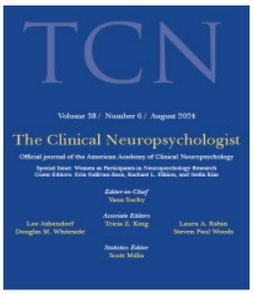

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Large-scale evidence for the validity of remote MoCA administration among people with cerebellar ataxia

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ABSTRACT

Objective: For over half a century, studies of rare diseases using in-person cognitive tools have faced challenges, such as long study periods and small sample sizes (e.g. $n=10$). The Montreal Cognitive Assessment (MoCA) was widely employed to assess mild cognitive impairment (MCI). We aimed to validate a modified online version of the MoCA in a large sample of a rare disease (population prevalence < .01%). **Method**: First, we analyzed 20 previous findings ($n=1,377$), comparing the MoCA scores between large groups of neurotypically healthy (NH; $n=837$) and cerebellar ataxia (CA; $n=540$), where studies were conducted in-person. Second, we administered the MoCA in-person to a group of NH ($n=41$) and a large group of CA ($n=103$). Third, we administered a video conferencing version of the MoCA to NH ($n=38$) and a large group of CA ($n=83$). **Results**: We observed no performance differences between online and in-person MoCA administration in the NH and CA groups ($p > .05$, $\eta^2 = 0.001$), supporting reliability. Additionally, our online CA group had lower MoCA scores than the NH group ($p < .001$, Hedges' $g=0.68$). This result is consistent with previous studies, as demonstrated by our forest plot across 20 previous in-person findings, supporting construct validity. **Conclusion**: The results indicate that an online screening tool is valid in a large sample of individuals with CA. Online testing is not only time and cost-effective, but facilitates disease management and monitoring, ultimately enabling early detection of MCI.

Abbreviations: CA: Cerebellar ataxia; NH: Neurotypical healthy; MoCA: The Montreal Cognitive Assessment; PD: Parkinson's disease; VC: Videoconference; BF: Bayes factor

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1. Introduction

Despite technological advances, traditional cognitive screening tools still require in-person administration and are not accessible and scalable. Traditional in-person neuropsychological testing is inherently challenging to conduct because testing requires the recruitment and participation of people with neurological conditions. Thus, there is a critical need for time and cost-effective cognitive impairment assessments for both basic research and translational studies worldwide. Particularly, the shift towards remote assessment has accelerated rapidly due to safety measures implemented in response to COVID-19 (Dupraz et al., 2022; Geddes et al., 2020).

For over half a century, researchers and clinicians have utilized cognitive screening tools in laboratory or clinic in-person settings. In-person testing has many advantages, such as more personal person-to-person interactions and the ability to extract insights about cognitive function throughout the diagnostic process, not solely from the assessment's final score, as outlined in the Boston process approach (Libon et al., 2013; Milberg et al., 2009). However, traditional in-person recruitment and testing of people with neurological conditions have significant challenges.

These challenges are especially pronounced for rare medical conditions, such as Cerebellar Ataxia (CA), which affects less than 0.03% of the population (Salman, 2018). Additionally, individuals with CA, and other neurological conditions, often face motor and mobility restrictions that make commuting difficult. Also, some neurological conditions, such as CA, are progressive neurodegenerative diseases that require regular evaluations for disease management and monitoring, which can be challenging if conducted in-person in lab and clinic settings.

These unique challenges frequently result in long study periods (e.g. two years) and small sample sizes, typically fewer than 15 participants (Saban et al., 2024). Furthermore, many studies rely on participants from the same geographic area or family (Saban et al., 2024), leading to a lack of diversity in the sample and potential representation bias. These limitations, and others, emphasize the need for alternative data collection methods to identify mild cognitive impairment (MCI), especially among people with rare, motor, or progressive diseases, such as CA.

