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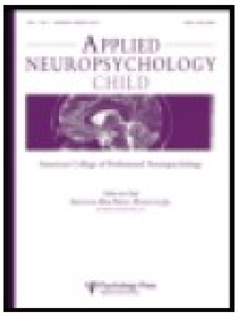

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Abstract

The aims of study 1 (S1) were (i) to compare the task performance of 361 typically developing (TD) children aged 7 to 12 years, according to the mode of WCST administration (manual vs. computerized), and ii) to examine the contributions of executive functions (EFs) (i.e., working memory (WM), shifting and inhibition) to each WCST version. The objectives of study 2 (S2) were (i) to study the comparability of the results obtained from the manual version to the results from the computer version in 43 children with ADHD and (ii) to compare task performance on both versions between children with ADHD and TD children. The effect of age was only significant for the manual WCST. Regression analyses revealed that WM and shifting contributed to manual WCST performance, whereas WM and inhibition contributed to the performance on the computer version. We observed differences depending on the WCST mode of administration, as better scores for the manual version were recorded for both TD children and children with ADHD, despite similar performance on tasks involving other EFs. Additionally, children with ADHD performed worse than TD children on both versions. Our findings suggest that verbal face-to-face interactions would play a significant role in supporting children's abilities to solve novel situations characterized by uncertainty.

Keywords: Manual WCST; Computerized WCST; Executive Functions, ADHD; Child Neuropsychology.

Introduction

The Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) is one of the most extensively used paradigms to assess executive function (EF) in children. Although it was originally developed to assess problem solving and decision-making abilities (Grant & Berg, 1948), it is currently used as a measure of EF, particularly when assessing the use of external cues to self-regulate behavior, the tendency towards perseveration (Romine et al., 2004) and set shifting ability (Miyake et al., 2000). Some authors have argued that during WCST performance several cognitive processes, in addition to shifting, are at stake, namely, working memory (WM), inhibition, decision-making and reasoning (Wang, Kakigy, & Hoshiyama, 2001).

Many studies of WCST have confirmed its value in clinical practice and research in the field of neuropsychology. The WCST has been used to assess EF in patients with ADHD (Miranda, Presentación, Siegenthaler, & Jara, 2013), autism spectrum disorders (Kaland, Smith, & Mortensen, 2008), fetal alcohol syndrome (Kodituwakku, May, Clericuzio, & Weers, 2001), epilepsy (Igarashi et al., 2002; Longo, Kerr & Smith, 2013) and hydrocephalus (Fletcher et al., 1996), among other disorders. Research has also revealed its clinical usefulness in the study of EF in children and adolescents with learning disorders (Fisher, Deluca, & Rourke, 1997; Snow, 1998). According to data from recent studies, most studies on ADHD include the WCST within their evaluation batteries (Ochoa Angrino & Cruz Panesso, 2007), and approximately 75% of neuropsychologists use it for both diagnostic and research purposes (Butler, Retzlaff, & Vanderploeg, 1991). Therefore, there has been growing interest in the study of the WCST, including its sensitivity and specificity (see Romine et al., 2004 for review), the establishment of developmental norms according to age and sex (see Rosselli & Ardila, 1993; Shu, Tien, Lung &

Chang, 2000) and the analysis of the equivalence between its different modes of administration (i.e., manual vs. computer).

Manual vs. *computerized versions of the WCST*

Currently, there are two modes of WCST administration: manual and computerized. Both modes also have different forms (e.g., WCST-64 and WCST-3). Although studies have used both versions indistinguishably, controversy remains concerning their equivalence.

For instance, both versions have been shown to be equivalent in healthy subjects and in clinical populations. Notably, Fortuny and Heaton (1996) compared the performance of 119 Spanish-speaking healthy subjects aged 15 to 59 years on the computerized WCST to the manual version; subjects were randomly assigned to WCST versions. The authors found no significant differences between the results obtained from both forms of the WCST. Furthermore, Shan, Chen, Lee, and Su (2008) compared the results from both versions among 475 healthy Taiwanese adults aged 20 to 89 years with 9 to 16 years of education; they found no significant differences between WCST outcomes. According to Peretti Wagner and Marceli Trentini (2009), the two modes yielded similar results when analyzing the performance of 54 older Brazilian adults aged 60 to 82 years who were matched by age and educational level. The authors argued that although these results support the hypotheses that both WCST versions are equivalent, the outcomes should be cautiously interpreted based on the small sample size and the age group analyzed. Finally, Tien et al. (1996) compared the performance of 33 healthy subjects and subjects with psychiatric disorders aged 17 to 65 years, with a mean educational level of 12.9 years, on both versions. The order of administration of both versions was randomly assigned. The results were similar between both versions. However, authors noticed poorer scores in subjects who completed the computer version, probably due to differences in the response demands of each mode of administration.

Past studies have also failed to show the equivalence of the two WCST versions. For example, Feldstein et al. (1999) compared the performance of 110 healthy students on different computerized WCST versions to the manual version; students were randomly assigned to WCST versions. The two modes were not equivalent, as participants who completed the computer versions obtained poorer scores than participants who completed the manual version. According to the authors, these results reveal a need to develop norms and validity measures for computer versions of the WCST. In turn, Miranda, Coelho and Bueno (2009) compared the performance of Brazilian children aged 6 to 10 years on the computer version of the WCST to Brazilian and American children who completed the manual WCST. The authors actually found that the two versions were not equivalent and stressed the need to develop normative values for each version and country. Furthermore, Steinmetz, Brunner, Loarer, and Houssemand (2010) used a counterbalanced design to study the equivalence between both WCST versions in 100 healthy adults with a mean age of 26.3 years and a mean level of education of 15.1 years. The authors found that scores on the manual and the computer versions show incomplete psychometric equivalence and highlighted the importance of using caution when treating both versions as interchangeable for clinical or research purposes. Finally, studies conducted in clinical populations also reported significant differences according to the mode of administration. For example, children with autism perform better on the computer version of the WCST than on the manual version, suggesting that the two versions are not equivalent in the assessment of children with this disorder (Ozonoff, 1995). However, a more recent study found equivalence between both versions in children with autism spectrum disorder (Williams & Jarrold, 2013).

