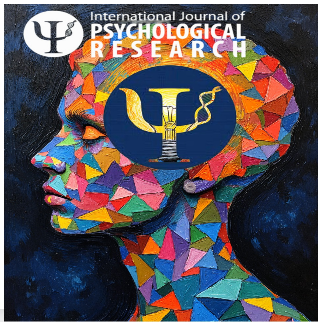
International Journal of PSYCHOLOGICAL RESEARCH

RESEARCH ARTICLE



Vol 18, N° 1
https://revistas.usb.edu.co/index.php/IJPR
ISSN 2011-2084
E-ISSN 2011-7922

Executive Functions and Juvenile Delinquency: A Comparative Analysis of Institutionalized Adolescents in Colombia

Funciones Ejecutivas y delincuencia juvenil: Un Análisis Comparativo en adolescentes Institucionalizados de Colombia

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OPEN ACCESS

Manuscript received: 19-11-2024
Revised: 25-01-2025
Accepted: 20-02-2025

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Declaration of data availability: All relevant data are within the article, as well as the information support files.

Conflict of interests: The authors have declared that there is no conflict of interest.

How to Cite:
Alejo, E. G., Valencia Piedrahita, M., & Cuartas Arias, J. M. (2025). Executive Functions and Juvenile Delinquency: A Comparative Analysis of Institutionalized Adolescents in Colombia. *International Journal of Psychological Research*, *18*(1), 6–20. https://doi.org/10.21500/20112084.7709

Abstract.
Introduction. During adolescence, conduct disorders emerge, associated with frontal alterations and executive function (EF) deficits, influencing delinquent trajectories. The study aimed to compare EF in delinquent ($N = 125$) and non-delinquent ($N = 153$) adolescents. **Method.** We administered the WCST, TMT-2, PM, Go/NoGo, ToL, and Wechsler backward digit span tests, and conducted both parametric and non-parametric MANOVA/MANCOVA. **Results.** Delinquents exhibited more non-perseverative (WCST), type 2 (ToL), and total (PM) errors, as well as more NoGo errors and lifting movements (TMT-2). Non-delinquents showed more stops/pauses (TMT-2), longer GO reaction times, and higher memory scores (ID-W). Differences were significant ($p < .001$) with small-to-moderate effect sizes. These differences persisted after controlling for IQ, and age did not influence the results. **Conclusions.** Delinquents demonstrated poorer inhibitory control, reduced interference control, and lower working memory, potentially linked to early delinquent trajectories. These findings support interventions focused on improving EF in vulnerable populations.

Resumen.
Introducción. Durante la adolescencia surgen trastornos de conducta asociados a alteraciones frontales y déficits en funciones ejecutivas (FE), influyendo en trayectorias delictivas. El objetivo del estudio fue comparar las FE en adolescentes infractores ($N = 125$) y no infractores ($N = 153$). **Método.** Se aplicaron el WCST, el TMT-2, el PM, el Go/NoGo, el ToL y la prueba de dígitos inversos (Wechsler), y se realizó MANOVA/MANCOVA paramétrico y no paramétrico. **Resultados.** Los infractores mostraron más errores no perseverativos (WCST), tipo 2 (ToL), totales (PM), en NoGo y mayor levantamiento (TMT-2); los no infractores tuvieron más paradas/pausas (TMT-2), mayor tiempo de reacción en GO y mejor puntuación en memoria (ID-W). Las diferencias fueron significativas ($p < .001$) con tamaños de efecto pequeños-moderados. Estas diferencias se mantuvieron tras controlar el CI, y la edad no influyó en el resultado. **Conclusiones.** Los infractores exhibieron peor control inhibitorio, menor control de interferencia y menor memoria de trabajo, lo que podría relacionarse con trayectorias delictivas tempranas. Estos hallazgos apoyan intervenciones dirigidas a mejorar las FE en poblaciones vulnerables.

Keywords.
Juvenile Delinquency, Behavioral Disorders, Executive Functions, Inhibitory Control, Adolescence.
Palabras Clave.
Delincuencia juvenil, trastornos de conducta, funciones ejecutivas, control inhibitorio, adolescencia.

1. Introduction

Adolescence is a stage of significant change, characterized by disruptive behaviors, impulsivity, substance use, and risk-taking behaviors (Swann et al., 2009; Soe-Agnie et al., 2018; Bacon et al., 2018). These behaviors are associated with delays in the maturation of brain structures responsible for executive functioning (van Duijvenvoorde et al., 2016; Steinberg, 2008) and with the development of criminal (van Hoorn et al., 2020) and psychopathological trajectories (Burt et al., 2011; Morgado & Vale-Días, 2013; Yanuari et al., 2021; Rutter, 2003; Ayano et al., 2024). The early identification of these trajectories represents a significant opportunity to develop strategies for rehabilitation and the prevention of delinquency (Dattagupta et al., 2024; Novak, 2023; Pezzoli et al., 2024).

Juvenile delinquency is a phenomenon of significant scientific relevance (Moffitt, 1993; Moffitt, 2018; Morgado & Vale-Días, 2013) and a global public health issue (Ayano et al., 2024). Numerous neuroscience studies have aimed to identify the neurophysiological and neuropsychological precursors of juvenile delinquency, finding structural and neurofunctional differences between juvenile offenders and controls (Choy & Raine, 2024).

Specifically, alterations have been identified in the prefrontal cortex (PFC) (Gao et al., 2024), the orbitofrontal cortex (OFC), the anterior cingulate cortex (ACC) (Lee et al., 2018; Chaibi et al., 2023), and the ventromedial PFC (vmPFC) (Ibrahim et al., 2021). Additionally, alterations have been observed in the superior temporal gyrus, the bilateral temporal lobe, and limbic structures such as the amygdala (Fairchild et al., 2013), the hippocampus, the bilateral insula (Sterzer et al., 2007), the ventral striatum (van Hoorn et al., 2020), and the septum pellucidum (Blair & Zhang, 2020). These alterations are associated with deficits in executive functions, such as emotional processing and regulation, sensitivity to reinforcement, and inhibitory control (Noordermeer et al., 2016; Rogers & De Brito, 2016).

