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Differences in sensory processing in children using the AULA test: A comparative analysis of auditory and visual stimuli

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ABSTRACT. L'ADHD è un disturbo che colpisce principalmente bambini e adolescenti ed è caratterizzato da sintomi importanti e duraturi di disattenzione, iperattività e impulsività. Questo studio indaga il modo in cui i bambini con sviluppo tipico (TD) rispondono agli stimoli uditivi e visivi, confrontando il loro comportamento con i bambini che presentano sospetto di disturbo da deficit di attenzione e iperattività. Per la ricerca sono stati raccolti due campioni, uno composto da 1295 partecipanti e l'altro da 378 partecipanti, di età compresa tra gli 8 e i 16 anni. L'ipotesi principale afferma che non ci sarà alcuna differenza nella risposta del partecipante agli stimoli visivi e uditivi mentre la seconda suggerisce che se la prima ipotesi non è supportata, ci saranno notevoli differenze nelle risposte del campione clinico a questi stimoli.

SUMMARY. ADHD is a disorder that primarily affects children and adolescents, characterised by prominent and enduring symptoms of inattention, overactivity, and impulsivity. This study investigates how children with typical development (TD) respond to auditory and visual stimuli, comparing their behaviour to clinic-referred children who are suspected of having ADHD. Two samples were collected for this analysis, one consisting of 1,295 participants and the other consisting of 378 participants between the ages of 8 and 16. The main hypothesis states that there will be no difference in the participant's response to visual and auditory stimuli. The second hypothesis suggests that if the first hypothesis is not supported, there will be noticeable differences in the responses of the clinical sample to these stimuli. Results suggest that the first hypothesis is fulfilled for all variables except for the variables mean time for correct responses and omissions. Likewise, differences are also present in the clinical sample, confirming the second hypothesis.

Keywords: *ADHD, Attention, Children, AULA test, Auditory stimuli, Visual stimuli*

INTRODUCTION

In humans, the perception of the world, including sensory information processing, is influenced by perceptions of the environment, our emotional state, and relevant information from the surrounding environment (Carrasco, 2011; Chen et al., 2015). Processing of the stimuli received is carried out through the complex cognitive process of attention, which involves selection and focus on specific information among the multitude of stimuli around us (Gabay, Gabay, Schiff & Henik, 2019; Green, Doesburg, Ward & McDonald, 2011).

Attention can be divided into visual attention and auditory attention according to the nature of the stimulus. Visual attention focuses on the ability to enhance or process important information while inhibiting or ignoring relatively irrelevant information (Steinman & Steinman, 1998). On the other hand, auditory attention is focused on the ability to recognise relevant acoustic cues, such as speech or linguistic stimuli, and sustain that attention for an age-appropriate period of time (Andrews & Dowling, 1991; Bussing, Mason, Bell, Porter & Garvan, 2010). Both cognitive processes require specific brain mechanisms (Fiebelkorn et al., 2011), which vary according to the sex of the individual (Solberg et al., 2018). In typically developed individuals (TD), different levels of attentional performance are observed in boys and girls (Climent-Martinez & Banterla, 2011).

The most prominent psychological pathology associated with poor attention is Attention Deficit Hyperactivity Disorder (ADHD) (Schmidt & Petermann, 2009). ADHD is considered one of the most common causes of mental health problems (Hoseini, Ajilian, Moghaddam, Khademi & Saeidi, 2014) and is associated with perception, learning, memory, and executive functioning (Callahan & Terry, 2015).

ADHD manifests itself in a variety of ways, with different types of symptoms in varying levels of severity. In the case of children with ADHD, they are more likely to experience poor school performance, social isolation, and antisocial behaviour than their peers and often face significant difficulties after school (Hoseini et al., 2014).

This pathology in the school population reaches a prevalence rate of 11.4% (Willcut, 2012), causing children to experience dysfunctions that affect various activities, including academic skills in the classroom and behavioural inhibition deficits (Chiang, Chen, Lo, Tseng & Gau, 2015; Imeraj et al., 2016). Furthermore, it is often chronic, with between one third and one half of the affected persisting into adulthood.

To efficiently assess and diagnose this pathology, a virtual reality (VR) test called *Attention Kids Aula* (*AULA*) is available on the market (Iriarte et al., 2016) which has been tested in more than 1326 children, translated into more than 12 languages and with a presence in more than 24 countries around the world (Attention Kids Aula, 2021).

Its clinical report examines the significance of visual and auditory stimuli in the performance of the examinee (Climent-Martinez & Banterla, 2011). This knowledge is fundamental to the development of effective strategies that support parents, caregivers, and health professionals to manage and treat the symptoms of ADHD in these children. It may also involve environmental adjustments, such as changes in lighting or noise level in a room, and the use of specific sensory therapies to help the child regulate sensory processing, thus improving concentration and behaviour control.

To improve this study, it is essential to analyse the relationship between visual and auditory stimuli in TD children and compare it with the analysis of the prevalence of such relationships in children with suspected ADHD (clinical children). Although Lin and colleagues (Lin, Chiu, Hsieh & Wang, 2023) and Simões and colleagues (Simões, Carvalho & Schmidt, 2021) have researched auditory and visual stimuli in TD and ADHD children, they did not use the AULA test for this purpose excluding the comparison of their results to this study.