The present study

The present study compared the performance on the manual and computerized WCST among TD children and children with ADHD and examined the contributions of EF to each WCST version. Although previous studies have analyzed the equivalence between both versions in healthy and clinical samples, important issues remain to be addressed. First, to our knowledge, no studies have compared the performance of Spanish-speaking children between both modes or analyzed the effect of age on each version. These findings may be particularly relevant, as the WCST is not predicted to be a culture-free test (Coelho, do Rosário, Mastrorosa, Miranda, & Amodeo Bueno, 2012; Coffey, Marmol, Schock, & Adams, 2005; Kohli & Kaur, 2006; Shan et al., 2008), stressing the importance of developing norms for each version (see Feldstein et al., 1999; Miranda et al., 2009). Second, no study has compared the performance of children with ADHD on both versions. The WCST is one of the most frequently used tests to assess the EF deficits associated with ADHD. Most children with ADHD exhibit a weaker performance on WCST variables (Romine et al., 2004), and the test enables to differentiate between subjects with ADHD and controls (Sergeant, Geurts, & Oosterlaan, 2002). This evidence highlights the importance of analyzing whether the performance of children with disorder is equivalent for different WCST versions.

We also included other EF tasks in the study for two main reasons. First, these tasks were included as control measures, because EFs have been shown to influence WCST performance. For instance, research on children has found that shifting, inhibition and WM contribute to WCST performance (Huizinga & van der Molen 2007). The performance of healthy students on the WCST also depends on WM capacity (Lehto, 1996) and shifting ability (Miyake et al., 2000). Thus, comparable proficiency with secondary EF skills between groups would support the hypothesis that the mode of administration constitutes one of the main factors explaining the variability in WCST performance according to version. Second, it is intriguing to explore the contribution of EF to each WCST version, since these alternative formats could either magnify or limit demands on specific executive processes. We therefore included tasks to assess the three often-postulated EFs (i.e., WM, shifting and inhibition) (Miyake et al., 2000; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003) to determine whether there were significant differences in these measures between groups and to analyze the contributions of the different EFs to each WCST version.

Study 1 (S1)

Method

Participants

The sample consisting of 361 children was divided into the following groups: (1) Manual WCST: A total of 139 Spanish-speaking children and adolescents of both sexes aged between 7 to 12 years and (2) Computer WCST: A total of 222 Spanish-speaking children and adolescents of both sexes aged between 7 and 12 years. Parents or legal guardians provided written consent before the assessment. Inclusion criteria included children and adolescents with no known history of neurological or psychiatric treatments, who attend school regularly and have not repeated a grade. The Department of Education suggests a school socioeconomic coefficient scale based on family income that ranges from *very good* to *deficient*. Based on this scale, the socioeconomic coefficient of the schools included in the present study was ‘good’. According to this classification *good* refers to those families in which the parents have paid jobs and fixed salaries. In addition, the mother’s education level was recorded using a scale ranging from 1 to 5. The levels were classified as follows: 1. primary level, 2. secondary level, 3. higher than secondary school level but lower than a university degree, 4. university degree, and 5. Master's degree or higher education. The average education level of the mothers was 3.52 (*SD* = 0.52) for the participants who completed the computerized version and 2.70 (*SD* = 0.65) for the participants who completed the manual version. Most of the mothers had completed their secondary education or university degree. Prior to administering EF tasks, the K-BIT (Kaufman & Kaufman, 2000) was used to determine whether children had a performance within the range expected for their age group. Intellectual function was within the range expected for both samples who completed the manual (*M* = 92.79; *SD* = 10.38) and computerized (*M* = 92.14; *SD* = 11.81) versions. Before analyzing differences in performance on each version of the WCST, Student's *t*-test was used to verify a lack of significant differences in age (t (243.480) = 1.065, p = .288), IQ level (t (359) = -0.536, p = .592) and performance on other EF tasks, including the WM task of the WISC IV (t (235.426) = .358, p = .721), phonological verbal fluency (t (359) = 1.741, p = .083) and nonverbal fluency (Five Point Test) (t (359) = -1.109, p = .268), between groups. Significant differences were only observed for performance on the Stroop color-word sheet variable (t (359) = 4.096, $p < .001$) and semantic verbal fluency (SVF) task (t (359) = 5.724, $p <$ .001) in favor of those children who completed the computerized version. **Table 1** shows the means and standard deviations of these measures for the two groups. Following Cohen's guidelines, *d* values of .20 represent a small effect, .50 a medium effect, and .80 a large effect (Lakens, 2013). Separate MANOVAs were performed to determine the effect of sex on performance on both WCST versions. No significant main effect of sex was observed on performance on the computerized WCST (Hotelling's $F(10, 211) = 0.676$; $p = .746$, partial η^2 = .03) or the manual version (Hotelling's $F(11, 127) = 1.719$; $p = .076$, partial $\eta^2 = .13$).

Table 1. *Descriptive statistics for cognitive measures in TD children*

	Group				
	Manual WCST		Computerized WCST		Effect size Cohen's *d*
	M	*SD*	*M*	*SD*	
Age	9.58	1.70	9.76	1.34	-0.11
IQ K-BIT	92.79	10.38	92.14	11.81	0.06
WM WISC-IV	29.97	6.67	30.20	5.03	-0.03
Stroop-CW	24.32	6.52	27.50	7.53	-0.45*
SVF	20.96	5.59	24.65	6.16	-0.63**
PVF	17.35	7.17	18.79	7.89	-0.19
FPT	22.36	8.23	21.34	8.68	0.12

Notes. IQ K-BIT = Kaufman Brief Intelligence Test; WM WISC-IV = working memory subtests of Wechsler Intelligence Scale for Children – Fourth Edition; Stroop-CW = color-word sheet of the Stroop test; SFV = semantic verbal fluency; PVF = phonological verbal fluency; FPT = Five Point Test.
Effect sizes: (mean-differences in independent groups) *$d > .20$; **$d > .50$

Procedures and Materials

Children were individually assessed in three sessions lasting for up to 30 to 40 minutes per session, and they worked in a quiet room within the educational institution. The assessment was conducted by highly qualified specialists (i.e., neuropsychologists and psychologists). All children had familiarity and experience with computers, as the schools included in this study taught information technology as a compulsory or optional subject. The materials used for analysis are described below.

Wisconsin Card Sorting Test (WCST), Manual (Heaton, Chelune, Talley, Kay, & Curtiss, 1997) and Computer versions. The task was administered in its manual or computerized version. Both groups (manual and computer) received the manual standard instructions orally. First, researchers confirmed that all subjects had understood the task and its procedure. The manual WCST introduces four key cards (i.e., one red triangle, two green stars, three yellow crosses, and four blue circles) to participants. Then, participants received a stack of

128 additional response cards and were asked to match each card to one of the key cards. Examiners informed participants about whether their answers were right or wrong as they matched the different cards; however, categories were not provided to participants during sorting. The following variables were studied: trials to complete first category (TC1st), number of trials (NT), total correct (TC), total errors (TE), perseverative responses (PR), percentage of perseverative responses (PPR), perseverative errors (PE), percentage of perseverative errors (PPE), nonperseverative errors (NPE), failure to maintain set (FMS) and complete categories (CC). Stability coefficients range between .39 and .72 (Heaton et al., 1993). The computerized WCST version displays four key cards (one red triangle, two green stars, three yellow crosses, and four blue circles) on the screen; subjects are asked to match the response cards that appear on the screen with one of the four key cards. Similar to the manual version, subjects are not informed on how the cards should be matched, but instead they must match the cards according to the feedback they received (correct or incorrect) from the computer screen. During the administration of the computerized version, the machine reports whether the answer is correct.

