tool to study which underlying constructs are represented in different tests and which are responsible for the variance of a group of items in an independent test or in a battery (Agelink van Rentergem et al., 2020; Santos et al., 2015; Spikman et al., 2001; Ustárroz et al., 2012).

Thus, they proposed a model that studies four factors (Table 1), based on factor analysis applied to the results of patients with traumatic brain injury and normal subjects in some classic attention tests (Stroop; Trail Making Test; Wisconsin Card Sorting Test; Ríos Lago et al., 2008).

Table 1
Factors in Attention Measures

High-level Processes	Low-level Processes
Control	Speed of Information Processing
Interference Control	
Cognitive Flexibility	
Working Memory	

Ríos et al. (2004) attention factorial model.

Components of Care

The components of care according to this model are described below.

Speed of Processing. It is the amount of information that can be processed per unit of time (Spikman et al., 2001). As it has been highlighted, it is more a substrate on which attention develops than an attentional component. Although it is not an attentional process per se, it is closely related to attention and can affect attentional performance, such that if attention is not fast it may not fully fulfill its adaptive function.

Attentional Control. Three components are grouped under this denomination.

- **Cognitive Flexibility**. It is the ability to shift the focus of attention from one scheme of action to a different one and modify behavior in response to changes in the environment.
- **Operative Memory**. This is the ability to maintain information that has been experienced in previous instants, or information retrieved from long-term memory, and which is no longer available in the environment, also implying the ability to manipulate this information (Ríos Lago et al., 2008). Likewise, the ability to change the attentional focus would depend on working memory (Baddeley, 2001).
- **Control of Interference**. One of the most consistent findings in the work on attention, this factor shows the ability to control the tendency of overlearned automatic responses and distractions from irrelevant stimuli (Klenberg et al., 2001; Pineda Salazar et al., 2000).

Consequently, in order to perform attentional tasks, both components, speed and control, would be necessary. These components reflect two characteristics of the tasks: time pressure and structure, respectively. If the task is highly structured, the amount of control required will be minimal, the main factor being the processing speed. If, on the contrary, the task has little organization, the control required for its performance will be the maximum, since it cannot be solved with routine responses and will require interference control, cognitive flexibility, and working memory (Ríos Lago et al., 2008).

Our objectives with this study are 1) validation of the Factorial Model of Attention by Ríos Lago and Muñoz-Céspedes (2004) in ADHD, assuming the hypothesis that the factorial analysis will reveal four factors equivalent to those of the Ríos et al. (2004) model, and 2) to verify the attentional and executive impairments that occur in ADHD, according to the model by Ríos Lago and Muñoz-Céspedes (2004), in order to differentiate which tests or scores better distinguish between healthy subjects and controls.

Methods

Subjects

Data for this study were obtained from a sample of 40 subjects, aged 7 to 16 years. The sample included 20 ADHD patients and 20 healthy controls who participated as volunteers. The clinical subjects were referred by the Guidance and Behavior Team of the Junta de Castilla y León, after requesting their participation in this study. The inclusion criteria for participation in this study were as follows:

- **Clinical Group**. Diagnosis of ADHD (following the ADHD coordination protocol of the Junta de Castilla y León), drug control (withdrawal 24 hours before the application of the tests) under the supervision of the neurologist and acceptance by the parents, age between 7–16 years, and no other medical complications or psychiatric disorders. The parents signed an informed consent for their children to participate in the study.
- **Control Group**. Same age criteria as the clinical group and no medical complication or psychiatric alteration.

The ethics committee of our affiliated research institution (Research and Telemedicine Center for Neurological Diseases in Children—the CEFORATEN project) approved the study with the following authorization number: ECN 6227/23. We complied with all the ethical standards asserted in the Declaration of Helsinki in the study's design.