The present study aims to analyse the response of typically developed children to auditory and visual stimuli and to compare it with the behaviour of children with suspected ADHD (clinical children) based on age and sex using the AULA test.

METHOD

Participants

To carry out the study, two different samples were obtained.

The first corresponds to the sample used to perform the AULA's normative study and comprises 1,295 participants (48% female), aged from 6 to 16 years (M = 10.43, SD = 2.86). This sample may be considered representative of the population of TD children because the prevalence of ADHD in a normal population is less than 12%.

The collaboration was proposed to schools in the Basque Country and Navarre; the schools were randomly selected based on their willingness to participate in the AULA's normative study. At the same time, informed consent was obtained from the parents of all study participants, and all students in schools between the ages of 6 and 16 were free to participate in the study. Thus, every student in the selected schools who fell within the defined age range had the same opportunity to participate in the AULA's normative study. In the end, five urban charter schools participated.

The second corresponds to the clinic data sample and comprises 378 participants (28% female), aged from 8 to 16 years (M = 11.15, SD = 2.41). This sample includes suspected ADHD children, children who are symptom-positive and who visit the clinic but whose clinical diagnosis has not been obtained for this study.

The collaboration was proposed in 108 clinics in different countries, where qualified clinic staff administered the AULA test to children aged 8-16 years with suspected ADHD. The distribution of clinics per country was as follows: AR (2), CL (3), CO (2), CR (1), EC (2), ES (75), MA (1), MX (15), PE (1), PL (1), US (4) and UY (1).

Assessment tool

The assessment tool used is a virtual reality test, AULA, which was developed to measure attention in children between 6 and 16 years of age. Its virtual setting is similar to a classroom, and the perspective places the examinee on one of the desks, facing the blackboard (see Figure 1). The head movements of the examinee are captured by the VR headset and the software updates the scene accordingly, giving the examinee the real feeling of being in the classroom. In the classroom, the examinee listens to the instructions for the tasks to be performed. To complete the task, according to specific instructions, they have to press the push button each time the presented stimulus does not appear (target stimulus), or every time the presented stimulus appears. In addition, the examinees have to face a series of distractors common in this environment, e.g., noises from the street, classmates talking/doing other things, a knocking on the door.

Figure 1 – Screenshot of the main AULA scenario

AULA is a continuous performance test (CPT) that involves two different paradigms: an X-No paradigm, where the button has to be pressed each time the examinee does not see or hear the target stimulus, and an exercise based on an X paradigm, where the examinee has to press the button whenever they see or hear the target stimulus. Likewise, before starting the test, a usability task is carried out in which the examinee has to find some balloons and pop them to become acquainted with the test. Also, note that each paradigm (X-No and X) has a training task before starting the task.

Variables

The variables that will be included in the study are described below (see Table 1).

There is an inverse linear relationship between errors (omissions/commission) and correct answers. For this reason, only omissions and commissions are examined, since the calculation of overall performance is complementary to errors on the task.

Hypothesis

The main hypothesis is that the participants' visual stimulus exposure will be identical to the participants' auditory stimulus exposure (sample based on the AULA's normative study). The second hypothesis is that these differences will be present in the sample of children with suspected ADHD (clinical children) if differences are found between auditory and visual stimuli (the first hypothesis does not hold).

Procedure

The task and data recording procedures were performed considering the AULA administration protocol (Climent-Martínez & Banterla, 2011). This protocol consists of 3 phases of administration:

The first part, before administering the test, is used to familiarise the examinee with the equipment used. Here are the instructions to be followed by the examinee during the test. The equipment is then provided to the examinee, ensuring a comfortable position and readiness to start the test. During the test, the test administrator is required to ensure the correctness of the test and the correct collection of data. Finally, at the end of the task, the data are transferred to the computer, and the administrator of the test has the responsibility to remove the equipment from the examinee.

In terms of the technical aspect of the data collection, the VR equipment receives the test data and is connected via WIFI to a computer server that receives the data from each examinee in JSON format. Subsequently, a CSV file is generated with the variables obtained during the test.

Next, the relevant variables are selected according to the objectives of this research (see Table 1) and a descriptive analysis of the variables is carried out, as well as a hypothesis test to determine whether their distribution is normal or not, and based on these results, the statistical technique is chosen.

R version 4.2.3 (R Core Team, 2020) is used, specifically the libraries: psych (Revelle, 2024) to analyse the nature of these variables, MVN (Korkmaz, Goksuluk & Zararsiz, 2014) for testing hypotheses, VCD (Meyer, Zeileis & Hornik, 2023) for Cramer's V ratio and lubridate (Grolemund & Wickham, 2011), dplyr (Wickham, François, Henry, Müller & Vaughan, 2023), stringr (Wickham, 2022) for data handling and manipulation.

Once the statistical technique has been narrowed, the significance between the stimuli of each sample must be determined to compare the results between the two samples: the sample based on the AULA's normative study and the sample of children with suspected ADHD.

Data analysis

A descriptive analysis of the variables was carried out to provide a detailed understanding of the data. The most important characteristics of the variables are summarised (see Tables 2 and 3).

Then, an Anderson-Darling test (Anderson & Darling, 1952; Marsaglia & Marsaglia, 2004) was used to test the normality of each variable according to the rank of the age and sex set by the scale. This test is a modification of the Kolmogorov-Smirnov test, which provides a larger weight for the tails. It calculates the critical values by using a specific distribution. This has the advantage of being a sensitive test, but the disadvantage of having to calculate critical values for each distribution (see Tables 4, 5, 6 and 7).