Working Memory

Digit Span and Letter–Number Sequencing subtests of the WISC-IV (Wechsler, 2003). This test involves two main subtests: digits (D) that provides a measure of immediate oral retention when assessed with digit forward (DF), and maintenance and manipulation of information when using digit backwards (DB). Letters and numbers (LN) concern a series of numbers and disorganized letters for participants to recall, order the numbers from lowest to highest and arrange the letters alphabetically. The WISC IV has been standardized in Argentina. The average internal consistency using the two-half method is .85 for LN, .82 for DF and .74 for

DB. The test-retest reliability coefficient is .77 for LN, and .76 and .68 for DF and DB (Wechsler, 2010).

Inhibition

Stroop Color-Word Test (Golden, 1999). This test measures interference control and the ability to inhibit an automatic verbal response. It includes three response demands: (1) the word condition, (b) the color condition, and (c) the color-word condition. The words 'blue', 'red' and 'green' are written in black capital letters and arbitrarily arranged on the word condition sheet. The color condition sheet consists of elements (e.g., xxxx) that are equally arranged but randomly printed in blue, green or red. The color-word condition sheet includes the same group of words as the first sheet; however, the semantic relevance of the written word is discrepant with the color the words are printed in. This phase imposes a heavier demand on inhibition as well as shifting away from a habitual response. This phase imposes a heavier demand on inhibition as well as shifting away from a habitual response. The test-retest reliability is .86 for the word page, .82 for the color page and .73 for the color-word page (Golden, 1999).

Shifting

Semantic Verbal Fluency (SVF) and Phonologic Verbal Fluency (PVF) (FAS fluency test; Benton & Hamsher, 1989). Participants must retrieve and say all possible words belonging to a particular category (fruits and animals) or starting with a specific letter (F, A and S) in the course of 60 seconds. VF tasks have standards for Spanish-speaking children (Arán Filippetti & Allegri, 2011; Ardila & Rosselli, 1994).

Five-Point test (Regard, Strauss, & Knapp, 1982). This paper-and-pencil test offers a measure of nonverbal fluency and cognitive flexibility. It consists of a page that contains 35 identical squares arranged in five columns and seven rows. Each square includes five symmetrically organized dots. Participants are asked to produce as many different designs as possible in a 3-minute period by connecting two or more dots with straight lines. The test-retest reliability coefficient for the number of unique designs is .77 (Tucha, Aschenbrenner, Koerts, & Lange, 2012).

Intelligence

KBIT, Kaufman brief intelligence test (Kaufman & Kaufman, 2000*)*. This test offers a measure of crystallized (Gc) and fluid (Gf) intelligence and consists of two subtests: (a) vocabulary (verbal/crystallized/knowledge), which includes part A to assess the expressive vocabulary and part B to assess definitions, and (b) matrices (manipulative/fluid/mental processing). Internal consistency analyzed through the two halves method is .98 for the vocabulary subtest and of .97 for the matrices subtest. The test-retest stability coefficient is .94 for the vocabulary subtest and .86 for the matrices subtest (Kaufman & Kaufman, 2000).

Statistical Analyses

Separate multivariate analyses of variance (MANOVAs) were performed, followed by the Scheffé post hoc test when equal variances were assumed or the Games-Howell post hoc test for unequal variances, to ascertain the effect of age (i.e., 7-8, 9-10, 11-12 years) on performance on each version and the effect of the mode of administration (computerized vs. manual) on WCST performance. Partial η^2 (Castro & Martini, 2014; Lakens, 2013) was used to calculate size effects. Following conventions for partial η^2, values of .01 represent a small effect, .06 a medium effect and .14 a large effect (Murphy & Myors, 2004). Finally, stepwise regression analyses were employed to explore the relative contributions of different EFs to WCST performance. All analyses were performed using SPSS software for Windows, version 22.0.

Results

1. Computerized WCST performance stratified by age

MANOVA results did not reveal a significant main effect of age, Hotelling's $F(20, 418) = .748$; $p = .775$, partial $\eta^2 = .03$. Means and standard deviations for each age group are presented in **Table 2**.

Table 2. *Means and standard deviations of computerized WCST scores in TD children according to age*

Variables	Age Group						F (2, 219)	p-value	Effect size Partial η^2
	7-8		9-10		11-12				
	M	*SD*	*M*	*SD*	*M*	*SD*			
TC1st	20.35	20.85	23.45	22.48	19.87	16.06	0.743	.477	.007
NT	123.08	9.49	124.68	9.44	122.40	13.60	1.035	.357	.009
TC	71.58	12.71	71.94	16.04	75.86	12.97	1.619	.200	.015*
TE	50.54	18.31	52.74	19.21	45.78	18.05	2.937	.055	.026*
PR	28.81	13.13	31.19	14.01	28.54	14	0.913	.403	.008
PPR	23.15	9.59	24.72	10.63	22.86	10.30	0.783	.458	.007
PE	24.08	9.67	26.08	10.97	23.37	10.67	1.494	.227	.013*
PPE	19.29	7.13	20.67	8.26	18.67	7.87	1.425	.243	.013*
NPE	26.46	12.46	26.66	14.22	22.41	11.49	2.268	.106	.020*
FMS	5.35	2.71	5.89	2.21	5.43	2.45	1.175	.311	.011*
CC	3.50	1.88	3.26	1.69	3.79	1.67	2.067	.129	.019*

Notes. TC1st = trials to complete first category; NT = number of trials; TC = total correct: TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE = percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
**p*-values are statistically significant.
Effect sizes: * $\eta p^2 > .01$; ** $\eta p^2 > .06$; *** $\eta p^2 > .14$.

2. Manual WCST performance stratified by age

The MANOVA revealed a significant main effect of age, Hotelling's $F(22, 250) = 4.059$; $p < .001$, partial $\eta^2 = .26$. Univariate F tests indicated significant differences in most of the WCST variables between groups (**see Table 3**).