The constraints of traditional in-person methods have spurred the growth of online methods in behavioral studies. Recent research indicates that remote testing, including video telehealth approaches, is as reliable and valid as in-person testing (Bilder et al., 2020; Binoy et al., 2023; Buhrmester et al., 2018; Chandler & Shapiro, 2016; Geddes et al., 2020; Marra et al., 2020; Saban & Ivry, 2021). Remote testing offers several advantages. For instance, it makes research participation more accessible for individuals with neurological conditions by eliminating the need for travel. It also enables rapid data collection and comprehensive assessments (Binoy et al., 2023), reaching a broader and more diverse pool of participants (Binoy et al., 2023; Saban & Ivry, 2021).

The Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) is a globally recognized screening tool commonly used by healthcare providers and researchers. The MoCA is a brief 10-min tool that can detect risk for MCI (Nasreddine et al., 2005). The test consists of eight cognitive domains: visuospatial, naming, memory, attention, language, abstraction, delayed recall, and orientation (MoCA Cognition, 2023). The MoCA has been demonstrated as a valid and reliable (Dupraz et al., 2022; Mara et al.,

2020), with high sensitivity (86%) and specificity (88%) for MCI detection (Julayanont et al., 2013), which is higher than those of other cognitive assessments, such as the Mini-Mental State Examination (MMSE) (Larner, 2012). MCI corresponds to the early stages of various neurological conditions (Petersen, 2016) or a transitional state between no impairment and pathological cognitive aging, aiming to identify individuals at risk for dementia (Stephan et al., 2012; Zhuang et al., 2021). With the growing use of technology, there has been a large interest in the validity of administering the MoCA remotely in healthy and clinical populations (Loring et al., 2023), such as CA (Binoy et al., 2023).

The defining features of CA are primarily motor symptoms such as unstable gait and incoordination (Luo et al., 2017; Pilotto & Saxena, 2018; Radmard et al., 2023; Sullivan et al., 2019). However, the cognitive manifestation of CA is a subject of ongoing debate. Some studies report no difference in MoCA scores between healthy controls and patients with CA in in-person experiments (Saban et al., 2024; Tanaka et al., 2021). Yet, many studies report significant differences in MoCA scores between a healthy control group and CA group (Chen et al., 2022; Chirino-Pérez et al., 2021; Kang et al., 2017), with lower scores for those with CA. In one study, patients with CA scored an average of 21.06 points, while controls scored an average of 28.06 (Mercadillo et al., 2014). These mixed results in the literature may depend on several factors, such as disease duration.

A few studies have explored a video conferencing version of the MoCA (MoCA-VC). A recent study found no differences between in-person and the MoCA-VC scores, but only in healthy participants (Loring et al., 2023). Another study on people with mild-to-severe dementia found similar average MoCA scores for remote and in-person testing (Lindauer et al., 2017). The feasibility of remotely administering the MoCA to participants with Parkinson's Disease (PD) was also demonstrated. However, it was on a small sample ($n = 8$), and the study did not compare the online data to in-person results (Abdolahi et al., 2016). Another pilot study on a small sample ($n = 11$) of PD participants found no differences between in-person and VC MoCA (Stillerova et al., 2016). One study showed the feasibility of remote MoCA in a large sample ($n = 166$) of PD participants, but did not compare them to healthy participants (Binoy, Monstaser-Kouhsari, et al., 2024; Dorsey et al., 2015).

Alternative remote administration methods for the MoCA have been proposed, including the eMoCA, which facilitates automated testing (Wallace et al., 2019). However, this approach presents certain drawbacks compared to the MoCA-VC. Firstly, eMoCA necessitates a specialized touchscreen tablet mailed to the patient or an installation of an application on the patient's device. In contrast, VC offers a simpler option that is accessible from any device. Secondly, employing eMoCA requires some technological proficiency, while video conferencing involves monitored processes mediated by a researcher, which is particularly beneficial for older patients. Thirdly, eMoCA lacks availability in multiple languages, whereas the MoCA-VC can be adapted for use in any valid language version of the MoCA. Online administration of the MoCA on participants with CA has been tested in a limited capacity. Pilot studies administered an online version of the MoCA on a small sample ($n = 18/20$) of CA participants. No differences between the online administration and previous in-person experiments were found, but these studies tested only a small sample and did not compare the

administration methods directly (Binoy et al., 2023). Therefore, a direct comparison between online and in-person administration methods is clearly needed, especially for clinical populations, such as CA. This is particularly true given that previous studies had small sample sizes, making the generalizability of their findings unclear.