Table 1 – Description of the variables

Variables	*Description*
General performance according to visual stimuli	Overall number of correct answers according to visual stimuli throughout the test. This variable is related to the general performance of the examinee throughout the test.
General performance according to auditory stimuli	Overall number of correct answers according to auditory stimuli throughout the test. This variable is related to the general performance of the examinee throughout the test.
Visual omission	Total number of visual omissions throughout the test, i.e., when the person has to press the button once the visual stimulus is presented but does not do so. This variable is indicative of the level of arousal in response to the visual target stimuli.
Auditory omission	Total number of auditory omissions throughout the test, i.e., when the person has to press the button once the auditory stimulus is presented but does not do so. This variable is indicative of the level of arousal when responding to the target auditory stimuli.
Visual commission	Total number of visual commissions throughout the test, i.e., when the person should not press the button to the presented visual stimulus and, nevertheless, presses. These errors represent an index of impulsivity or the ability to inhibit the response involved in selective attention processes.
Auditory commission	Total number of auditory commissions throughout the test, i.e., when the person should not press the button to the presented auditory stimulus and, nevertheless, presses. These errors represent an index of impulsivity or the ability to inhibit the response involved in selective attention processes.
Mean time for correct answers according to visual stimuli	This measure depicts the average time passed from the presentation of the visual target stimulus until the button pressed to respond. This measure reflects the examinee's response time.
Mean time for correct answers according to auditory stimuli	This measure depicts the average time passed from the presentation of the auditory target stimulus until the button is pressed to respond. This measure reflects the examinee's response time.
Standard deviation of time based on correct answers according to visual stimuli	Indicates the consistency of reaction time in correct answers on visual stimuli. This measure is indicative of changes in sustained attention or fatigability during the test.
Standard deviation of time based on correct answers according to auditory stimuli	Indicates the consistency of reaction time in correct answers on auditory stimuli. This measure is indicative of changes in sustained attention or fatigability during the test.

In the Anderson-Darling test, the null hypothesis is that the data follow a normal distribution. The alternative hypothesis is the lack of a normal distribution of data.

Note that according to the statistical justification of AULA, the study is adapted to the sex and age groups defined on the test scales.

A person who gets a small number of correct answers may have a smaller spread of correct answers than a person who gets a large number of correct answers and has a small number of outliers. This fact makes this variable unsuitable for this study, and therefore, the time standard deviation variable based on correct answers will be removed from the analysis.

Table 2 – Descriptive analysis of the variables based on the sample from the AULA's normative study

Variable	*Mean*	*SD*	*Min.*	*q1*	*Median*	*q3*	*Max.*	*Skew*	*Kurtosis*
Visual omission	17.72	21.07	0	3	8	26	93	1.49	1.35
Auditory omission	7.058	12.35	0	1	3	8	87	3.57	14.22
Visual commission	8.77	9.71	0	4	7	11	82	4.9	31.11
Auditory commission	5.99	9.09	0	2	4	7	80	5.05	31.14
Mean time for correct answers according to visual stimuli	702.97	169.03	0	586.77	674	789.37	2301	1.46	8.35
Mean time for correct answers according to auditory stimuli	1044.17	161.38	0	932.45	1039.62	1150.02	2277.74	.33	3.76
Standard deviation of time based on correct answers according to visual stimuli	263.60	122.88	0	171	239.98	330.93	867.87	.94	1.01
Standard deviation of time based on correct answers according to auditory stimuli	358.89	306.45	0	275.11	343.71	414.43	10318.68	21.41	875.13

For variables with a normal distribution, the test of equal or given proportions description was used (Wilson, 1927). For variables with a non-normal distribution, Fisher's exact test was used, which is more suited to this type of distribution (Fisher, 1922).

The test of equal or given proportions is a statistical significance test used to compare the proportions between two or more groups. The test is a comparison of the observed proportions of each category in the sample with the expected proportions, which may be either a specific set of proportions or simply the overall proportion across all categories. The null hypothesis is that the proportions in each group are equal to or a perfect match to the expected proportions, while the alternative hypothesis is that the proportions are significantly different.

If the *p*-value is less than a pre-specified significance level (= .05), the null hypothesis is rejected, and it is concluded that there is sufficient evidence to state that the proportions are significantly different.

Fisher's exact test is a non-parametric statistical test that determines whether there are significant differences between two proportions. In particular, when the sample size is small, this test is useful. The null hypothesis in Fisher's test is that the proportions are equal, indicating that the variables are independent of each other. The alternative hypothesis is that the proportions are different, indicating that the variables are dependent.