Instruments

Neuropsychological factors and tests included:

- **Speed of Processing**. For this component, test or subtest scores involving speed or time pressure were used, such as the Trail Making Test (TMT), Letters and Numbers (LN), Symbol Search (BS) and Number Key (CN) of the WISC-IV, Stroop P, Stroop PC, and Brief Test of Attention (BTA). The TMT is a neuropsychological instrument widely used as an indicator of processing speed (Sánchez-Cubillo et al., 2009). Both parts A and B require speed in execution, with time being a decisive aspect in the performance of the task. CN and BS are part of the Processing Speed index of the WISC-IV. In both, the subject is under time pressure, since they have to perform the task in a certain amount of time—speed playing a primordial role for the correct performance of the task. In other tests such as LN or BTA (total), although time measures are not taken and they are not considered processing speed tests, these are tasks where the rate of stimulus presentation is not controlled by the patient but by the examiner. The task has a standard rate and not one appropriate for each patient, so there is some implicit time pressure (Ríos et al., 2004). Likewise, the Stroop test requires an adequate processing speed for its correct performance.
- **Cognitive Flexibility**. For this factor we used the Wisconsin Card Sorting Test (WCST) hits, perseverative errors and perseverative responses and the TMT B/A score (Ríos et al., 2004). The WCST has been one of the most widely used tests in the attentional switching paradigm, both in clinical and research contexts (Periáñez et al., 2004). The WCST also reflects skills related to cognitive flexibility that are not measured by other prefrontal tests (Barceló et al., 2000). Perseverative responses would reflect inflexibility in shifting attentional focus to another set (Ríos et al., 2004; Greve et al., 1999), on the contrary, the percentage of successes in the test is related to the ability to shift attentional focus (Ríos et al., 2004). As for the TMT B/A ratio, it reflects alternating attention, which also implies the ability to shift attention from one sequence to another; in this score the influence of processing speed is eliminated (Ríos et al., 2004) and the influences of visuoperceptual and working memory demands are minimized, thus obtaining a relatively purer indicator of control (Sánchez-Cubillo et al., 2009).
- **Operative Memory**. This factor consisted of scores related to information maintenance and manipulation; that is, LN, BTA Total, set loss, and nonperseverative errors on the WCST (Ríos et al., 2004). The LN score is clearly related to working memory processes, being a working memory index of the WISC-IV (Wechsler, 2007). The BTA score reflects, among other things, the ability to mentally manipulate numerical information that is not already present while attending to a series of items being presented (Ríos et al., 2004). Several factors underlie the performance of the WCST, so not only are its scores indicative of Cognitive Flexibility but its performance would also involve working memory (Brauer et al., 1998; Ríos et al., 2004). Although there has been some confusion about whether working memory is involved in the performance of the TMT, Kortte et al. (2002) found that neither part A nor part B was related to the maintenance of information.
- **Control of Interference**. This factor included two Stroop test scores (Stroop PC and Interference), the TMT B/A ratio and the

Paced Auditory Serial Addition Test score (PASAT, in this case 3); the Stroop PC and Stroop Interference scores suggest that there is a cognitive process that controls the tendency of automatic responses. In the PASAT, the presence of interference control is evident since it is necessary for the subject to inhibit the responses that they offer in order to correctly attend to the list of numbers that is presented to them audibly (Ríos et al., 2004). The score extracted from the B/A ratio of the TMT implies an attentional shift that is composed of a change of focus to another point of attention and, in addition, of an inhibition or control component (Arbuthnott & Frank, 2000; Ríos et al., 2004). This inhibition component would therefore be an important element of control (Mecklinger et al., 1999).

In addition, the finger-tapping test (FTT; Enokizono et al., 2022) was applied as a measure of motor speed.

Procedure

To collect the data, each participant was invited to the NEPSA Neurological Rehabilitation Clinic (Salamanca). The subjects in the clinical group had not taken medication in the previous 24 hours. All subjects were evaluated after their parents' signed consent and the subsequent return of a report with their performance in these tests.

First, a form was collected that included their demographic variables (sex, age, date of birth, group, and contact data). The tests were applied in an office under the same conditions, with the following order: Digits and Number Key (CN) from the WISC-IV, Stroop test, Wisconsin Card Sorting Test (WCST), Brief Test of Attention (BTA), Trail Making Test (TMT), Paced Auditory Serial Addition Test (PASAT), finger-tapping test (FTT), Letters and Numbers (LN) and Symbol Search (BS) from the WISC-IV. Despite alternating between manipulative and verbal tests, there seemed to be no influence of the order of application of these tests on test performance, according to Ríos Lago and Muñoz-Céspedes (2004). The rules of each test were explained, making sure that all participants understood what had to be done in each test. The duration of the tests ranged from 50 to 75 min. Optionally, the possibility of an intellectual capacity assessment on another day was offered to all those who were interested, subsequent to the attention assessment. The data were coded in an Excel spreadsheet for later analysis.