Moreover, the orbitofrontal cortex (OFC) and the ventromedial prefrontal cortex (vmPFC) receive afferent inputs from multimodal sensory systems and connect with the amygdala and hippocampus, playing a fundamental role in executive control (Mackey & Petrides, 2014; Miller & Cohen, 2014). Lesions in the OFC and vmPFC are associated with alterations in sensory and emotional processing, risk assessment, rule-following, and self-control (Kennerley & Walton, 2011; Brockett & Roesch, 2021), resulting in erratic behaviors (Pessiglione & Daunizeau, 2021), emotional dysregulation, and high sensitivity to delayed gratification (Schneider & Koenigs, 2017; Gläscher et al., 2012).

Similarly, lesions in the dorsolateral prefrontal cortex (dlPFC) and the anterior cingulate cortex (ACC) are associated with deficits in cognitive flexibility (Miller & Cohen, 2014), difficulties in interference control (Gläscher et al., 2012), and deficits in working memory and planning (Noordermeer et al., 2016; Rogers & De Brito, 2016). These structures regulate processes responsible for executive control that are severely affected in individuals with disruptive disorders, antisocial behavior, uncontrollable impulsivity, and aggression (Griffith et al., 2024; Jansen & Franse, 2024; Jansen, 2022).

In this context, research on executive functions (EF) has advanced through the use of neuropsychological tests (Demakis, 2004; Ferguson et al., 2021), identifying various types of EF grouped into three main categories: cognitive flexibility or shifting, updating and monitoring of working memory, and inhibition (Miyake et al., 2000; Baggetta & Alexander, 2016).

To date, various systematic reviews and meta-analyses have confirmed the link between deficits in executive functions (EF) and delinquency (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Griffith et al., 2024; Jansen & Franse, 2024; Türel et al., 2024). In addition, several studies have suggested that EF deterioration in individuals with antisocial behavior may be associated with potential lesions in the dorsolateral prefrontal cortex (dlPFC), the ventromedial prefrontal cortex (vmPFC), and the limbic system. Furthermore, neuropsychological tests such as the Trail Making Test (TMT), the Wisconsin Card Sorting Test (WCST), the Go/NoGo test, the Porteus Maze Test (PM), and the Tower of London Test (ToL) have proven to be effective tools for assessing this deterioration (Burgess, 2020; Borrani et al., 2015; Pihet et al., 2012; Demakis, 2003).

In Colombia, studies on EF in adolescents with antisocial behavior problems are limited. However, research conducted by Sepúlveda et al. (2022) and Gil-Fenoy et al. (2018) has provided additional evidence supporting the hypothesis of executive dysfunction associated with antisocial behavior.

Likewise, in the case of children with conduct disorders in Colombia, a study by Urazán-Torres et al. (2013) evaluated EF differences between children with conduct disorder (CD) and a control group. The findings revealed deficits in cognitive flexibility and skills related to memory and language.

This study aims to identify differences in EF measures between a sample of institutionalized juvenile offenders in Colombia and a control group of adolescents from a public school in Medellín. The objective is to verify the presence of executive dysfunction in Colombian juvenile offenders and to contribute valuable insights to the understanding of juvenile delinquency and the neuropsychological factors associated with this condition.

2. Method

2.1 Participants

This study employs an observational design with comparative groups, nested within a cross-sectional study. A convenience sample of 125 male adolescents aged 14 to 17 years ($M = 15.79$; $SD = .76$) was selected. These individuals were institutionalized for serious offenses such as aggravated theft, personal injury, and homicide. They belong to juvenile offender institutions located in the cities of Medellín and Bogotá, affiliated with Colombia's juvenile criminal responsibility system (Velasco, 2020; Torres-Vásquez & Tirado-Acero, 2023). In this study, they will be referred to as **OFFENDERS**.

Additionally, a convenience sample of 153 male secondary school students from a public institution in Medellín, aged 14 to 17 years ($M = 16.13$; $SD = .93$), was selected. These participants will be referred to as **NON-OFFENDERS**.

To ensure eligibility, an informed consent form was provided and explained to the legal representatives of each participant, which was duly completed and signed. All participants with estimated intelligence quotient (IQ) scores of 71 or higher ($M = 96.5$; $SD = 14.6$) were included. Given the initial differences in IQ scores and age between the **OFFENDERS** and **NON-OFFENDERS** groups (see Table 1), these differences were retained and subsequently controlled for in the analyses to preserve the sample size.

2.2 Instruments

2.2.1 IQ Estimation

The Matrices and Vocabulary subscales of the Wechsler Intelligence Scale for Children (WISC-IV) were administered, following prorating rules to estimate IQ based on two subscales (Sattler, 2010). An estimated IQ for each participant was calculated using standardized scores and age variable.

2.2.2 Executive Functions (EF) Assessment

The Neuroclinictest® application was developed to administer various EF tests using touch tablets. This application accurately records responses and reaction times for each task, minimizing digitization and writing errors by evaluators. The evaluation utilized 11-inch touch tablets with stylus input. The application was developed in Unity® with C++ programming language, and the data interface was built in Android Studio® using Java. Furthermore, the use of digital tests in neuropsychological assessments has garnered considerable attention. Several studies have demonstrated the utility of these digital versions (Krumm & Arán Filippetti, 2017; Steinmetz Jean-Paul et al., 2010; Çelik et al., 2021; Wagner & Trentini, 2009), showing equivalence in psychometric properties between digital and traditional versions (Çelik et al., 2021; Mueller & Piper, 2014). Furthermore, they have been noted for greater sensitivity and precision, improved measurements, and high test-retest validity (Makizako et al., 2013; Dahmen et al., 2017).