Table 3. *Means and standard deviations of manual WCST scores in TD children according to age*

Variables	Age group						F (2, 136)	p-value	Effect size Partial η^2
	7-8		9-10		11-12				
	M	*SD*	*M*	*SD*	*M*	*SD*			
TC1st	17.30_{*a}	15.86	12.26	3.88	11.23_{*b}	1.13	5.743	.004*	.078**
NT	112.43_{a}	18.04	107.02_{a}	20.32	90.68_{b}	21.19	15.789	<.001*	.188***
TC	77.57_{a}	10.07	77.29_{a}	10.45	69.57_{b}	9.81	9.964	<.001*	.128**
TE	35.07_{a}	17.56	29.76	16.16	21.45_{b}	15.83	8.433	<.001*	.110**
PR	26.43_{*a}	15.80	17.52_{*b}	10.49	12.13_{*b}	13.95	13.264	<.001*	.163***
PPR	22.27_{a}	11.17	15.70_{b}	7.42	13.20_{b}	12.34	9.002	<.001*	.117**
PE	21.91_{*a}	12.96	14.17_{*b}	8.55	10.19_{*b}	10.96	13.846	<.001*	.169***
PPE	18.56_{a}	9.11	12.66_{b}	6.10	11.33_{b}	10.77	8.348	<.001*	.109**
NPE	13.16	7.17	15.60	9.90	11.21	8.83	2.980	.054	.042*
FMS	1.64_{*a}	1.14	1.31_{*a}	1.19	0.49_{*b}	0.82	15.456	<.001*	.185***
CC	4.75_{*a}	1.58	5.19	1.36	5.62_{*b}	0.86	5.590	.005*	.076**

Notes. TC1st = trials to complete first category; NT = number of trials; TC = total correct: TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE = percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
Mean scores with different subindexes indicate significant differences at $p \leq .05$, according to the Scheffé test or to the Games-Howell test when marked with an asterisk (*).
**p*-values are statistically significant.
Effect sizes: *$\eta p^2 > .01$; **$\eta p^2 > .06$; ***$\eta p^2 > .14$.

3. WCST performance according to mode of administration

The MANOVA revealed a significant main effect of the mode of administration, Hotelling's $F(11, 349) = 72.818$; $p < .001$, partial $\eta^2 = .70$. The manual WCST group achieved better scores for all variables than the computerized WCST group. The results of univariate F tests and p-values are presented in **Table 4**.

Table 4. *Mean scores and p-values of TD children stratified by WCST version (computerized* vs. *manual)*

Variables	WCST version						
	Computerized		Manual		F (1, 359)	p-value	Effect size Partial η^2
	M	*SD*	*M*	*SD*			
TC1st	22.07	20.65	13.46	9.51	21.324	<.001*	.056*
NT	123.85	10.79	102.50	22.01	150.903	<.001*	.296***
TC	73.01	14.91	74.43	10.72	0.955	.329	.003
TE	50.51	18.95	28.27	17.36	125.353	<.001*	.259***
PR	30.16	13.91	18.29	14.82	59.142	<.001*	.141**
PPR	24.01	10.41	16.83	11.29	38.078	<.001*	.096**
PE	25.08	10.77	15.10	11.98	67.163	<.001*	.158***
PPE	19.94	8.05	14.02	9.51	40.124	<.001*	.101**
NPE	25.43	13.38	13.15	8.82	91.986	<.001*	.204***
FMS	5.70	2.34	1.10	1.15	462.192	<.001*	.563***
CC	3.44	1.72	5.22	1.32	107.799	<.001*	.231***

Notes. TC1st = trials to complete first category; NT = number of trials; TC = total correct; TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE = percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
**p*-values are statistically significant.
Effect sizes: $*\eta p^2 > .01$; $**\eta p^2 > .06$; $***\eta p^2 > .14$.

4. Multiple regression analyses

Stepwise regression analyses were used to examine the contributions of WM, inhibition and shifting to performance on the computerized and manual WCST. For the number of complete categories on the computer version, WM has a stronger predictive value and explained 9% of the variance, followed by inhibition, which explained and additional 2% of the variance. The (percentage of perseverative errors) PPE was predicted by WM, explaining 8% of the variance. For the number of complete categories on the manual version, WM was also the strongest predictor and accounted for 15% of the variance, while shifting explained an additional 4% of the variance. The PPE was predicted by WM, explaining 16% of the variance (see the complete results in **Table 5**).

Table 5. *Complete results of the stepwise regression analysis of the performance of TD children on the WCST administered in each mode.*

Version	Variables	ANOVA for model	R^2	R^2 *change*	*β*	*p*
Computerized WCST	**CC**					
	Step 1					
	WM	$F(1, 220) = 22.060^{***}$	.09	.09	.30	< .001
	Step 2					
	WM	$F(2, 221) = 13.954^{***}$	.11	.02	.24	< .001
	Inhibition				.16	.021
	PPE					
	WM	$F(1, 220) = 19.607^{***}$	.08	.08	-.29	< .001
Manual WCST	**CC**					
	Step 1					
	WM	$F(1, 137) = 24.185^{***}$	.15	.15	.39	< .001
	Step 2					
	WM	$F(2, 136) = 15.806^{***}$	.19	.04	.27	.003
	Shifting (VF)				.23	.012
	PPE					
	WM	$F(1, 137) = 25.390^{***}$	.16	.16	-.40	< .001

Notes. CC = categories completed; PPE = percentage of perseverative errors; VF = verbal fluency.
*** $p < .001$

Conclusions for S1

Findings from this study are consistent with results from previous studies showing (1) better performance on the manual WCST with age, (2) the contributions of specific domains of EF to WCST performance and (3) the differences in the scores observed, depending on the mode of administration (manual vs. computerized).

First, performance on the manual version improves with age. Specifically, we observed that 7-8-year-old children completed approximately 4.75 categories, 9-10-year-old children completed 5.19 categories and 11-12-year-old children completed 5.62 categories. Accordingly, the number of perseverative errors decreased from 21.91 at 7-8 years to 10.19 at 11-12 years.

These results are similar to those reported in studies conducted in other countries with Spanish- (Rosselli & Ardila, 1993) and English-speaking (Chelune & Baer, 1986) children. Specifically, Rosselli and Ardila (1993) noticed that 7-8-year-old children completed 4.6 categories, 9-10-year-old children completed 5.1 categories and 11-12-year-old children completed 5.7 categories. These values are slightly higher than those reported by Chelune and Baer (1986) who found that 7-year-old children completed 4.07 categories, 8-year-old children completed 4.05 categories, 9-year-old children completed 4.81 categories, 10-year-old children completed 5.60 categories, 11-year-old children completed 5.58 categories and 12-year-old children completed 5.70 categories. In contrast, performance on the computer version was not significantly different with age, and the norm scores were lower than scores for the manual version. Specifically, 7-8-year-old children completed 3.50 categories, 9-10-year-old children completed 3.26 categories and 11-12-year-old children completed 3.79 categories. In addition, the number of perseverative errors decreased from 24.08 at 7-8 years to 23.37 at 11-12 years. These data are similar to the findings reported by Yeniceri and Altan-Atalay (2011) who observed that children aged 8, 9, 10, and 11 years completed 3.66, 3.98, 4.19 and 4.44 categories, respectively. Lower values have been reported for Brazilian children by Coelho et al. (2012), who also found that the level of adult performance would be reached at approximately the age of 13.