Given the motor symptoms and mobility impairments associated with CA, coupled with its rarity and progressive nature, the need for more accessible remote cognitive testing methods is of utmost importance. In the present study, we aimed to assess the validity of the MoCA-VC in two groups: neurotypically healthy individuals (NH) and a large-scale cohort of individuals with CA.

Firstly, we conducted a comprehensive analysis of 20 prior studies that directly compared the typical MoCA scores of CA and neurotypically healthy (NH) groups collected in-person. Secondly, to evaluate construct validity, we administered a modified MoCA-VC to both NH and CA cohorts, predicting similar results to those of the 20 previous in-person studies. Thirdly, to assess the reliability of the MoCA-VC, we compared our MoCA-VC scores with the standard in-person MoCA scores within each group (NH and CA) separately. Finally, we also compared the specific domains of the MoCA between the two administration methods and across groups. This methodology enabled us to assess the validity and reliability of the modified MoCA-VC in CA.

2. Methods

2.1. Typical in-person CA's MoCA score – meta-analysis

Using five databases (Web of Science, PubMed, Primo Search, Academic Search Premier, Science Direct) and specific search terms ("MoCA," "Cerebellar ataxia," and "Control group"), we found articles reporting MoCA total scores for both healthy and CA participants (with various genetic subtypes). We did not include any articles that did not report the mean, standard deviations, or number of participants for both groups. Figure 1A Forest Plot shows the effect sizes we extracted from each study and the pooled effect size (diamond).

2.2. Participants

A total of 265 participants were evaluated. Individuals diagnosed with CA and NH were recruited through our clinical Center for Accessible Neuropsychology (CAN) database. The database comprises individuals tested in CAN before or those who have responded to online advertisements (e.g. support groups/Facebook groups dedicated to CA). We contacted individuals who expressed interest in the study by email to invite them to participate in an online, live interview with an experimenter. All sessions were conducted through Zoom software, which the participants logged on to from their devices. Although help was offered, all the participants logged in independently. The session included confirming basic demographic information, obtaining medical history, and administering the MoCA test. Prior to conducting each item, we ensured there were no video or audio issues so as not to interrupt the assessments. If there was any issue, we resolved it during the meeting or, in rare cases (<5), rescheduled the session at a time convenient for the participant.