2.2.3 Wisconsin Card Sorting Test (WCST)

A digital version of the 128-card WCST (Heaton et al., 2009) was used, administered in a hetero-applied format. An initial screen displayed 4 stimulus cards, followed by the sequential presentation of trial cards at the bottom of the screen (see Figure 1, Panel A). Participants were allowed to freely match trial cards with stimulus cards based on color, shape, or number categories, receiving feedback only in the form of "correct" or "incorrect" according to the active rule. Each trial card remained on the screen until the participant provided a response, followed by a 2000 milliseconds (ms) pause.

After 10 consecutive correct responses under the active rule, the rule was changed without prior warning. During the task, the following variables were recorded: correct responses, errors, perseverative and non-perseverative errors, levels achieved, and reaction times.

Trail Making Test (TMT). A digital version of the TMT 1 and 2 tests was used (see Figure 1, Panel B). For this study, only the TMT-2 was employed, as it is more sensitive for EF evaluation (Kortte et al., 2002; Gaudino et al., 1995; Arbuthnott & Frank, 2000). The TMT-2 consisted of 25 circles with an alphanumeric sequence of numbers (1-13) and letters (A-L) arranged according to the pattern established in the manual (Spreen & Strauss, 1998; Bowie & Harvey, 2006). Participants were required to connect the circles by alternating numbers and letters continuously without lifting the stylus or crossing lines (Periáñez et al., 2007; Mahurin et al., 2006). Pauses, stylus lifts, sequence errors, line crossings, interruptions, and total execution time were recorded. Digital versions of the TMT have been used in various populations, demonstrating high validity and reproducibility (Woods et al., 2015; Dahmen et al., 2017; Fellows et al., 2017; Salthouse & Fristoe, 1995).

Tower of London (ToL). A digital version of the ToL test was used, based on Shallice (1982) and Culberson & Zillmer (1998), with 10 problems and one practice trial. The target model was displayed on the top left corner of the screen (see Figure 1, Panel C), and participants were instructed to replicate it by moving spheres between pegs from an initial configuration. Two rules were established: moving only one sphere at a time (Rule A) and not exceeding the peg capacity (Rule B). Errors of types A and B, movement times, number of moves, and total problem-solving time were recorded. Tasks were penalized after one minute and marked as failed after two minutes. Scoring followed the manual (Culberson & Zillmer, 1998).

Go/NoGo Test. In the Go/NoGo test, four visual stimuli (blue square, blue triangle, red square, red triangle) were presented across two runs. In the first run, the GO stimulus was red, and in the second, it was the square shape. Each run consisted of 160 presentations with a random ratio of 70% NOGO and 30% GO. Stimuli remained on-screen for 1000 ms, with 1500 ms for responses and a 1000 ms inter-trial interval featuring a central fixation (+). GO/NOGO hits, errors, and average reaction times were recorded.

Table 1

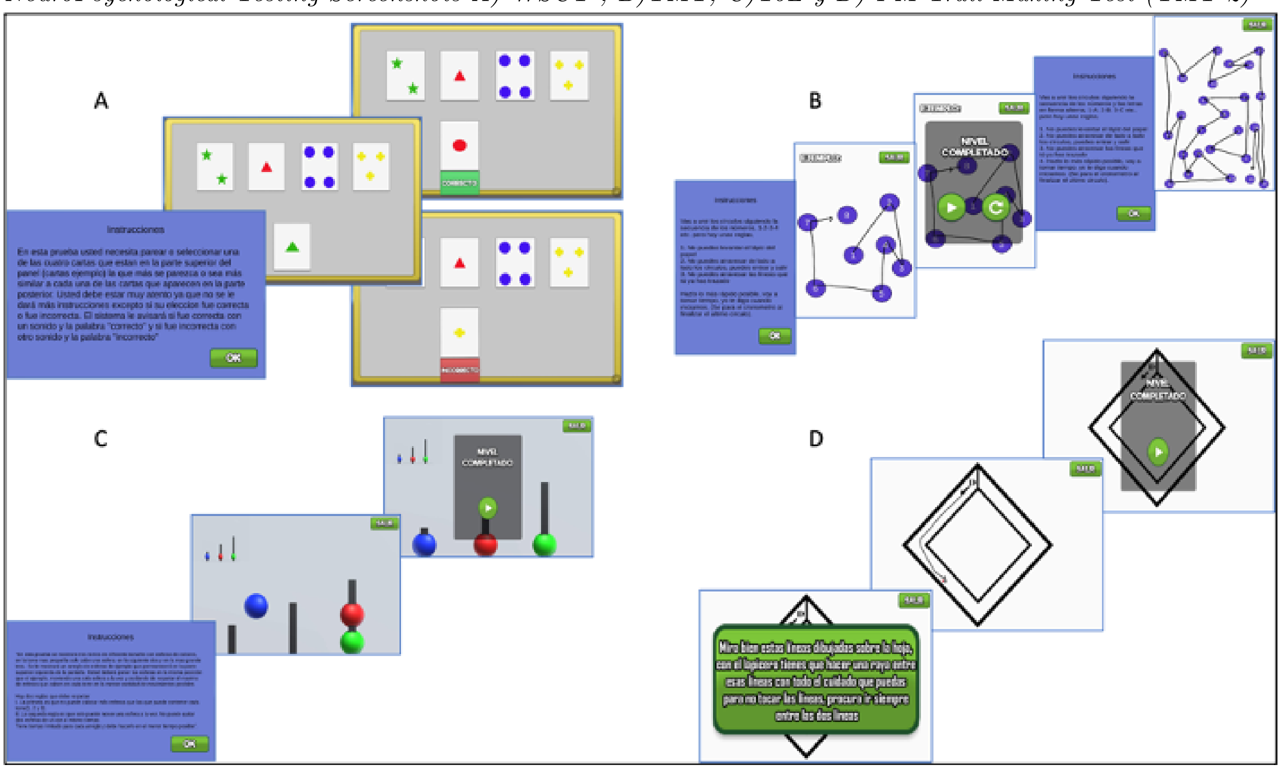
Descriptive Statistics of Non-Offender and Offender Samples