This test calculates the probability of obtaining the observed distribution of the data, as well as any more extreme distributions, given the null hypothesis. The sum of these

Table 3 – Descriptive analysis of the variables based on the sample of children with suspected ADHD

Variable	*Mean*	*SD*	*Min.*	*q1*	*Median*	*q3*	*Max.*	*Skew*	*Kurtosis*
Visual omission	23.38	23.80	0	4	15	36	93	1.08	.23
Auditory omission	12.38	16.61	0	2	6	15.75	87	2.31	5.66
Visual commission	11.7	13.63	0	5	8	13	93	3.44	13.79
Auditory commission	10.08	14.97	0	3	5	10	86	3.05	9.68
Mean time for correct answers according to visual stimuli	586.39	290.96	0	402.82	527.22	713.52	2477	1.53	5.64
Mean time for correct answers according to auditory stimuli	1104.2	205.55	0	986.02	1118.39	1226.15	1777	−1.06	4.87
Standard deviation of time based on correct answers according to visual stimuli	299.69	151.28	0	175.4	270.61	401.48	983.14	.73	.55
Standard deviation of time based on correct answers according to auditory stimuli	384.89	126.76	0	301.52	381.75	452.41	841.25	.32	.95

probabilities is the *p*-value associated with the test. If the *p*-value is less than a pre-specified significance level (= .05), the null hypothesis is rejected and concluded that there is sufficient evidence to state that the variables are dependent, or the proportions are different.

Because Fisher's test checks whether variables are associated, the effect size is known as the strength of the association. There are several measures of association. The most prominent are φ and Cramer's V (Cramér & Harald, 1946). The cut-off values used for their classification are as follows: .1 (small), .3 (medium), and .5 (large) based on one degree of freedom. The smaller the better, as this is intended to ensure that the two variables being measured are not related.

For hypothesis testing, the median is taken as the reference value. This is used to compare the visual stimulus with the auditory stimulus. The median is a statistic that in most cases reflects the behaviour of the population very well (Ruiz-Ruano García & López Puga, 2022). A simple division operation between visual and auditory stimuli is used to calculate the weight of the stimuli.

RESULTS

Table 8 shows results based on the sample from the AULA's normative study and Table 9 shows results based on the sample of children with suspected ADHD. Finally, Tables 10, 11, 12 and 13 summarise the results according to sample (AULA's normative study or suspected ADHD) and sex (male or female).

Table 4 – Normality of each variable based on the sample from the AULA's normative study (male): Anderson-Darling test

Variable/Year	06 (*n* = 90)		07 (*n* = 88)		08 (*n* = 46)		09 (*n* = 74)		10 (*n* = 64)		11 (*n* = 65)		12-16 (*n* = 236)	
	st	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*
Visual omission	1.52	<.001	2.71	<.001	2.20	<.001	4.97	<.001	3.44	<.001	4.94	<.001	29.50	<.001
Auditory omission	10.33	<.001	11.29	<.001	4.85	<.001	9.94	<.001	8.41	<.001	8.39	<.001	33.65	<.001
Visual commission	5.05	<.001	1.02	.01	3.41	<.001	8.22	<.001	.70	.061*	12.77	<.001	27.88	<.001
Auditory commission	6.03	<.001	3.56	<.001	3.59	<.001	11.79	<.001	1.57	<.001	11.89	<.001	41.62	<.001
Mean time for correct answers according to visual stimuli	2.88	<.001	.81	.034	1.98	<.001	.89	.02	1.33	.002	.50	.197*	3.79	<.001
Mean time for correct answers according to auditory stimuli	.54	.154*	1.06	.008	.49	.199*	.46	.25*	2.22	<.001	.53	.161*	.76	.046
Standard deviation of time based on correct answers according to visual stimuli	.75	.004	1.04	.008	.71	.056*	.65	.08*	.48	.214*	1.04	.009	6.66	<.001
Standard deviation of time based on correct answers according to auditory stimuli	.29	.603*	5.54	<.001	.44	.273*	.61	.69*	20.78	<.001	.74	.05*	.59	.118*

Legenda. * = normality is fulfilled (p>.05); n = sample size; st = statistic; p = p-value.

Table 5 – Normality of each variable based on the sample from the AULA's normative study (female): Anderson-Darling test

Variable/Year	06 (n = 71)		07 (n = 61)		08 (n = 68)		09 (n = 65)		10 (n = 72)		11 (n = 46)		12-16 (n = 231)	
	st	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*
Visual omission	13.07	.002	.74	.049	4.45	<.001	3.61	<.001	7.32	<.001	5.05	<.001	25.21	<.001
Auditory omission	8.63	<.001	3.43	<.001	3.50	<.001	8.62	<.001	13.91	<.001	5.50	<.001	29.93	<.001
Visual commission	6.22	<.001	1.59	<.001	7.98	<.001	.70	.061*	.94	.015	1.15	.004	25.2	<.001
Auditory commission	6.97	<.001	1.81	<.001	7.40	<.001	1.64	<.001	3.42	<.001	1.71	<.001	50.16	<.001
Mean time for correct answers according to visual stimuli	1.10	.006	.85	.025	1.15	.004	.62	.098*	.87	.023	.33	.496*	2.75	<.001
Mean time for correct answers according to auditory stimuli	.85	.026	.30	.565*	.25	.717*	.53	.167*	.43	.289	.60	.112*	1.01	.011
Standard deviation of time based on correct answers according to visual stimuli	.52	.176*	.66	.08*	.50	.192*	.63	.095*	.60	.111	.51	.186*	6.69	<.001
Standard deviation of time based on correct answers according to auditory stimuli	12.74	<.001	.35	.449*	.51	.187*	.26	.670*	2.09	<.001	.34	.466*	1.55	<.001

Legenda. * = normality is fulfilled (p>.05); n = sample size; *st* = statistic; p = p-value.