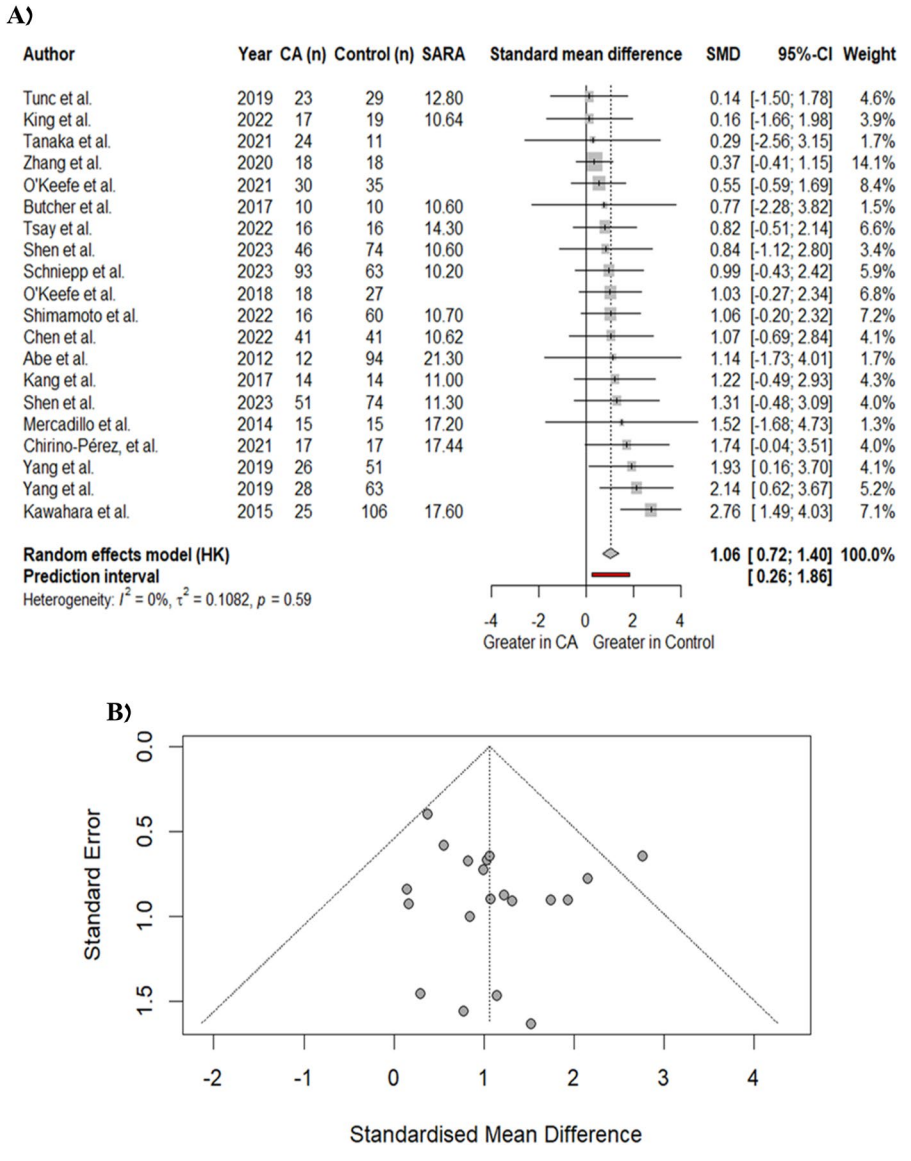

Figure 1. (A) Forest plot of studies reporting the MoCA scores of CA and healthy participants *(n* = 1,377*)*. Effect sizes are expressed in standard deviations, using hedges' g, with 95% CI, and are sorted by magnitude. (B) Funnel plot of previous in-person findings. No significant asymmetry was found. (SMD = Standardized mean difference; CA = Cerebellar ataxia; SARA = Scale for Assessment and Rating of Ataxia).

Given that CA is a progressive condition that deteriorates over time, and to avoid potential test-retest effects, each participant completed the MoCA using one administration method. We randomly assigned all participants to one of the two administration methods (in-person or VC). We obtained each participant's demographic and medical history, including diagnoses, and administered the MoCA. The participants' demographic information is presented in Table 1. Tel Aviv University ethics committee approved the protocol, and all participants provided informed consent.

All participants were required to be able to understand and provide informed consent, aged 18 years and above, and have access to an internet connection and a device capable of video chat. Individuals with other neurological conditions (not CA), psychiatric conditions, learning disabilities, and severe visual or auditory impairments were excluded from the study.

MoCA scores across all participants ranged from 21 to 30 (MoCA below 21 indicates a significant cognitive impairment) (Dalrymple-Alford et al., 2010; Dautzenberg et al., 2021; Pinto et al., 2019). Two participants from the NH group who received a MoCA score lower than 21 were excluded (2.4%). This was done to ensure that all of the NH group had normal cognitive function. The NH group consisted of 79 participants (41 in-person, 38 online) who reported having normal cognitive functioning and no known diagnosis. Since a recent study demonstrated the validity of the online MoCA-VC among a large group of healthy participants (Loring et al., 2023), we were focused on having a large sample of CA participants.