		NON-OFFENDERS		OFFENDERS	
Variable	**Level**	**Mean**	*SD*	**Mean**	*SD*
Age		15.797	.755	16.136	.936
Total IQ		96.503	14.697	83.624	10.911
		N	% Total	*N*	% Total
Grade	4	0	.0%	1	.4%
	5	1	.4%	10	3.6%
	6	3	1.1%	33	11.9%
	7	4	1.4%	34	12.2%
	8	4	1.4%	17	6.1%
	9	3	1.1%	15	5.4%
	10	136	48.9%	9	3.2%
	11	2	.7%	6	2.2%
Socioeconomic Status	1	14	5.0%	18	6.5%
	2	63	22.7%	70	25.2%
	3	56	20.1%	33	11.9%
	4	20	7.2%	4	1.4%
Region	Medellín	148	53.2%	83	29.9%
	Bogotá	5	1.8%	42	15.1%
TOTAL		153	100%	125	100%

Note. Grade= scholar level in Secondary School; Total IQ= IQ estimated from WISC IV subscales Vocabulary and Matrices

Figure 1

NeuroPsychological Testing Screenshots A) WSCT , B)TMT, C)ToL y D) PM Trail Making Test (TMT-2)



Note. A= Wisconsin Card Sorting Test screenshots; B= TMT screenshots; C= ToL screenshots; D= Porteus Mazes Test screenshots

Porteus Mazes (PM). A digital version of the TEA® Porteus Mazes was used (see Figure 1, Panel D), following the instructions and scoring guidelines (Porteus, 1999; Krikorian & Bartok, 1998). The test was administered in a hetero-applied format using touch tablets and a stylus. Levels I through V were used as training, while higher levels were evaluated. Execution time, tracing errors, stylus lifts, interruptions, failures, and completed mazes were recorded, with a 2000 ms interval between tests.

Wechsler Backward Digit Span (ID-W). The backward digit span from the WISC-IV digit subscale was applied, following the application and scoring guidelines (Wechler, 2005). This test has shown sensitivity to working memory difficulties (Conway et al., 2005; Gathercole et al., 2004). Each participant was orally presented with a list of numbers of increasing length and asked to recall them in reverse order. The number of digits correctly recalled in sequence was recorded, with a 2-second delay between the presentation of the list and the request for recall.

2.3 Procedure

The study was standardized and approved by the Ethics Committee of Universidad San Buenaventura in Medellín. After obtaining the necessary permissions from each institution, the tutors, parents, or legal representatives of the minors were contacted to present the project. A total of 32 virtual meetings with parents were conducted to obtain informed consent.

Subsequently, the administration of the tests had an average duration of 1 hour per participant and was conducted in person at the recruitment institutions. The evaluations were carried out by psychologists trained in administering each test. The order of test administration was as follows: Vocabulary and Matrix subtests from the WISC-IV (for IQ estimation), Digit Span subtest from the WISC-IV, WCST, TMT, ToL, and PM.

3. Data Analysis

The scores of various EF measures were compared between juvenile offenders and non-offenders, controlling for IQ and age as covariates. Data analysis was conducted using SPSS version 30.0, employing a General Linear Model (GLM) to perform MANOVA and MANCOVA analyses. The homogeneity of covariance matrices was assessed with the Box test, while multivariate normality was evaluated using the Shapiro-Wilk test (Burdenski, 2000; Korkmaz et al., 2014).

As a result, given the observed differences in variances between groups, the absence of normality in the variables, and the violation of the homogeneity of covariance matrix assumptions, a Permutational Multivariate ANOVA (PERMANOVA) was carried out. This nonparametric method, based on distance matrices, does not require multivariate normality assumptions and provides robust statistics (Anderson, 2017). The statistical software R version 4.4.1, along with R-Studio version 2024.09 and the packages *npmv::nonpartest* and *vegan::adonis*, was used for this analysis (Oksanen et al., 2024) (see Supplementary Material 1).

Additionally, ANCOVA analyses were performed using JASP version 19.1, controlling for IQ as a covariate. For post hoc comparisons, the Games-Howell method was used, as it is suitable for data with unequal variances. JASP also provided additional effect size measures, such as Cohen's d index for standard Tukey t values in post hoc comparisons and the Vovk-Sellke Maximum p-Ratio (V-S pratio), which serves as an alternative to the limitations of the p-value as an indicator of statistical significance (Sellke et al., 2001; Bayarri & Berger, 2000). This index aligns with other effect size measures, such as the Wald estimator and biserial correlation (Guzmán et al., 2023).

4. Results

The descriptive statistics for all analyzed variables are presented in Table 2. A total of 9 measures were obtained for the WCST test, 5 for ToL, 8 for TMT-2, 4 for Go/NoGo, 6 for PM, and 1 for Backward Digit Span, resulting in a total of 33 EF measures. Detailed information on the nature of each variable can be found in Supplementary Material 3.

All EF measures exhibited non-normal distributions, with kurtosis values skewed toward lower levels. Some variables were excluded from the analysis due to excessively high kurtosis values, which suggested the presence of a significant number of outliers. The variables ultimately selected for analysis are presented in Table 2.

After conducting an initial MANOVA (see Table 3), significant differences were identified in WCST scores. Offenders showed lower levels reached ($F = 8.03$, $p = .005$), a higher number of perseverative errors ($F = 8.37$, $p = .004$), and non-perseverative errors ($F = 14.44$, $p < .001$) compared to non-offenders. The VS-MPR values were 13.98, 16.191, and 223.977, respectively, with non-perseverative errors showing the largest difference between the two groups. This error tendency may be more related to impulsivity and reduced interference control than difficulties in disengaging from the rule, which typically explains perseveration and inflexibility (Lange et al., 2016).