We regressed the number of complete categories and the percentage of perseverative errors of the WCST (manual and computer) on WM, inhibition and shifting measures to analyze the contributions of different EFs to the performance on each WCST version. According to the regression analysis, WCST performance imposes different demands on EF according to the mode of administration. Specifically, performance on the computerized WCST was predicted by WM and inhibition, while performance on the manual WCST was predicted by WM and shifting. As expected, WM was the main predictor of both manual and computer task performance. These results are consistent with findings from previous studies showing that WCST performance depends on WM ability, as it would enable the subject to continuously recall different rules in mind (Huizinga & van der Molen 2007) and activate different aspects related to the task (Lehto, 1996) while inferring the sorting principles based on feedback. However, WM accounted for a higher percentage of the variance in the performance on the manual version than on the computer version. We argued that the differences in timing of the verbal feedback and the high interference during WCST manual performance place a greater demand on verbal WM as the participant must recall the sorting principles while waiting for both the examiner´s oral feedback and coding of the responses. Besides, the visually displayed stimuli on the screen and the visual feedback of the computerized WCST could reduce the load on verbal WM. Finally, it should be noted that the manual WCST uses a "hands-on, accomplishing-by-doing" predicate versus responding without these intervening, tangible components. Therefore, although WM contributes to both WCST versions, the demands on the central representational work space of verbal WM would differ between these integrated response demands. The results showing that inhibition contributes to performance on the computer version of the WCST are consistent with studies reporting that the ability to inhibit interfering responses contributes to WCST performance (Huizinga & van der Molen 2007). However, inhibition did not predict performance on the manual WCST. As the administration of the manual version indirectly introduces an external pacing control, this implicitly shapes more uniform deliberations, because the examinee is not able to simply complete the task with exceptionally rapid proposals. Conversely, the computerized version would require greater self-control, as external verbal regulation/pacing is not available. Additionally, adult-level performance on the manual version is achieved at younger ages, potentially limiting demands on inhibition. This observation is consistent with a study showing that inhibition recruitment during WCST performance differs as a function of age (Huizinga & van der Molen, 2007). Finally, shifting ability was associated with performance on the manual WCST, as it would ease flexible switch between the different sorting rules (i.e., color, shape and number). However, this ability did not predict performance on the computerized WCST. This could be due to the fact the present study used spontaneous cognitive flexibility tasks (i.e., verbal and nonverbal fluency) that differ from the reactive flexibility component valued by the WCST (Eslinger, Biddle, Pennington, & Page, 1999). These two main types of cognitive flexibility have been proposed by Eslinger and Grattan (1993). Reactive flexibility refers to the aptitude to modify one's behavior in terms of changing demands. In turn, spontaneous flexibility involves the ability to provide different responses and produce new ideas. Furthermore, it is worth stressing that only verbal fluency (contrary to non-verbal fluency) predicted performance on the WCST manual version. Therefore, it may be that the verbal nature of this shifting task and its strong relationship with verbal WM (Arán Filippetti & Allegri, 2011) could partly explain the selective contribution of verbal fluency to WCST performance according to the format.

Finally, children who completed the manual version performed better than children who completed the computer version. These findings are consistent with the study by Shu et al. (2000), who also observed poorer scores for Taiwanese children who completed the computerized version compared to those results reported by Rosselli and Ardila (1993) and Chelune and Baer (1986) obtained using the manual version. Interestingly, the groups did not differ in terms of IQ or performance on other EF tasks, and only exhibited differences in inhibition and SVF. Thus, based on the current results and those reported in previous studies, TD children would exhibit differences in WCST performance depending on the mode of administration.

Study 2 (S2)

Participants

The sample consisting of 103 children was divided into the following groups: (1) TD children: A total of 60 children and adolescents of both sexes aged 7 to 12 years. The group comprised 30 children who performed the computer version of the WCST and 30 children who performed the manual WCST. Similar to S1, written consent was obtained from all parents or legal guardians before the evaluation, and the same inclusion criteria were utilized. Intellectual function was within the range expected for both the sample of children who performed the manual version (M = 94.40; SD = 12.29) and the sample to which the computer version was administered (M = 93.77; SD = 9.66). (2) ADHD children: Archived data collected from 43 children with ADHD of both sexes aged between 7 and 12 years were analyzed. Children were clinically diagnosed by different specialists (pediatric neurologists and neuropsychologists) based on DSM IV criteria (American Psychiatric Association, 1994), the abbreviated Conners' Rating Scales for parents (CPRS-HI) (Conners, 1990) and diagnostic interviews with parents and teachers. The presence of clinical symptoms of ADHD was further established using the Conners' Continuous Performance Test II. The CPT is one of the most widely used instruments for neuropsychological assessments of children with ADHD (Riccio, Reynolds, & Lowe, 2001). This assessment enables to discriminate between children with ADHD and TD children (Nichols & Waschbusch, 2004) and to predict the presence of ADHD symptomatology (Epstein et al., 2003). All children included in the sample exhibited results that were consistent with an ADHD clinical profile, according to the test reports. The exclusion criteria were (1) an IQ less than 75, (2) continuous performance testing that fell within expected limits instead of revealing clinically significant impairments, (3) the presence of other neurological disorders and (4) illiteracy. None of the children with ADHD were taking medication. This group was subsequently divided into two subgroups according to WCST versions administered: (1) WCST manual version: 21 children with ADHD of both sexes (2 F/19 M) and (2) WCST computer version: 22 children with ADHD of both sexes (6 F/16 M). Before analyzing the differences in task performance according to the version administered, a *t* test for independent samples was used to determine whether there were significant differences in terms of age (t [41] = -0.831, p = .411), IQ level (t [41] = 0.206, p = .838) and performance on other tasks that value EF, including Stroop (color-word sheet) (t [39] = 0.393, p = .697) and PVF (t [35] = -2.281, p = .209) between groups. **Table 6** shows the descriptive statistics for each sample.