Data Analysis

All analyses were performed using SPSS version 25.0 software, except for the effect size, which was obtained using the Cohen's *d* calculator of the University of Colorado (https://www.uccs.edu/lbecker/). The statistical analyses performed were as follows:

For objective 1, the possibility of obtaining a factorial structure of the utilized scores was studied by considering the results of two tests, Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity. Afterward, a principal component analysis was conducted. Varimax rotation method used with Kaiser normalization.

For objective 2, the Shapiro-Wilk test of normality was performed to assess the fit of each score to a normal distribution. Subsequently, a mean difference test was applied using either the parametric Student's *t*-test for normally distributed scores or the nonparametric Mann-Whitney U test for nonnormally distributed scores. Cohen's *d* was used to calculate effect sizes.

Results

The results obtained from the aforementioned analysis are presented below.

No significant differences were found between groups with respect to age (Table 2).

In regard to objective 1, as shown in Table 3, both assumptions, factorial structure and relationship between variables, are met.

Table 2

ADHD and Control Groups Ages

	ADHD	Control	U Mann-Whitney	*p*
Age	*M* = 129.85	*M* = 137.75	177.5	.547
	DT = 33.14	*DT* = 35.01		
	N = 20	*N* = 20		

Table 3
KMO and Bartlett Tests

KMO	Bartlett's Sphericity		
	Approx. Chi-squared	gl	Sig.
.687	630.419	105	.000

The principal component analysis yielded a grouping into four factors that explained 78.81% of the variance (Table 4). Table 5 shows, marked in bold, the scores that loaded for each factor.

In regard to objective 2, we further present the results for each test.

In the Stroop test, only the Interference score of the control group was normally distributed, so the Mann-Whitney U test was chosen to study their mean differences. Significant differences were found in all scores (Stroop P: $U = 90$, $p = .002$, $d = 1.228$; Stroop C: $U = 92$, $p = .003$, $d = 1.014$; Stroop PC: $U = 111$, $p = .015$, $d = 0.966$) except for the Interference score (Stroop Interference: $U = 152$, $p = .194$, $d = 0.460$). However, for the latter data, the effect size was medium, compared to the acceptable effect size for the other scores of the same test. The clinical group was significantly worse than the control in Word, Color, and Word-Color scores.

Table 4
Explained Variance

Component	Percentage of variance per factor	Percentage of cumulative variance
1 Speed of Processing	46.498	46.498
2 Cognitive Flexibility	16.152	62.650
3 Operative Memory	8.702	71.352
4 Control of Interference	7.461	78.813

Table 5
Rotated Component Array

	Components			
	1	2	3	4
ST-P	**.874**	−.099	−.138	−.208
TMT-A	**−.883**	.050	.150	.050
TMT-B	**−.678**	.141	.210	**.617**
ST-PC	**.954**	.031	−.050	−.135
CL-A	**.719**	.061	.167	−.300
BS	**.732**	.188	.139	−.317
LN-T	**.597**	−.124	**−.559**	−.287
BTA-T	**.751**	−.229	−.230	.026
WCST % Perseverative Errors	−.205	**.582**	**.513**	−.084
WCST % Conceptual Level	.035	**−.973**	−.117	−.056
TMT B/A	−.143	.101	.166	**.899**
WCST Set Loss	.067	-.061	**.828**	.158
WCST % Nonperseverative Errors	.130	**.893**	−.177	.134
ST-INT	**.848**	.134	−.006	.058
PASAT Correct Responses	**.715**	−.121	**−.496**	−.051

Note. Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization. The rotation has converged in six iterations.

As for the WISC-IV Number Key subtest, a normal distribution was found in the correct scores, but not in the errors made. Therefore, the *t* and *U* statistics were applied respectively. Significant differences were found in correct scores (t = 3.285, p = .002, d = 1.039), however, the clinical group did not make more errors (U = 170, p = .429, d = 0.454), with a moderate effect size.