In the TMT, offenders showed a higher number of lifting errors ($F = 6.59$, $p = .01$) but fewer stops ($F = 11.35$, $p < .001$) and pauses ($F = 20.15$, $p < .001$). Lifting errors violate test instructions, while stops (pausing at circles) and pauses (brief interruptions during tracing without lifting the stylus) indicate planning and execution periods. During these periods, executive control involves the activation of working memory and attention processes. The observed "time penalties," characterized

Table 2

Descriptive Statistics of Non-Offender and Offender Samples

	N	Mean	*SD*	Skew	Kurt	Sh-W	P	Min	Max
Age	278	15.95	.86	−.29	−.82	.85	< .001	14.00	17.00
Total IQ	278	90.71	14.60	.50	−.67	.94	< .001	71.00	135.00
Reverse Digits	278	7.31	1.98	.89	1.96	.93	< .001	4.00	16.00
W_ACERTAIN	278	90.74	12.88	−.46	−.49	.97	< .001	55.00	114.00
W_ERROR	278	37.26	12.88	.46	−.49	.97	< .001	14.00	73.00
W_LEVEL	278	5.48	2.05	.01	−.63	.97	< .001	.00	10.00
W_PERS_ER_ER_ER	278	12.25	7.30	.71	−.03	.95	< .001	1.00	36.00
W_PERS_AC_ER	278	13.30	2.66	.35	−.34	.98	< .001	8.00	21.00
W_PERS_TTAL	278	25.54	8.91	.58	−.26	.96	< .001	10.00	50.00
W_NOPERSE_ERROR	278	11.72	6.25	1.44	3.48	.90	< .001	10.00	40.00
W_media_time_ac	278	1316.11	607.15	1.95	6.85	.86	< .001	316.74	5205.87
W_media_time_err	278	2172.98	1231.72	2.70	10.93	.77	< .001	578.91	9701.61
TRR_TTAL_LEVEL	278	9.73	.49	−1.58	1.59	.57	< .001	8.00	10.00
TRR_MOVIM	278	88.13	19.53	.42	−.14	.98	.002	51.00	155.00
TRR_ERR_A	278	.62	1.09	2.64	10.31	.62	< .001	.00	8.00
TRR_ERR_B	278	.95	1.78	3.39	14.02	.57	< .001	.00	12.00
TRR_TIME_TTAL	278	305297.4	116977.7	1.15	1.77	.93	< .001	82896.3	805833.8
TM_N2_TTotal	270	151448.3	68878.3	1.17	1.06	.90	< .001	54484.3	409335.5
TM_N2_EU	270	3.66	12.06	14.31	223.16	.19	< .001	.00	192.00
TM_N2_CL	270	9.63	9.63	3.62	21.39	.68	< .001	1.00	90.00
TM_N2_STOPS	271	10.12	4.39	.26	−.34	.99	.011	.00	24.00
TM_N2_#Levan	270	4.07	8.73	5.33	35.64	.45	< .001	.00	75.00
TM_N2_TLevan	270	13211.6	24450.3	3.10	10.94	.59	< .001	.00	146979.5
TM_N2_#Pauses	270	50.31	44.77	2.43	8.84	.78	< .001	3.00	335.00
TM_N2_TPauses	270	27571.9	29256.1	2.80	9.36	.68	< .001	3687.8	188690.9
GNG_errors_GO	271	17.45	17.43	5.64	54.14	.57	< .001	11.00	330.00
GNG_errors_NOGO	271	14.86	12.04	1.95	3.74	.72	< .001	9.00	100.00
GNG_mediatime_GO	271	630.13	135.58	1.20	1.51	.91	< .001	442.66	1160.48
GNG_mediatime error_NOGO*	142	567.59	322.17	3.16	12.52	.66	< .001	333.67	2274.90
LAB_PuntuTotal	269	17.32	4.19	−.62	−.13	.96	< .001	5.00	27.50
LAB_levels	269	12.14	4.46	1.09	5.92	.86	< .001	1.00	37.00
LAB_complete	267	8.20	3.20	−.10	−.60	.96	< .001	.00	16.00
LAB_incomplete	267	3.62	2.19	1.18	1.34	.89	< .001	.00	12.00
LAB_error_TOTAL	267	21.45	16.29	.96	.31	.92	< .001	.00	75.00
LAB_AVERAGE_ERROR_-COMPLET	267	3.05	2.78	1.60	2.77	.84	< .001	.00	16.50

Note. *Only the averages of the "GNG_mediatime error_NOGO" were taken, discarding the '0' times of those who did not present errors.

by stops at circles (1200-1800 ms) and shorter pauses (300-800 ms), reflect the inhibition necessary to monitor and adjust execution. Thus, it is not surprising that offenders, displaying greater impulsivity, dedicate less time to planning, making fewer stops and pauses.

In a similar vein, in the Go/NoGo Test, offenders made a higher number of GO errors ($F = 5.09$, $p = .025$) and NOGO errors ($F = 45.02$, $p < .001$). They also exhibited shorter reaction times to GO stimuli (574.36 ms, $SD = 11.92$) compared to non-offenders (677.87 ms, $SD = 137.45$). These findings highlight an impulsive tendency that leads to errors due to anticipation. The inability to inhibit automatic responses to NOGO stimuli results in more errors in this type of trial. Previous studies have shown that a longer latency in the P3 signal for NOGO stimuli is associated with antisocial behavior (Delfin et al., 2022), which could explain these difficulties. On the other hand, GO errors may be linked to deficits in facilitation processes, potentially influenced by the lower proportion of GO stimuli in the test. However, further studies are needed to explore the differences in inhibition and facilitation processes in individuals with antisocial behavior (Thomas et al., 2009).