Table 6 – Normality of each variable based on the sample of children suspected of ADHD (male): Anderson-Darling test

Variable/Year	08 (*n* = 45)		09 (*n* = 49)		10 (*n* = 26)		11 (*n* = 30)		12-16 (*n* = 124)	
	st	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*
Visual omission	.44	.278*	1.24	.002	4.63	<.001	1.97	<.001	10.92	<.001
Auditory omission	2.94	<.001	3.88	<.001	4.55	<.001	3.39	<.001	15.12	<.001
Visual commission	5.50	<.001	1.53	<.001	7.41	<.001	3.06	<.001	12.04	<.001
Auditory commission	5.39	<.001	3.99	<.001	8.75	<.001	4.33	<.001	19.37	<.001
Mean time for correct answers according to visual stimuli	.57	.125*	2.41	<.001	.34	.462*	1.19	.003	6.51	<.001
Mean time for correct answers according to auditory stimuli	1.76	<.001	1.31	.001	.35	.441*	.88	.020	.58	.127*
Standard deviation of time based on correct answers according to visual stimuli	.19	.888*	.38	.384*	.24	.723*	.79	.034	4.76	<.001
Standard deviation of time based on correct answers according to auditory stimuli	.56	.131*	.41	.318*	.63	.081*	.32	.512*	.48	.228*

Legenda. * = normality is fulfilled (p>.05); n = sample size; st = statistic; p = p-value.

Table 7 – Normality of each variable based on the sample of children suspected of ADHD (female): Anderson-Darling test

Variable/Year	08 (*n* = 21)		09 (*n* = 17)		10 (*n* = 10)		11 (*n* = 11)		12-16 (*n* = 45)	
	st	*p*	*st*	*p*	*st*	*p*	*st*	*p*	*st*	*p*
Visual omission	.19	.866*	.60	.099*	.56	.104*	.63	.07*	4.63	<.01
Auditory omission	.43	.272*	.85	.022	.31	.479*	1.66	<.001	4.55	<.01
Visual commission	2.95	<.001	1.59	<.001	.74	.034	.46	.202*	7.41	<.01
Auditory commission	2.61	<.001	.79	.032	.97	.008	.53	.130*	8.75	<.01
Mean time for correct answers according to visual stimuli	.46	.229*	.34	.450*	.87	.015	.42	.265*	2.26	<.01
Mean time for correct answers according to auditory stimuli	1.04	.007	.18	.900*	.28	.552*	.30	.512*	.30	.565*
Standard deviation of time based on correct answers according to visual stimuli	.28	.603*	.41	.303*	.30	.509*	.37	.341*	.95	.014
Standard deviation of time based on correct answers according to auditory stimuli	.41	.309*	.44	.247*	.22	.741*	.24	.676*	.28	.599*

Legenda. * = normality is fulfilled (p>.05); n = sample size; *st* = statistic; p = p-value.

Table 8 – Significance and prevalence of each variable by sex and age from the sample of the AULA's normative study

Group	*Variable*	*Sig.*	*Weight*	*Cramer*	*Prev*
Male					
06 (*n* = 90)					
	Mean time for correct answers	yes	1342	.149	auditory
	Omission	yes	203	.250	visual
	Commission	no	889	.087	none
07 (*n* = 88)					
	Mean time for correct answers	yes	1369	.038	auditory
	Omission	yes	179	.242	visual
	Commission	no	.75	.027	none
08 (*n* = 46)					
	Mean time for correct answers	yes	1451	.082	auditory
	Omission	no	276	.113	none
	Commission	no	.55	.030	none
09 (*n* = 74)					
	Mean time for correct answers	no	1529	.019	none
	Omission	no	278	.141	none
	Commission	no	455	.097	none
10 (*n* = 64)					
	Mean time for correct answers	yes	1575	.100	auditory
	Omission	no	353	.167	none
	Commission	no	444	.089	none
11 (*n* = 65)					
	Mean time for correct answers	yes	1.64	.036	auditory
	Omission	no	286	.141	none
	Commission	no	.5	.072	none
12-16 (*n* = 236)					
	Mean time for correct answers	yes	1662	.047	auditory
	Omission	no	667	.023	none
	Commission	no	429	.087	none

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Group	*Variable*	*Sig.*	*Weight*	*Cramer*	*Prev*
Female					
06 (*n* = 71)					
	Mean time for correct answers	yes	1265	.063	auditory
	Omission	yes	216	.225	visual
	Commission	no	857	.011	none
07 (*n* = 61)					
	Mean time for correct answers	yes	1.46	.045	auditory
	Omission	yes	208	.191	visual
	Commission	no	.75	.051	none
08 (*n* = 68)					
	Mean time for correct answers	yes	1465	.030	auditory
	Omission	no	.32	.005	none
	Commission	no	.8	.023	none
09 (*n* = 65)					
	Mean time for correct answers	no	1588	.004	none
	Omission	no	273	.131	none
	Commission	no	.5	.078	none
10 (*n* = 72)					
	Mean time for correct answers	no	1584	.019	none
	Omission	no	333	.119	none
	Commission	no	333	.196	none
11 (*n* = 46)					
	Mean time for correct answers	no	1557	.027	none
	Omission	no	.2	.064	none
	Commission	no	.5	.057	none
12-16 (*n* = 231)					
	Mean time for correct answers	yes	1604	.071	auditory
	Omission	no	333	.064	none
	Commission	no	.4	.075	none