In Digits, we found a total score that was significantly worse in the clinical group with respect to the control group (U = 81, p = .001, d = 0.979), obtaining a large effect size.

The mean difference in the BTA total score showed that the clinical group scored significantly higher than the control (t = 2.523, p = .016, d = 0.799). A mean effect size was obtained for this test.

TMT, a significant difference between groups was obtained in the B score (U = 95, p = .004, d = 0.839) with a large effect size, and in the B/A speed free score (U = 90.5, p = .002, d = 1.059), also with a large effect size.

The clinical group also scored significantly worse on the Letters and Numbers subtest (U = 93.5, p = .003, d = 1.029), with a large effect size.

In the Symbol Search subtest, the clinical group scored significantly worse than the control group (U = 121, p = .033, d = 0.724) although, again, they did not make more errors than the control group (U = 171.5, p = .445, d = 0.154). This last finding should be taken with caution due to the small effect size obtained.

Motor speed, as measured by FTT, was not found to be different between groups (U = 144, p = .134, d = 0.336), although a small effect size was obtained.

No significant differences were found in any PASAT score (Hits: U = 129.5, p = .056, d = 0.583; Omissions: U = 160, p = .289, d = 0.487; Errors: U = 172, p = .461, d = 0.147). The clinical group, again, did not make more errors, but similarly a low effect size was found for this score.

No significant differences were found in any WCST score between the groups (Number of attempts: U = 174, p = .495, d = 0.201; Number of categories: U = 165.5, p = .355, d = 0.358; % Hits: U = 195, p = .904, d = 0.140; % Errors: U = 186.5, p = .718, d = 0.193; % Perseverative Errors: U = 167, p = .383, d = 0.306; % Nonperseverative Errors: U = 188, p = .758, d = 0.121; Perseverative %RR: U = 173.5, p = .478, d = 0.226; % Conceptual Level: U = 184, p = .678, d = 0.236; Set loss: U = 181, p = .620, d = 0.200), although the low effect size obtained for each of the scores must be taken into account.

The clinical group performed worse on the Working Memory Index than the control (U = 86.4, p = .002, d = 1.072), achieving a large effect size.

As for the Processing Speed Index, there was no significant difference between groups (U = 150.5, p = .183, d = 0.519), with a moderate effect size.

Discussion

The factors found after principal component analysis were able to explain 78.81% of the variance of the data. Four factors were found, as in the Ríos et al. model, which, due to the scores that loaded on each of the factors (Table 5), and according to neuropsychological criteria, were similar to those presented in the work of Ríos et al. (2004).

Key Factors

1 Speed of Processing. The first factor included scores where processing speed or time pressure is present in test performance. In this factor, we loaded scores such as CL and BS which, although they may involve other functions or subfunctions for their performance, have processing speed as their main construct and in fact constitute the two main tests for the calculation of the WISC-IV Processing Speed Index. In addition, other tests carry time pressure explicitly, such as the Stroop subtests, or those of the TMT, or implicitly, such as LN, BTA, and PASAT, where time pressure is exerted by stimulus presentation ratio (1 item/1s or 1 item/3s, for example). The B/A ratio of the TMT did not saturate in this factor, probably because it is an a posteriori calculation where the influence of speed is precisely isolated.

2 Cognitive Flexibility. The second factor was composed of WCST scores, where cognitive flexibility, the ability to shift the focus of attention from one task to another, is a mandatory skill. Thus, the percentage of perseverative errors shows the inability to leave the focus of attention from one stimulus source and switch to another when demands dictate it. Similarly, the percentage of successes is a measure of the effective ability to shift focus when required. The percentage of nonperseverative errors would, like the previous score, be related to the ability to be flexible; a higher number of nonperseverative errors (as opposed to perseverative errors) would inform us that the subject's problem is not in flexibility but in other issues related to a test as complex as the WCST.

3 Operative Memory. The third factor includes scores that have in common some relationship to working memory. LN is a core test of the WISC-IV Working Memory Index, as well as there is sufficient literature support for the influence of WCST on working memory (Monchi et al., 2001). The PASAT clearly includes the ability to mentally retain information and operate with it, so it is not surprising that it is also one of the saturating scores in this factor.