Table 6. *Descriptive statistics for cognitive and behavioral indicators in children with ADHD*

	ADHD Group				Effect size Cohen's *d*
	Manual WCST		Computerized WCST		
	M	*SD*	*M*	*SD*	
Age	8.57	1.83	9.00	1.54	-0.25*
IQ	91.71	9.27	91.05	11.82	0.06
Stroop-CW	23.10	8.04	22.24	5.90	0.12
PVF	14.20	5.60	17.27	8.04	-0.44*
CPT O	26.43	14.31	35.59	22.23	-0.48*
CPT C	30.10	4.99	26.41	4.94	0.74**
CPT D	.08	.21	.20	.27	-0.49*
CPT HIT RT	474.74	124.28	496.17	92.28	-0.19
HI Conners RS	22.52	2.21	22.68	2.23	-0.07

Notes. Stroop-CW = color-word sheet; PVF = phonological verbal fluency; CPT O = omissions of CPT; CPT C = commissions of CPT; CPT D = detectability of CPT; CPT HIT RS = mean response time for all target responses of CPT; HI Conners RS = hyperactivity index of the Conners Rating Scale.
Effect sizes: (mean differences in independent groups) *d > 0.2; **d > 0.5; ***d > 0.8

Instruments

Wisconsin Card Sorting Test (WCST) in its manual and computer versions. See the descriptions in S1.

Continuous Performance Test (Conners, 2000). The CPT is a widely used measure of sustained attention and inhibitory control. Participants are asked to press the space bar every time any letter appears, except for the letter "X" (non-target stimulus). Main indicators are (1) omissions (failure to respond to targets), (2) commissions (responses to nontargets), (3) detectability (differences between targets and nontargets) and (4) hit response time (average response time). This instrument is typically used to assist understand how the fallout associated with ADHD is manifested and may also be useful for monitoring and/or influencing the course of therapeutic interventions (Narbona & Chevrie-Muller, 1997).

Stroop Color-Word Test (Golden, 1999). See the description in S1.

Phonologic Verbal Fluency (PVF) (FAS fluency test; Benton & Hamsher, 1989). See the description in S1.

KBIT, Kaufman brief intelligence test (Kaufman & Kaufman, 2000). See the description in S1.

Statistical Analyses

MANOVA was performed to compare task performance of children with ADHD according to the WCST mode of administration (computerized vs. manual). For group comparisons (ADHD vs. TD), Student's *t*-test was used. Effect sizes were calculated using partial η^2 for analysis of variance (Castro & Martini, 2014; Lakens, 2013) and Cohen's *d* for *t*-tests.

Results

1. *WCST performance of children with ADHD according to mode of administration*

MANOVA revealed a significant main effect of the mode of administration, Hotelling's $F(10, 32) = 18.640$; $p < .001$, partial $\eta^2 = .85$. Univariate *F* tests showed significant differences in the failure to maintain set and number of complete categories in favor of the group that completed the manual version (**see Table 7**).

Table 7. *Mean scores and p-values for children with ADHD stratified by the WCST version (computerized* vs. *manual)*

Variables	WCST version						Effect size partial η^2	
	Computerized		Manual		*F* (1, 41)	*p*-value		
	M	*SD*	*M*	*SD*				
NT	128.00	0.00	122.62	13.04	3.374	.060	.084**	C > M
TC	64.41	16.15	69.71	17.01	1.100	.300	.026*	C < M
TE	64.55	16.60	53.86	21.92	3.267	.078	.074**	C > M
PR	46.18	26.08	33.71	22.88	2.765	.104	.063**	C > M
PPR	36.08	20.37	26.80	17.43	2.562	.117	.059*	C > M
PE	36.82	19.27	29.62	18.18	1.584	.215	.037*	C > M
PPE	28.76	15.05	23.59	13.75	1.382	.247	.033*	C > M
NPE	27.73	12.99	22.33	14.10	1.704	.199	.040*	C > M
FMS	6.23	1.97	1.33	1.23	93.757	<.001*	.696***	C > M
CC	2.59	1.62	3.67	1.82	4.179	.047*	.096**	C < M

Notes. NT = number of trials; TC = total correct: TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE= percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
**p*-values are statistically significant.
Effect sizes: *$\eta p^2 > .01$; **$\eta p^2 > .06$; ***$\eta p^2 > .14$. C = computerized WCST. M = manual WCST.

2. *Computerized WCST performance of the Clinical and Nonclinical samples*

Significant differences in computerized WCST performance were observed in favor of TD children for the variables number of trials (t [29.000] = 2.469, p = .040), total correct (t [50] = -2.666, p = .010), total errors (t [50] = 3.589, p = .001), perseverative responses (t [28.545] = 2.934, p = .007), percentage of perseverative responses (t [27.810] = 2.843, p = .008) perseverative errors (t [29.506] = 2.918, p = .007), percentage of perseverative errors (t [28.594]

= 2.796, *p* = .009) and number of complete categories (*t* [50] = -3.179, *p* = .003). A large effect size was observed for the variables total errors, perseverative responses, percentage of perseverative responses, perseverative errors, percentage of perseverative errors and number of complete categories. A medium effect size was also observed for the variables number of trials and total correct answers. **Table 8** shows the means and standard deviations for each group.

Table 8. *Computerized WCST performance of the clinical and non-clinical samples*

Variables	Computerized WCST								
	ADHD		TD		*t*	*df*	*p*-value	Effect size Cohen's *d*	
	M	*SD*	*M*	*SD*					
NT	128.00	0.00	122.00	11.38	2.469	29.000	.040*	.0.74**	ADHD > TD
TC	64.41	16.15	75.77	14.42	-2.666	50	.010*	-0.74**	ADHD < TD
TE	64.55	16.15	47.10	17.81	3.589	50	.001*	1.02***	ADHD > TD
PR	46.18	26.08	28.47	12.89	2.934	28.545	.007*	0.86***	ADHD > TD
PPR	36.08	20.37	22.77	9.56	2.843	27.810	.008*	0.83***	ADHD > TD
PE	36.82	19.27	23.67	10.13	2.918	29.506	.007*	0.85***	ADHD > TD
PPE	28.76	15.05	19.01	7.47	2.796	28.594	.009*	0.82***	ADHD > TD
NPE	27.73	12.99	23.43	11.24	1.273	50	.209	0.35*	ADHD > TD
FMS	6.23	1.97	5.17	2.26	1.762	50	.084	0.50**	ADHD > TD
CC	2.59	1.62	3.93	1.41	-3.179	50	.003*	-0.88***	ADHD < TD

Notes. NT = number of trials; TC = total correct: TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE = percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
**p*-values are statistically significant.
Effect sizes: (mean-differences in independent groups) **d* > 0.2; ***d* > 0.5; ****d* > 0.8

3. *Manual WCST performance of the Clinical and Nonclinical samples*

Significant differences in manual WCST performance in favor of TD children were observed for the following variables: number of trials (*t* [48.322] = 4.555, *p* <.001), total errors (*t* [49] = 4.579, *p* <.001), perseverative responses (*t* [49] = 2.199, *p* = .033), perseverative errors (*t* [49] = 2.687, *p* = .010), nonperseverative errors (*t* [29.456] = 3.322, *p* = .002) and number of complete categories (*t* [33.694] = -3.597, *p* = .001). *d* values indicated large effect sizes for the numbers of trials, total errors, complete categories and nonperseverative errors. A medium effect size was also observed for perseverative responses and perseverative errors. **Table 9** shows the means and standard deviations for each group.