Table 9 – Significance and prevalence of each variable by sex and age from the sample of children suspected of ADHD

Group	*Variable*	*Sig*	*Weight*	*Cramer*	*Prev*
Male					
08 (*n* = 45)					
	Mean time for correct answers	yes	1725	.117	auditory
	Omission	yes	.4	.155	visual
	Commission	no	818	.018	none
09 (*n* = 49)					
	Mean time for correct answers	yes	1.93	.206	auditory
	Omission	yes	321	.181	visual
	Commission	no	727	.100	none
10 (*n* = 26)					
	Mean time for correct answers	yes	1975	.101	auditory
	Omission	no	765	.011	none
	Commission	no	765	.040	none
11 (*n* = 30)					
	Mean time for correct answers	yes	2196	.119	auditory
	Omission	yes	.3	.153	visual
	Commission	no	857	.071	none
12-16 (*n* = 124)					
	Mean time for correct answers	yes	2379	.284	auditory
	Omission	no	.5	.038	none
	Commission	no	429	.108	none
Female					
08 (*n* = 21)					
	Mean time for correct answers	yes	1719	.092	auditory
	Omission	no	436	.066	none
	Commission	no	1111	.035	none
09 (*n* = 17)					
	Mean time for correct answers	yes	1663	.058	auditory
	Omission	yes	.25	.225	visual

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Group	*Variable*	*Sig*	*Weight*	*Cramer*	*Prev*
	Commission	no	1	.111	none
10 (*n* = 10)					
	Mean time for correct answers	yes	1797	.130	auditory
	Omission	no	.5	.008	none
	Commission	no	889	.080	none
11 (*n* = 11)					
	Mean time for correct answers	yes	2302	.171	auditory
	Omission	no	438	.140	none
	Commission	no	1.75	.106	none
12-16 (*n* = 45)					
	Mean time for correct answers	yes	2687	.178	auditory
	Omission	no	.5	.052	none
	Commission	no	.5	.066	none

Table 10 – Summary of significance on the sample of the AULA's normative study (male)

Variable/Year	06 (*n* = 90)	07 (*n* = 88)	08 (*n* = 46)	10 (*n* = 64)	11 (*n* = 65)	12-16 (*n* = 236)
Mean time for correct answers	auditory	auditory	auditory	auditory	auditory	auditory
Omission	visual	visual				

Table 11 – Summary of significance on the sample of the AULA's normative study (female)

Variable/Year	06 (*n* = 71)	07 (*n* = 61)	08 (*n* = 68)	12-16 (*n* = 231)
Mean time for correct answers	auditory	auditory	auditory	auditory
Omission	visual	visual		

Table 12 – Summary of significance on the sample of children suspected of ADHD (male)

Variable/Year	08 (*n* = 45)	09 (*n* = 49)	10 (*n* = 26)	11 (*n* = 30)	12-16 (*n* = 124)
Mean time for correct answers	auditory	auditory	auditory	auditory	auditory
Omission	visual	visual		visual	

Table 13 – Summary of significance on the sample of children suspected of ADHD (female)

Variable/Year	08 (*n* = 21)	09 (*n* = 17)	10 (*n* = 10)	11 (*n* = 11)	12-16 (*n* = 124)
Mean time for correct answers	auditory	auditory	auditory	auditory	auditory
Omission		visual			

DISCUSSION

Visual and auditory stimuli can interact with each other to improve understanding of the environment. For example, in a video game, hearing helps the individual understand what is being played. Similarly, sight can help the person understand the rhythm and movement of the notes on the sheet music when listening to music.

Prioritising one type of stimulus over the other can help children regulate sensory processing, improve concentration, and foster better behavioural control. When a significant value is observed in these variables, it may signify challenges in the child's interpretation of this stimulus compared to the other. This is due to the unique nature of these variables, where lower values indicate better performance, different from the general performance variable.

In the first phase of the study, to answer the first hypotheses presented, the variables were analysed to identify the type of stimulus that was more significant in the population represented by the sample from the AULA's normative study. In this study, two variables were found to be significant among stimuli: the mean time for correct answers and the omission. In conclusion, the auditory stimulus was predominant for the first variable and the visual stimulus was predominant for the second variable. However, this significance for the visual stimulus occurs only up to the age of 9 years, and no distinction is made between boys and girls. For the remaining variables, no significance was found between auditory and visual stimuli.

A positive outcome is the absence of significant differences between visual and auditory stimuli in a wide range of variables. This indicates that any noteworthy findings in test performance, visual or auditory, should be emphasised by clinicians given the lack of overall significance in the population.

These findings are instrumental in establishing a knowledge base on the importance of visual and auditory stimuli as the primary variables in AULA. When a test is administered to an examinee and their performance deviates from that of the general population, this incongruity must be explicitly noted in the report to the clinician, as this information is crucial to helping children regulate their sensory processing, thus improving their ability to concentrate and control their behaviours.

In the second phase of the study, analysing the sample of children suspected of ADHD, it was observed that the mean time for correct answers variable continued to show the same behaviour as in the first phase of the study. That is, the auditory stimuli have shown the greatest significance. On the contrary, a greater diversity of results was found for the omission variable. Children in the AULA normative sample show a significant preference for visual stimuli between the ages of 6 and 7, but after this age, there is no clear preference for either stimulus. In contrast, in both boys and girls in the sample of children suspected of having ADHD, the preference for visual stimuli persists in boys until the age of 11, while in girls this preference is reduced at the age of 9.