The CA group consisted of 186 participants (103 in-person, 83 online) with a diverse known genetic subtype (5 SCA1,17 SCA2, 26 SCA3, 5 SCA5, 22 SCA6, 4 SCA7, 6 CSA8, 2 SCA10, 1 SCA15, 2 SCA17, 2 SCA28, 1 SCA 35, 1 SCA42,1 SCA44,1 SPG7, 1 ARSACS, 1 OPCA, 3 AOA2, 6 Sporadic, 2 Episodic, 1 Gluten, 2 Autoimmune, 2 Idiopathic, 1 Acquired (alcohol), 1 Perrault Syndrome, 1 Friedreich's, 1 Astrocytoma) and 68 with CA of unknown etiology. Their mean duration since diagnosis was 10.6 (Overall: ($SD = 9.8$), Range = [1–50]; Online: 11.7, ($SD = 9.7$), Range = [1–47]; In-person: 10.9, ($SD = 9.2$), Range = [1–50]). Interestingly, we did not find a difference between disease duration between administration methods in the CA group ($p > 0.05$). As CA is a degenerative condition, disease duration is regarded as a measure of disease severity (Matsushima et al., 2015; Monte et al., 2018; Zhou et al., 2011). There is no significant correlation between disease duration and MoCA score in each administration method (In-person: $\rho = -0.071$, $p = .481$; Online: $\rho = -0.165$, $p = .142$). This result is consistent with the literature, reporting no significant correlation between cognitive scores and disease duration (Conrad et al., 2023; Rodríguez-Labrada et al., 2022).

The groups did not differ in age, years of education, or gender ($p < .05$). However, when comparing the administration methods in each group, there is a difference in age (CA: $t(184) = -2.284$, $p = .024$; NH: $t(77) = 3.229$, $p = .002$). In the CA group, age

Table 1. Demographic summary of all groups.

Group	*N*	Age	Years of education	Females (%)
CA In-person	103	54.7 [12.7] (21–84)	16 [2.9] (12–25)	57.3
CA online	83	59.0 [12.7] (21–80)	16.6 [2.3] (12–24)	60.2
CA total	186	56.6 [12.8] (21–84)	16.3 [2.7] (12–25)	58.6
NH In-person	41	61.6 [11.3] (34–84)	18.2 [2.5] (14–27)	63.4
NH Online	38	52.9 [12.7] (19–78)	16.4 [1.9] (11–20)	65.8
NH total	79	57.4 [12.7] (19–84)	17.3 [2.4] (11–27)	64.6
Overall	265	56.9 [12.8] (19–84)	16.6 [2.6] (11–27)	60.4

Mean [*SD*] (range). CA = Cerebellar ataxia, NH = Neurotypical healthy.

is higher in the online administration method (see Table 1), and in the NH group, age is higher in the in-person method. In the NH group, there is also a difference in years of education between administration methods ($t(77) = 3.404$, $p = .001$), where in-person education is higher than online (see Table 1). Importantly, all groups' ages ranged from 52.9 to 61.6, and MoCA scores do not change significantly within this age range (Freitas et al., 2012; Rossetti et al., 2011). The mean years of education of all groups ranged from 16 to 18.2 years. Years of education above 12 are often treated as the same education level, and no effect on the MoCA score is expected within this category (Bernstein et al., 2011; Freitas et al., 2012; Rossetti et al., 2011; White et al., 2022).

2.3. MoCA administration

The in-person evaluation was conducted in accordance with the standard administration of the MoCA (version 8.1) (Nasreddine et al., 2005). As per MoCA guidance, each participant was evaluated by one rater. All raters were required to obtain official MoCA guidance for administering and scoring the test. Though we cannot assess inter-rater reliability measures, we analyzed the mean differences across raters and found no significant discrepancies ($t = 1.258$, $p = .249$).

We adhered to the official instructions for the VC administration provided on the MoCA website, with modifications to minimize deviations from the typical in-person administration. The visuospatial and naming tests (six items) were presented using PowerPoint slides using the share-screen option on Zoom. The Trail-making item was excluded from the online version, and to compensate for this, we adjusted the total score proportionally (observed score multiplied by 30 and divided by 29). Additionally, the Visuospatial/executive domain score was adjusted in a similar manner (observed score multiplied by 5 and divided by 4). The Cube-copy and Clock drawing tests were individually displayed on the screen, and the slides contained "Cube copy" next to the figure to closely mimic the paper and pencil presentation. Participants were instructed to draw the cube and the clock on their own piece of paper and present their drawings in front of the camera. The naming items were also individually displayed on the screen. For orientation items, we referred to the participant's actual location.