Table 9. *Manual WCST performance of the clinical and non-clinical samples*

Variables	Manual WCST								
	ADHD		TD		*t*	*df*	*p*-value	Effect size Cohen's *d*	
	M	*SD*	*M*	*SD*					
NT	122.62	13.94	100.70	21.24	4.555	48.322	<.001*	1.22***	ADHD > TD
TC	69.71	17.01	73.47	10.86	-0.891	31.279	.380	-0.26*	ADHD < TD
TE	53.86	21.92	27.27	19.29	4.579	49	<.001*	1.29***	ADHD > TD
PR	33.71	22.88	19.87	21.59	2.199	49	.033*	0.62**	ADHD > TD
PPR	26.80	17.43	19.64	17.88	1.422	49	.161	0.40*	ADHD > TD
PE	29.62	18.18	16.27	16.95	2.687	49	.010*	0.76**	ADHD > TD
PPE	23.59	13.75	16.51	15.23	1.697	49	.096	0.48*	ADHD > TD
NPE	22.33	14.10	10.97	8.20	3.322	29.456	.002*	0.98***	ADHD > TD
FMS	1.33	1.23	1.07	1.14	0.793	49	.432	0.21*	ADHD > TD
CC	3.67	1.82	5.33	1.29	-3.597	33.694	.001*	-1.05***	ADHD < TD

Notes. NT = number of trials; TC = total correct: TE = total errors; PR = perseverative responses; PPR = percentage of perseverative responses; PE = perseverative errors; PPE = percentage of perseverative errors; NPE = nonperseverative errors; FMS = failure to maintain set; CC = categories completed.
**p*-values are statistically significant.
Effect sizes: (mean differences in independent groups) *d > 0.2; **d > 0.5; ***d > 0.8

Conclusions for S2

Consistent with the findings from S1, results revealed significant differences between groups in performance on the different WCST versions. Specifically, children with ADHD who received the manual version of the WCST completed more categories across the 128 cards that were presented and were less vulnerable to losing track of their procedural set (a variable that is formally described as failure to maintain set). Although no significant differences were observed in the other WCST variables, children who completed the manual version received better scores.

To our knowledge, no studies have compared the performance of children with ADHD on both versions of the WCST. However, previous studies using either the manual version of the WCST with 128 cards or the computerized version show differences among the scores, consistent with the findings from our study. Children who completed the manual version appear to be more proficient with these implicit decision-making requirements than children who completed the computer version. For instance, using the manual version, Loge, Staton, and Beatty (1990) found that children with ADHD complete 4.1 categories, whereas Lawrence et al. (2004) recorded a completion of 4.59 categories. Subsequently, Barkley, Grodzinsky and DuPaul (1992) reported the completion of 3.9 categories (mean age of 9.2 years), while Shue and Douglas (1992) reported the completion of 3.79 categories. Finally, and consistent with our results, Pineda et al. (1998) observed the completion of 3.4 categories by Spanish-speaking children with ADHD. Overall, most studies that have used the manual version have found that children with ADHD complete 3.4 to 4.6 categories. These values are somewhat superior to the values reported in studies that used the computer version. For example, in the study by Yilmaz, Gokcen, Fettahoglu, and Ozatalay (2013), children with ADHD completed 2.63 categories. Consistent with these findings, Narvaez et al. (2014) reported that Brazilian children and adolescents completed 2.22 categories. Thus, based on both our results and those of previous studies, children who complete the manual version would obtain better outcomes than children who complete the computer version. **Table 10** provides a brief description of these studies.

Table 10. *Categories completed on the computerized and manual WCST in studies of children with ADHD*

WCST version	Age	Categories completed	Results	Study authors
Manual	6-12	4.1	ADHD < controls, ns	Loge et al. (1990)
Manual	6-12	4.59	ADHD < controls, ns	Lawrence et al. (2004)

Manual	9.2 (mean age)	3.9	ADHD < controls, ns	Barkley et al. (1992)
Manual	8-12	3.79	ADHD < controls	Shue and Douglas (1992)
Manual	7-12	3.4	ADHD < controls	Pineda et al. (1998)
Computer	7-12	2.63	ADHD < controls	Yilmaz Gokcen et al. (2013)
Computer	6-17	2.22	ADHD (no controls)	Narvaez et al. (2014)

Note. *ns: nonsignificant differences*

Interestingly, although significant differences were observed depending on the mode of administration, children with ADHD performed worse on both versions than TD children. Effect sizes varied between WCST variables both within and between the two versions. Most of the computerized WCST variables had medium to large effect sizes, while a greater number of the manual WCST variables produced a small effect. At a broader level, the main variables of the computerized WCST appear to be more sensitive to the presence of ADHD, with the exception of completed categories of the manual version that had a larger effect size than the computer version. Based on our results, both versions could be used to assess cognitive flexibility in children with ADHD and show sensitivity for the recognition of EF deficits related to ADHD. This hypothesis is consistent with the findings reported by Sergeant et al. (2002) and Romine et al. (2004). Although some studies have failed to confirm the sensitivity of the WCST to ADHD, researchers have argued that this could be due to the use of small sample sizes (Barkley et al., 1992).

General Discussion

Because diverse neurodevelopment disorders are associated with executive dysfunction (e.g., ADHD, autism, epilepsies and intrauterine alcohol exposure disorders, among others) and executive processes play a central role in academic performance (Arán Filippetti & Richaud, 2017), there is a need for valid and reliable instruments to measure EF in children and adolescents. The WCST is one of the most widely used tests to assess these higher-order cognitive skills. Its extensive use, both in neuropsychological clinics and in the field of neuroeducational research, highlights the necessity of presenting relevant normative information that distinguish the unique aspects of the manual versus computerized formats. Some studies have failed to show the equivalence of the two formats (see e.g., Feldstein et al., 1999) and the WCST would not be a culture-free test, as already reported in studies conducted both in children (Coelho et al., 2012; Shu et al., 2000) and adults (Coffey et al., 2005; Kohli & Kaur, 2006; Shan et al., 2008). However, to our knowledge, no studies have established norms for the computer version (including 128 cards) in Spanish-speaking children or compared the performance on both versions between children with ADHD and TD children.