CONCLUSIONS AND FUTURE PERSPECTIVES

The main hypothesis, that the participants' visual stimulus exposure will be identical to the participants' auditory stimulus exposure (sample based on the normative AULA study), is fulfilled for all variables except for the following: mean time for correct responses and omissions. There is a higher sensitivity toward auditory stimuli in the meantime for correct responses variable and a higher sensitivity towards visual stimuli in the omission variable, but this variable is no longer significant for either sex from the age of seven years.

There are also differences in the sample of children with suspected ADHD, which confirms the second hypothesis. It is important to note that the significance of visual stimulus in the omission variable extends until the age of 11 for boys, while for girls, it persists until the age of 9. For this reason, the omission variable shows a different trend between boys and girls with suspected ADHD.

In general, AULA variables show no significance between visual and auditory stimuli, except for two of them (mean time for correct responses and omissions). In addition, it is important to note that these variables work inversely to the general performance variables, since a shorter mean time for correct responses is better than a longer mean time for correct responses. In addition, a small number of omissions is more appropriate than a large number of omissions. This is an aspect to be considered when drawing conclusions from the results obtained.

The results of the present study are limited by the low number of cases in some age and sex subgroups. Therefore, it is recommended that the sample be expanded and include two new study groups: one exclusively with children with ADHD and the other with TD children. This extension would enrich the conclusions of this study.

References

ANDERSON, T.W., & DARLING, D.A. (1952). Asymptotic theory of certain "goodness of fit" criteria based on stochastic processes. *The Annals of Mathematical Statistics*, *23* (2), 193-212. doi.org/10.1214/aoms/1177729437

ANDREWS, M.W., & DOWLING, W.J. (1991). The development of perception of interleaved melodies and control of auditory attention. *Music Perception*, *8* (4), 349-368. doi.org/10.2307/40285518

Attention Kids Aula (2021, September 9). Nesplora. https://nesplora.com/producto/attention-kids-aula/

BUSSING, R., MASON, D.M., BELL, L., PORTER, P., & GARVAN, C. (2010). Adolescent outcomes of childhood attention-deficit/hyperactivity disorder in a diverse community sample. *Journal of the American Academy of Child and Adolescent Psychiatry*, *49* (6), 595-605. doi.org/10.1097/00004583-201006000-00008

CALLAHAN, P.M., & TERRY, A.V. (2015). *Attention*. In K. Kantak

& J. Wettstein (Eds.), *Cognitive enhancement. Handbook of experimental pharmacology*, *vol 228*. Cham, CH: Springer. doi.org/10.1007/978-3-319-16522-6_5

CARRASCO, M. (2011). Visual attention: The past 25 years. *Vision Research*, *51* (13), 1484-1525. doi.org/10.1016/j.visres.2011.04.012

CHEN, T., MICHELS, L., SUPEKAR, K., KOCHALKA, J., RYALI, S., & MENON, V. (2015). Role of the anterior insular cortex in integrative causal signaling during multisensory auditory-visual attention. *The European Journal of Neuroscience*, *41* (2), 264-274. doi.org/10.1111/ejn.12764

CHIANG, H.-L., CHEN, Y.-J., LO, Y.-C., TSENG, W.-Y. I., & GAU, S.S. (2015). Altered white matter tract property related to impaired focused attention, sustained attention, cognitive impulsivity and vigilance in attention-deficit/ hyperactivity disorder. *Journal of Psychiatry & Neuroscience: JPN*, *40* (5), 325-335. doi.org/10.1503/jpn.140106

CLIMENT-MARTÍNEZ, G., & BANTERLA, F. (2011). *AULA. Manual teórico*. San Sebastián: Nesplora.

CRAMÉR, H. (1946). A contribution to the theory of statistical estimation. *Scandinavian Actuarial Journal*, *1946* (1), 85-94. doi.org/10.1080/03461238.1946.10419631

FIEBELKORN, I.C., FOXE, J.J., BUTLER, J.S., MERCIER, M.R., SNYDER, A.C., & MOLHOLM, S. (2011). Ready, set, reset: Stimulus-locked periodicity in behavioral performance demonstrates the consequences of cross-sensory phase reset. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *31* (27), 9971-9981. doi.org/10.1523/JNEUROSCI.1338-11.2011

FISHER, R.A. (1922). On the interpretation of χ^2 from contingency tables, and the calculation of P. *Journal of the Royal Statistical Society*, *85* (1), 87. doi.org/10.2307/2340521

GABAY, Y., GABAY, S., SCHIFF, R., & HENIK, A. (2019). Visual and auditory interference control of attention in developmental dyslexia. *Journal of the International Neuropsychological Society: JINS*, *26* (4), 407-417. doi.org/10.1017/S135561771900122X

GOMES, H., WOLFSON, V., & HALPERIN, J.M. (2007). Is there a selective relationship between language functioning and auditory attention in children? *Journal of Clinical and Experimental Neuropsychology*, *29* (6), 660-668. doi.org/10.1080/13803390600920455