2.4. Analysis

All analyses were conducted using the R software (Posit Team, 2023; R Core Team, 2022). To calculate the required sample sizes, we conducted a power analysis (alpha = 0.05; power = 0.95) using effect size derived from the 20 findings that compared CA and NH groups in the MoCA test (effect size = 1.06, large effect size). This analysis suggested a minimal sample size of 23 participants for each group. As such, the sample sizes of our groups (>34) had sufficient power to detect group differences.

We carried out a two-way analysis of variance (ANOVA) with a group (NH, CA) and administration method (Online, In-person) as the independent between-subject variables, and the MoCA score as the dependent measure.

Since we predicted a null hypothesis in some comparisons (e.g. no difference between administration methods), we also calculated Bayes Factors (BF_{10}). The BF_{10} provides information about the ratio between the strength of evidence of the alternative hypothesis (quantified in the BF numerator) and the strength of evidence of the null hypothesis (quantified in the BF denominator) (Dienes, 2014). As previously suggested (Lee & Wagenmakers, 2013), the BF10 values can be classified by the following: <1 the null hypothesis is more likely than the alternative hypothesis, 1–3 anecdotal, 3–10 medium, 10–30 strong, and 30–100 very strong evidence for the alternative hypothesis (H1). The BF analyses were conducted using Jamovi (2022).

3. Results

3.1. Typical in-person CA's MoCA score – meta-analysis

We reviewed previous findings to assess the differences between NH and CA in the typical in-person MoCA across studies. In total, we found 20 previous findings directly comparing these groups, with a sample size of 1,377 participants (NH = 837 and CA = 540).

Figure 1A shows the effect sizes of each study and the pooled effect size of the 20 previous findings presented in a diamond shape. Effects are expressed in standard deviations using Hedges' g, inverse variance weights, and a random-effects model. The pooled effect size across all studies is 1.06 (large, $p < .0001$, 95% confidence interval 0.72 to 1.40). Mean MoCA scores for CA and NH groups were 23.57 ($SD = 2.5$) and 26.86 ($SD = 1.2$), respectively. Thus, looking at previous findings, we found a significantly lower MoCA score in the CA group compared to the NH group.

Also, the analysis suggests no statistically significant evidence of heterogeneity among the included studies ($p = .590$). This means that the observed variation in effect sizes among studies is not greater than expected due to chance. Potential publication bias was tested using a funnel plot, as seen in Figure 1B. Additionally, the linear regression test of funnel plot asymmetry revealed no significant asymmetry ($p = .369$; Bias = 0.585, $SE = 0.635$).

3.2. Variance

We conducted Levene's test to compare the variances between the conditions in our data. The test results showed no significant difference in the variances between the administration methods ($F(1, 263) = 0.307$, $p = .579$). However, we found a significant difference between the variances of the CA and NH groups within each administration method and across them (Online: $F(1, 119) = 8.211$, $p = .004$; In-person: $F(1, 142) = 13.716$, $p < .001$; Across methods: $F(1, 263) = 21.44$, $p < .001$). These results suggest that the assumption of homogeneity of variances was not met. Therefore, we conducted further statistical analyses that do not assume equal variances between groups.

3.3. MoCA total scores

See Figure 2 for our main analysis comparing the groups and administration method. As expected by the results of previous literature (see Figure 1 above), we found a significant main effect of Group on the MoCA score ($F(1) = 40.83$, $p < .001$, $\eta^2 = 0.13$,

BF_{10} > 1000). As expected, planned-comparison analyses revealed that the NH group performed significantly higher than the CA group in each method of administration (Online: $t(105.04) = 3.797$, $p < .001$, Hedges' $g = 0.68$, $BF_{10} > 30$; In-person: $t(117.89) = 7.02$, $p < .001$, Hedges' $g = 1.16$, $BF_{10} > 1000$). Notably, there was no significant main effect of the administration method ($F(1) = 0.39$, $p = .533$, $\eta^2 = 0.001$, $BF_{10} < 1$). Note that the BF_{10} was smaller than 1, meaning the null hypothesis is more likely than the alternative hypothesis. The mean scores for both the CA and NH groups were above the typical MoCA cut-off score, reflecting no cognitive impairment at the group level (CA = 26.2; NH = 27.8). See Figure 3 for the degree of overlap between the distributions of the two administration methods. Finally, we did not find a significant interaction effect between the Group and administration method ($F(1) = 1.884$, $p = .171$, $\eta^2 = 0.007$, $BF_{10} < 1$).