Our results are clinically significant and relevant to applied neuropsychological practice in several ways. First, our results showing the effect of age on task performance are similar to those reported in previous studies conducted with children from different countries. For the manual version, as children age, they complete more categories and recorded fewer perseverative responses. Consistent with the findings reported by Chelune and Baer (1986) and Rosselli and Ardila (1993), children would reach the level of adult performance at approximately an age of 10-11 years. However, for the computer version, we observed a similar task performance among the three age groups. Thus, the adult level performance would not yet be reached at the age of 12 years. According to a previous study, the performance of children on the computer version will not approach the performance of older age groups until the age of 13 years (Coelho et al., 2012). Second, we observed differences in performance between the versions administered. Children who completed the computer version exhibited worse performance than children who completed the manual version. Our computer scores are consistent with previous studies that administered the computer version to Turkish (Yeniceri & Altan-Atalay, 2011) and Brazilian (Coelho et al.,

2012) children. Apparently, TD children and adolescents find the computerized WCST more difficult to complete than the manual version. According to Fortuny and Heaton (1996), who conducted their study with adolescents and adults, the computer version is likely to be initially more intimidating than the manual version, as observed in the differences between versions on the number of trials to complete first category. However, when examinees become familiar with the computer format the overall performance would be equivalent between versions. According to our results this would not be the case for children, as we observed differences in almost all the WCST variables between versions. Based on these findings and those of previous studies, we argued that differences among WCST versions are more apparent when task performance has not yet reached adult levels.

In study 2, we observed differences in the performance of children with ADHD on the two versions of the task. Specifically, children who worked with the computer version completed fewer categories and recorded greater failure to maintain set compared to children who completed the manual WCST. Thus, the WCST task performance of children with neurodevelopmental disorders should also be analyzed based on the mode of administration. To date, studies of clinical samples have yielded mixed results. For example, Ozonoff (1995) reported better performance for children with autism on the computer version than on the manual form. However, in a more recent study, both versions were equivalent when studying EF in children with autism (Williams & Jarrold, 2013). Therefore, it is crucial to carefully weigh what factors might influence either comparable or disparate results when different WCST versions are used with diverse clinical samples. Interestingly, although we identified differences in performance based on the WCST format, children with ADHD displayed significantly worse performance on both versions than TD children. These results are consistent with previous studies that used either the computerized WCST (see Tsuchiya, Oki, Yahara, & Fujieda, 2005; Yilmaz et al., 2013) or its manual version (see Arán Filippetti & Mias, 2009; Pineda et al., 1998). Therefore, both versions could be equally used to assess EF in children with ADHD. Poor WCST task performance might be due to the differences in brain structure and function associated with ADHD. In fact, neuroimaging studies have found a decrease in the total brain volume, smaller sizes and differences in the symmetry of the prefrontal regions, abnormalities in the caudate nucleus, the putamen and the cerebellum, and a reduction in gray and white matter in the prefrontal cortex regions in subjects with ADHD (see Krain & Castellanos, 2006 for a review). Moreover, structural brain imaging studies of children with ADHD who were performing the WCST have revealed a correlation between the reversed asymmetry of the caudate and poorer task performance (Semrud-Clikeman et al., 2000), and that the reduced gray matter volumes in the right orbitofrontal cortex and left posterior midcingulate cortex are associated with executive dysfunction, as evaluated by the WCST (He et al., 2015).

Before discussing the implications of the results, we must address some limitations. First, participants were not randomly assigned to WCST versions. However, the similar performance on other IQ and EF measures between groups supports the premise that the differences in performance between versions were due to the mode of administration. Second, we used verbal tasks to assess WM (i.e., phonological loop and central executive components) and inhibition (i.e., Stroop test). Thus, the inclusion of a visuospatial WM measure and a motor inhibition task might improve our understanding of the contributions of the WM subsystems and subtypes of inhibition to WCST performance. In addition, it would be important to study the contributions of other measures of reactive cognitive flexibility (e.g., trail making test) to WCST performance.

Finally, study 2 included a small sample of children with ADHD, and thus the current results cannot be generalized to adult samples.

The results from the present study have significant implications. First, knowing chronological age contributes to unique aspects of WCST performance according to the format has implications for the assessment of shifting abilities throughout development. Based on our findings and those of previous studies, children will reach adult-level performance on the manual version at approximately age 10. However, the same level of performance on the computer version would be reached after age 12. Therefore, the computer version might be more applicable to assessments of reactive cognitive flexibility throughout development. Next, WCST versions impose different demands on executive processes. Although WM contributed to the performance of both versions, inhibition and shifting domains exhibit contribute differently to WCST performance according to the mode of administration. Our findings also suggest that verbal face-to-face interactions would facilitate the use of the children's available cognitive resources. In other words, we hypothesized that children who complete the manual version are more able to make a proper use of their executive skills as they are eased by this mode of administration. For these reasons, clinicians and researchers are encouraged to interpret the test results in the context of the administered version. Finally, both WCST versions are commonly used in pretest and posttest designs to examine the effects of diverse interventions on children with ADHD. For instance, studies of the computerized WCST have reported its value for assessing cognitive changes in children with ADHD after the administration of methylphenidate (Yilmaz et al., 2013), atomoxetine for six months (Yang, Gao, Li, & Zhao, 2015) and physical exercise (Pan et al., 2015). Research on the manual WCST version has also shown an improvement in task performance after the administration of atomoxetine and methylphenidate (Yildiz, Sismanlar, Memik, Karakaya, & Agaoglu, 2011) to children with ADHD. Thus, the equivalence of these versions of the WCST must be examined in children with ADHD and other neurodevelopmental disorders to confirm whether both forms can be used interchangeably and whether they are sensitive to the identification of cognitive flexibility deficits. Future studies might also benefit from a comparison of the performance of children with ADHD on both versions in groups stratified by the ADHD subtype. Finally, while there is an increasing use of the computerized WCST version, several studies still employ the manual form both in clinical (see Fadaei et al., 2017) and nonclinical samples (see Silva de Oliveria et al., 2016). Therefore, developmental norms for both versions must be established. The results from our study and previous studies stress the need to use caution when employing both versions as interchangeable in clinical and nonclinical samples of children.

Although the computerized WCST offers advantages over its manual form, such as a higher reliability and a reduction of sources of error related to the handling of data (Tien et al., 1996), data must be interpreted according to developmental norms for each version. Since '*digital native'* kids do not express inhibition when presented with technological resources, we hypothesized that interpersonal relationships would have some mediating effect on the assessments that examiners provide. In addition to social-motivational components (Ozonoff, 1995), the qualitatively different experiences related to computer-based assessment vs. paper-and-pencil formats (McDonald, 2002) may also impact WCST performance according to the mode of administration.

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