On the other hand, offenders in the Labyrinth Test (PM) scored lower overall ($F = 7.19$, $p = .008$), completed fewer labyrinths ($F = 7.56$, $p = .006$), and showed a higher total number of errors ($F = 5.5$, $p = .02$). These results indicate greater difficulties in planning and in-

Table 3

MANOVA Analysis of Variance of EF in Offender and Non-Offender Groups

Variable	LEGAL	*N*	MeAN	*SD*	*df*	*F*	*p*	VS-MPR*
W_LEVEL	Non-Offender	153	5.732	2.215	1	8.03	.005	13.979
	Offender	125	5.160	1.780				
W_PERS_TTAL	Non-Offender	153	24.333	8.812	1	8.37	.004	16.191
	Offender	125	27.024	8.837				
W_NOPERSE_ERROR	Non-Offender	153	10.451	5.531	1	14.44	<.001	236.977
	Offender	125	13.272	6.729				
TRR_ERR_B	Non-Offender	153	.588	1.290	1	12.93	<.001	121.480
	Offender	125	1.384	2.158				
TM_N2_STOPS	Non-Offender	146	11.000	4.480	1	11.35	<.001	60.147
	Offender	125	9.096	4.073				
TM_N2_#Levan	Non-Offender	145	2.786	4.210	1	6.59	.011	7523.000
	Offender	125	5.552	11.862				
TM_N2_#Pauses	Non-Offender	145	61.110	50.801	1	20.15	<.001	2998.881
	Offender	125	37.784	32.498				
GNG_errors_GO	Non-Offender	146	13.700	5.929	1	5.09	.025	4.004
	Offender	125	21.200	11.497				
GNG_errors_NOGO	Non-Offender	146	6.990	4.718	1	45.02	<.001	1.358×10+8
	Offender	125	22.720	7.320				
GNG_mediatime_GO	Non-Offender	146	677.875	135.450	1	44.36	<.001	1.032×10+8
	Offender	125	574.360	112.926				
LAB_PuntuTotal	Non-Offender	144	17.924	4.052	1	7.19	.008	9.735
	Offender	125	16.628	4.247				
LAB_complete	Non-Offender	142	8.711	3.112	1	7.56	.006	11.400
	Offender	125	7.616	3.210				
LAB_error_TOTAL	Non-Offender	142	19.239	14.469	1	5.5	.02	4.735
	Offender	125	23.968	17.869				
Reverse Digits	Non-Offender	153	7.804	2.112	1	19.03	<.001	1824.656
	Offender	125	6.712	1.611				
MANOVA LEGAL (INFRAC-NO INFRAC)			**valor**	*F*	df_1	df_2	*p*	**VS-MPR***
Pillai trace			.379	10.9	14	251	<.001	3.928×10+16
Wilks' Lambda			.621	10.9	14	251	<.001	3.928×10+16

Note. Vovk-Sellke Maximum *p*-Ratio: Based on the *p*-value, the maximum possible odds in favor of H_1 over H_0 equals $1/(-e\ p\ \log(p))$ for $p \leq .37$ (Sellke, et al., 2001).

hibitory control, which resulted in errors and failures during the labyrinth-solving process.

Along these lines, in the ToL Test, differences were identified solely in the number of Type B errors ($F = 12.93, p < .001$), associated with attempting to place more balls on a peg than allowed. Offenders were more prone to violating the task's initial rules, a tendency also observed in lifting errors during the TMT ($F = 6.59$, $p = .01$).

Another task that showed significant differences was the ID-W, which assesses attention, short-term memory, and working memory (WM). Offenders scored significantly lower than non-offenders ($F = 19.03$, $p < .001$).

Such results highlight the broader pattern of executive dysfunction observed in offenders, which aligns with existing evidence on executive function deficits in adolescents with antisocial behavior problems (Jansen & Franse, 2024; Griffith et al., 2024; Türel et al., 2024). However, these studies also highlight inconsistencies regarding the moderating role of age and IQ_E. In this study, given that offenders and non-offenders showed marked differences in age and IQ_E at baseline, which could account for the observed differences in EF, a multivariate analysis of covariance was conducted. This analysis aimed to control for the effects of age and IQ_E in the model to assess whether these variables confound the association between executive deficits and delinquency (see Table 4).

The analyses identified significant differences between the offender and non-offender groups in executive function (EF) measures ($F = 8.148$ $(13; 250)$, $p < 001$, $\eta p2 = .3$). Additionally, a moderate covariation of estimated intellectual quotient (IQ) with executive tests was found ($F = 3.718\,(13; 259), p < .001, \eta p2 = .16$), while the variable Age showed no significant effect ($F = 1.002\,(13; 259), p = .449$). This finding aligns with previous research reporting that, in adolescent samples with narrow age ranges, age does not moderate the relationship between executive performance and delinquency (Griffith et al., 2024).

As shown in Table 4, age differences between groups did not influence the observed differences in EF. How-

Table 4

Multivariate analysis of covariance of differences in EF between offenders and non-offenders