4 Control of Interference. The fourth factor is exclusively configured by the TMT-B and TMT-B/A scores. Although these scores also saturate in flexibility, they do so here without the presence of other components of flexibility (such as the WCST scores), and studies show that in addition to a focus-shifting ability component, a prior focus inhibition component is necessary in the performance of this test (Houghton & Tipper, 1996; Mecklinger et al., 1999). It is not surprising that the Stroop interference subtest does not appear here; the sample size may have contributed to its undetectability as an element of this factor.

The results for objective 1 are compatible with accepting that the Ríos et al. model is replicable, fulfilled in a sample of children and adolescents, made up of both healthy controls and subjects with ADHD. In this study, we found a factorial structure underlying the tests used, a relationship between them and four principal components that are highly coincident with those proposed by Ríos et al. (2004).

As for objective 2, to study attentional disturbances in ADHD following the Ríos et al. model and to be able to decide which scores are more representative to differentiate between controls and ADHD, our data showed that subjects with ADHD performed significantly lower than controls in Stroop P, Stroop C, Stroop, PC, CL, Digits, BTA-t, TMT-B, TMT-B/A, LN, BS, and the Working Memory Index of the WISC-IV. These battery scores would therefore be more appropriate to distinguish subjects with ADHD from those without ADHD. If we consider the four factors of the model by the scores that make up each one of them, *4 Control of Interference* was affected 100% in ADHD, followed by *1 Speed of Processing*, affected 81.8%, after which *3 Operative Memory* was affected 25%. *2 Cognitive Flexibility* was not affected.

On the other hand, it should be noted that in those tests where errors were computed (CL and BS) no differences were found between the ADHD group and the control group. Errors in these tests can be of omission and commission; That is, for lack of response to the item or for responding in an inadequate way to the item. Both issues closely relate to the interference control; however, neither of these two tests appeared among the constituent of the interference factor, which could mean that the low performance of the ADHD group subjects in these tests is explained precisely by the alteration in the processing speed. Nor did subjects with ADHD perform worse compared to controls on the FTT, which could rule out motor slowing as a cause of poor performance on time-pressure tests involving paper and pencil.

Our study contributes to a better understanding of the underlying cognitive impairments in ADHD and provides valuable insights for clinical assessment and intervention. The factorial model of attention, validated in this study, offers a comprehensive framework for assessing and characterizing attentional deficits in individuals with ADHD. On the other hand, it is important to highlight that the study had a small sample size, which could be a potential source of bias in the results and their interpretations.

Future research should continue to explore the applicability of this factorial model in larger and more diverse samples to enhance its generalizability. Additionally, investigating the relationships between the identified factors and other relevant clinical variables may provide further insights into the complexity of ADHD and guide targeted interventions.

Conclusions

In conclusion, our study aimed to validate and apply the mentioned factorial model of attention in ADHD. The results provided strong support for the replicability of the model proposed by Ríos et al (2004). The identified factors were able to explain a significant portion (78.81%) of the variance in the data.

The factorial analysis revealed four distinct factors that closely aligned with the Ríos et al. model. These factors included Speed of Processing, Cognitive Flexibility, Operative Memory, and Control of Interference.

Furthermore, our findings demonstrated significant differences between individuals with ADHD and healthy controls in various tests, confirming the utility of using these tests in ADHD detection. Scores in tests such as Stroop, WCST, LN, and the Working Memory Index of the WISC-IV consistently differentiated between the two groups.

Author Acknowledgements

This article is part of a research project by María Agudo Juan and Rubén Pérez-Elvira within a collaboration with the Research and Telemedicine Center in Neurological Diseases in Children-CEFORATEN project (ID 928 SMIS-CSNR 13605) financed by ANCSI with the grant number 432/21.12.2012 through the Sectoral Operational Program "Increase of Economic Competitiveness."

Author Disclosure

The authors declare no conflict of interest. The authors received no financial support for the research, authorship, and/or publication of this article.

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Received: October 05, 2023
Accepted: October 30, 2023
Published: March 29, 2024