GREEN, J.J., DOESBURG, S.M., WARD, L.M., & McDONALD, J.J. (2011). Electrical neuroimaging of voluntary audiospatial attention: Evidence for a supramodal attention control network. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *31* (10), 3560-3564. doi.org/10.1523/JNEUROSCI.5758-10.2011

GROLEMUND, G., & WICKHAM, H. (2011). Dates and times made easy with lubridate. *Journal of Statistical Software*, *40* (3). doi.org/10.18637/jss.v040.i03

HOSEINI, B., AJILIAN, M., MOGHADDAM, H., KHADEMI, G., & SAEIDI, M. (2014). Attention Deficit Hyperactivity Disorder (ADHD) in children: A short review and literature. *International Journal of Pediatrics*, *2*, 443-450. doi.org/10.22038/ijp.2014.3749

IMERAJ, L., ANTROP, I., ROEYERS, H., DEBOUTTE, D., DESCHEPPER, E., BAL, S., & SONUGA-BARKE, E. (2016). The impact of idle time in the classroom: Differential effects on children with ADHD. *Journal of Attention Disorders*, *20* (1), 71-81. doi.org/10.1177/1087054713478464

IRIARTE, Y., DIAZ-ORUETA, U., CUETO, E., IRAZUSTABARRENA, P., BANTERLA, F., & CLIMENT, G. (2016). AULA-advanced virtual reality tool for the assessment of attention: Normative study in Spain. *Journal of Attention Disorders*, *20* (6), 542-568. doi.org/10.1177/1087054712465335

KORKMAZ, S., GOKSULUK, D., & ZARARSIZ, G. (2014). MVN: An R package for assessing multivariate normality. *The R Journal*, *6* (2), 151. doi.org/10.32614/rj-2014-031

LIN, H.-Y., CHIU, E.-C., HSIEH, H.-C., & WANG, P.-J. (2023). Gender differences in auditory and visual attentional performance in children with and without ADHD. *Archives of Clinical Neuropsychology: The Official Journal of the National Academy of Neuropsychologists*, *38* (6), 891-903. doi.org/10.1093/arclin/acad019

LIN, H.-Y., HSIEH, H.-C., LEE, P., HONG, F.-Y., CHANG, W.-D., & LIU, K.-C. (2017). Auditory and visual attention performance in children with ADHD: The attentional deficiency of ADHD is modality specific. *Journal of Attention Disorders*, *21* (10), 856-864. doi.org/10.1177/1087054714542004

MARSAGLIA, G., & MARSAGLIA, J. (2004). Evaluating the Anderson-darling distribution. *Journal of Statistical Software*, *9* (2). doi.org/10.18637/jss.v009.i02

MEYER, D., ZEILEIS A., & HORNIK, K. (2023). *Visualizing categorical data [R package vcd version 1.4-12]*. https://CRAN.R-project.org/package=vcd

R CORE TEAM (2020). *The R project for statistical computing*. R-project.org. https://www.R-project.org/

REVELLE, W. (2024). *Procedures for psychological, psychometric, and personality research [R package psych version 2.4.1]*. https://CRAN.R-project.org/package=psych

RUIZ-RUANO GARCÍA, A.M., & LÓPEZ PUGA, J. (2022). *Análisis de datos en psicología y educación*. Aula Magna Proyecto Clave, McGraw Hill.

RUSSELL, E.L. (2015). *Auditory and visual sustained attention on* *tasks with varied motivation and cognitive loads in children with and without ADHD*. https://thescholarship.ecu.edu/handle/10342/4993

SCHMIDT, S., & PETERMANN, F. (2009). Developmental psychopathology: Attention Deficit Hyperactivity Disorder (ADHD). *BMC Psychiatry*, *9* (1), 58. doi.org/10.1186/1471-244X-9-58

SIMÕES, E.N., CARVALHO, A.L.N., & SCHMIDT, S.L. (2021). The role of visual and auditory stimuli in continuous performance tests: Differential effects on children with ADHD. *Journal of Attention Disorders*, *25* (1), 53-62. doi.org/10.1177/1087054718769149

SOLBERG, B.S., HALMØY, A., ENGELAND, A., IGLAND, J., HAAVIK, J., & KLUNGSØYR, K. (2018). Gender differences in psychiatric comorbidity: A population-based study of 40 000 adults with attention deficit hyperactivity disorder. *Acta Psychiatrica Scandinavica*, *137* (3), 176-186. doi.org/10.1111/acps.12845

STEINMAN, S.B., & STEINMAN, B.A. (1998). Vision and attention. I: Current models of visual attention. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, *75* (2), 146-155. doi.org/10.1097/00006324-199802000-00018

WICKHAM, H. (2022). *Simple, consistent wrappers for common string operations*. https://stringr.tidyverse.org, https://github.com/tidyverse/stringr

WICKHAM, H., FRANÇOIS, R., HENRY, L., MÜLLER, K., & VAUGHAN, D. (2023). *dplyr: A grammar of data manipulation*. Independently Published.

WILLCUTT, E.G. (2012). The prevalence of DSM-IV attention-deficit/hyperactivity disorder: A meta-analytic review. *Neurotherapeutics: The Journal of the American Society for Experimental NeuroTherapeutics*, *9* (3), 490-499. doi.org/10.1007/s13311-012-0135-8

WILSON, E.B. (1927). Probable inference, the law of succession, and statistical inference. *Journal of the American Statistical Association*, *22* (158), 209. doi.org/10.2307/2276774