MANCOVA		**Total IQ**			**AGE**			**LEGAL**		
Variable	*df*	*F*	*p*	*ηp2*	*F*	*p*	*ηp2*	*F*	*p*	*ηp2*
W_NIVEL	1	7.809	.006	.029	.488	.485	.002	1.494	.223	.006
W_ERROR	1	15.772	0	.057	.147	.701	.001	3.117	.079	.012
TRR_ERR_B	1	5.368	.021	.02	1.284	.258	.005	6.049	.015	.023
TM_N2_STOPSIQ	1	1.453	.229	.006	.322	.571	.001	13.331	.000	.048
TM_N2_#Levan	1	.603	.438	.002	.823	.365	.003	4.561	.034	.017
TM_N2_#Pausas	1	1.001	.318	.004	.293	.589	.001	20.755	.000	.073
GNG_errors_GO	1	3.386	.067	.013	.037	.848	0	1.598	.207	.006
GNG_errors_NOGO	1	3.183	.076	.012	3.751	.054	.014	31.991	.000	.109
GNG_mediatime_GO	1	3.809	.052	.014	.456	.5	.002	27.778	.000	.096
LAB_PuntuTotal	1	.84	.36	.003	.023	.881	0	4.111	.044	.015
LAB_complete	1	8.95	.003	.033	3.861	.05	.015	2.524	.113	.01
LAB_error_TOTAL	1	.068	.795	0	.941	.333	.004	4.714	.031	.018
Reverse Digits	1	15.533	0	.056	1.687	.195	.006	6.503	.011	.024
					Value	*F(e)*	df_1	df_2	**Sig.**	*ηp2*
Total IQ		Pillai trace			.162	3.718	13	250	.000	.162
		Wilks Lambda			.838	3.718	13	250	.000	.162
Age		Pillai trace			.05	1.002	13	250	.449	.050
		Wilks' Lambda			.95	1.002	13	250	.449	.050
LEGAL		Pillai trace			.298	8.148	13	250	.000	.298
		Wilks' Lambda			.702	8.148	13	250	.000	.298

Note. Multivariate analysis of covariance taking Total IQ and age as covariates.

ever, IQ was significantly related to some EF measures, particularly in the WSCT. Moderation effects of IQ were primarily evident in WSCT results, especially in the strong association between IQ and non-perseverative errors ($rSp = -.35$, $p < .001$; $ZF = -.36$, see Supplementary Material 3). Nevertheless, IQ did not covary with other executive measures, such as perseverative errors, where differences between offenders and non-offenders were unaffected by IQ.

Similarly, differences observed in other tests, such as TMT, Go/NoGo, PM, and reverse digits, were not influenced by IQ, even though these measures were partially associated with this variable (Supplementary Material 3). Due to the violation of assumptions for conducting MANCOVA (pBox'M<.001 and pShapiro-Wilk<.001), a permutational MANOVA was performed, controlling for IQ effects. This analysis confirmed significant differences between offenders and non-offenders in EF measures (see Table 5). These findings were further corroborated through univariate ANCOVA for each EF variable, again controlling for IQ effects (see Table 6).

The main differences between non-offenders and offenders in executive function (EF) measures were observed in NOGO errors ($F = 31.99$, $p < .001$), the mean response time to GO stimuli ($F = 27.78$, $p < .001$), the number of pauses ($F = 20.76$, $p < .001$), and the number of stops ($F = 13.33$, $p < .001$) in the TMT test, as well as in the reverse digits subtest ($F = 6.50$, $p = .011$) (see Table 4). These group differences were further confirmed after controlling for IQE effects through ANCOVA analysis of each variable (see Table 6), revealing significant differences between non-offenders and offenders in the measures of Go/NoGo, TMT-2, and PM.

NOGO errors ($TG - H = 6.86$, $p_{\text{tukey}} < .001$, d=−.74) and the mean response time to GO stimuli ($TG - H = -6.526$, $p_{\text{tukey}} < .001$, d=.72) showed significant differences in EF measures. Similarly, significant differences were observed in lifting errors ($TG - H = -2.48$, $p_{\text{tukey}} = .014$, d=−0.29), stops ($TG - H = 3.66$, $p_{\text{tukey}} < .001$, dCohen=.52), and pauses ($TG - H = 4.55$, $p_{\text{tukey}} < .001$, d=.60) in the TMT-2 test.

Additionally, significant differences were confirmed between the groups in the total PM score ($TG - H = 2.55$, $p_{\text{tukey}} = .011$, $d = .28$) and the total number of errors committed during maze execution ($TG - H = -2.36$, $p_{\text{tukey}} = .019$, $d = -.28$). Likewise, significant differences were observed in the scores obtained in the reverse digits subtest ($TG - H = 4.89$, $p_{\text{tukey}} < .001$, $d = .37$).

In the case of the ToL, only type B errors differentiated non-offenders from offenders ($TG - H = -3.62$, $p_{\text{tukey}} < .001$, $d = -.34$). An association was found between type B errors in the ToL and NOGO errors ($rSp = .214$, $p < .001$, $ZF = -.218$; see supplementary material 3), suggesting that these errors are more related to failures in the inhibitory process than to a tendency to omit rules.

Table 5

Nonparametric MANOVA (permutational) differences in EF between NON-Offenders and Offenders

PERMANOVA	*df*	SumsOfSqs	MeanSqs	F.Model	R^2	$Pr(>F)$
LEGAL	1	62.2913	62.2913	14.7979	.0528	.001
Total IQ	1	10.1548	10.1548	2.4124	.0086	.016
LEGAL* Total IQ	1	3.3746	3.3746	.8017	.0029	.562

Pairwise comparisons

Variable	U-M.whitney	*p*-value	VS-MPR*	R(Biserial)	95% CI R(Biserial) Lower	Upper
Total IQ	14460.500	< .001	6.929×10+10	.512**	.405	.606
W_LEVEL	11222.000	.012	6.961	.174	.039	.302
W_ERROR	7210.500	< .001	112.856	−.246*	−.369	−.114
TRR_ERR_B	7225.000	< .001	450.241	−.244*	−.368	−.112
TM_N2_PARADES	11413.000	< .001	127.804	.251*	.118	.375
TM_N2_#Levan	8156.000	.144	1.317	−.1	−.234	.038
TM_N2_#Pauses	12283.000	< .001	52.557.397	.355**	.229	.47
GNG_errors_GO	7969.000	.061	2.162	−.127	−.259	.011
GNG_errors_NOGO	4546.500	< .001	3.274×10+11	−.502**	−.598	−.391
GNG_mediatime_GO	13651.000	< .001	6.912×10+9	.496**	.385	.593
LAB_PuntuTotal	10738.000	.006	11.639	.193	.057	.322
LAB_complete	10711.500	.003	19.426	.207	.071	.335
LAB_error_TOTAL	7623.000	.047	2.569	−.141	−.274	−.003
Reverse Digits	12459.000	< .001	3092.210	.303**	.174	.421

Note. *.2<R(Biserial)< .3; **R(Biserial)> .3.

Table 6

Analysis of covariance of differences between offenders and non-offenders

NON-OFFENDERS OFFENDERS		ANCOVA *df*	*F*	*p*	η_p^2	Games-Howell PostHoc. *t*	*df*	T-tukey p_{tukey}	Cohen's *d*
W_LEVEL	LEGAL	1	1.115	.292	.004	2.387	275.93	.018*	.142
	Total IQ	1	5.812	.017	.021				
W_ERROR	LEGAL	1	3.389	.067	.012	−3.614	261.73	< .001***	−,247
	Total IQ	1	11.246	< .001	.039				
TRR_ERR_B	LEGAL	1	6.259	.01	.022	−3.627	193.53	< .001***	−.336
	Total IQ	1	4.539	.034	.016				
TM_N2_PARADES	LEGAL	1	14.839	< .001	.052	3.663	268.02	< .001***	.519
	Total IQ	1	1.719	.191	.006				
TM_N2_#Levan	LEGAL	1	4.583	.03	.017	−2.476	150.86	.014*	−.289
	Total IQ	1	.295	.587	.001				
TM_N2_#Pauses	LEGAL	1	20.006	< .001	.07	4.553	248.21	< .001***	.603
	Total IQ	1	1.253	.264	.005				
GNG_errors_GO	LEGAL	1	1.670	.197	.006	−2.082	178.99	.039*	−.174
	Total IQ	1	2.554	.111	.009				
GNG_errors_NOGO	LEGAL	1	30.184	< .001	.101	−6.526	205.61	< .001***	−.74
	Total IQ	1	2.047	.154	.008				
GNG_mediatime_GO	LEGAL	1	28.485	< .001	.096	6.860	268.82	< .001***	.719
	Total IQ	1	3.588	.059	.013				
LAB_PuntuTotal	LEGAL	1	4.417	.037	.016	2.549	257.80	.011*	0.284
	Total IQ	1	.253	.616	.000				
LAB_complete	LEGAL	1	1.871	.173	.007	2.822	258.46	.005**	.186
	Total IQ	1	7.795	.006	.029				
LAB_error_TOTAL	LEGAL	1	4.328	.04	.016	−2.356	238.55	.019*	−.283
	Total IQ	1	.023	.879	.000				
Reverse Digits	LEGAL	1	7.624	.01	.027	4.888	274.75	< .001***	.371
	Total IQ	1	13.356	< .001	.046				

Note. Differences between LEGAL groups (NON-OFFENDERS OFFENDERS). The effect of Total IQ Covariate (Wechlser intelligence) is controlled.

5. Discussion

This study aimed to determine the existence of differences in executive functions (EF) between non-offending and offending juveniles. The results confirm substantial evidence suggesting that adolescents with antisocial behavior exhibit significant deficits in EF, such as inhibitory control (IC), working memory (WM), and monitoring of planning tasks (Jansen & Franse, 2024; Griffith et al., 2024; Orozco & Alvear, 2023; Sepúlveda et al., 2022).

The higher number of NOGO errors, the increase in type B errors on the ToL, a greater number of lifts on the TMT-2, and a higher total number of errors on the PM were key indicators of IC deficits among offenders. Tyburski et al. (2021) noted that the initiation time in planning tests, such as the ToL (mental planning phase), NOGO errors, and response times to GO stimuli are grouped under a common factor referred to as “plan inhibition”. In our study, offenders showed more NOGO errors, shorter response times to GO stimuli, and fewer stops and pauses on the TMT-2. These findings suggest that, in the case of the TMT-2, stops and pauses may represent periods of motor plan monitoring and that low IC reduces these periods, leading to an increased number of errors, such as lifts. Fellows et al. (2017) previously highlighted that pauses and their duration could be relevant measures of IC in digital TMT-2 evaluations. Thus, in complex planning tasks, low IC could contribute to poor execution planning and a tendency to commit more errors during task performance (Tyburski et al., 2021; Valori et al., 2022).

The inverse relationship observed between scores on the backward digit span test and perseverative and non-perseverative errors on the WSCT, along with a direct relationship between backward digit span scores and the number of correct responses on the WSCT, suggests a critical role for WM in task monitoring and updating. Neuroimaging studies have identified that inferior prefrontal areas are activated in both WM tasks and the WSCT, particularly during error identification (Konishi, 1999). Therefore, poor WM performance could be linked to difficulties in error recognition, contributing to greater inflexibility. In our study, offenders scored lower on the backward digit span test and committed more non-perseverative errors compared to non-offenders, suggesting that poor WM performance in adolescents with antisocial behavior may be associated with deficits in interference control, consistent with findings from previous studies on participants with WM deficits (Lange et al., 2016).

No significant differences were identified in flexibility measures (WSCT), although moderating effects of IQ were observed on flexibility measures in this test. However, IQ did not moderate measures related to IC or WM in other EF tests. Given that prior research has demonstrated a moderating effect of IQ on executive measures, and other studies have found a relationship between reduced intelligence and increased inflexibility (Colzato et al., 2006), it is unsurprising that, in our case, IQ differences between offenders and non-offenders may have masked differences in flexibility, such as perseverative errors in the WSCT. Nonetheless, it is noteworthy that the higher number of overall errors across all tests was more strongly related to IC deficits than to any other EF, and in this case, IQ did not show a moderating effect.

In conclusion, the evident deficits in IC, WM, and planning monitoring among Colombian juvenile offenders confirm findings reported in other contexts. The results of this study raise new questions about the intricate relationship between inhibition and planning, as well as between WM and flexibility, which could guide future research.

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