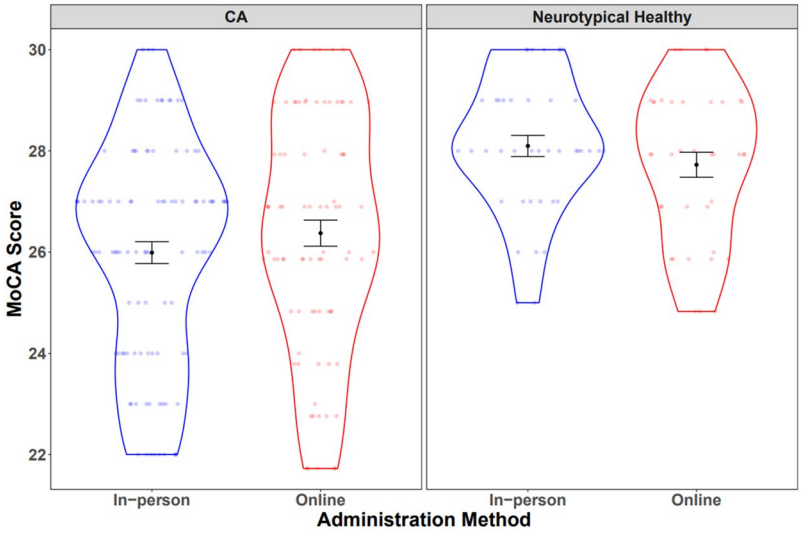

Figure 2. MoCA score as a function of group and administration method. The score for each participant is a dot. Each black dot represents the mean for each condition (*SE* = Error bars; CA = Cerebellar ataxia; MoCA = Montreal Cognitive Assessment). $N = 265$.

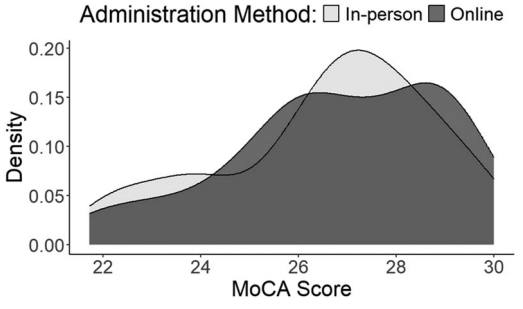

Figure 3. Histogram of the MoCA score for each administration method. The degree of overlap between the two distributions is 90% (MoCA = Montreal Cognitive Assessment). $N = 265$.

This pattern of results demonstrates the construct validity, reliability, and generalizability of the MoCA-VC.

3.4. MoCA domains

Additional planned-comparison analyses were conducted to compare the MoCA specific domains between the administration methods and exploratory comparison between the groups. A Bonferroni correction was made to the comparisons between administration methods to avoid type I errors. The comparisons between the groups are for exploratory purposes, and therefore, we did not make the correction for them. See full results in Table 2. This analysis did not include nine participants (<4%; six CA, three NH) because of missing data. When comparing the CA and NH groups across administration methods, a significant difference was found in Visuospatial/executive, Attention, Language, and Memory recall ($p < .005$ for all comparisons; $t(189.02) = -2.777$, $t(239.58) = -4.146$, $t(198.44) = -4.3$, $t(187.49) = -3.0482$, respectively). However, no difference was found in Abstraction, Naming, and Orientation ($p > 0.05$, $t(201.73) = -1.62$, $t(157.9) = 0.02$; ($t(218.42) = -0.4$; respectively). When looking at the NH group, we did not find significant differences between the administration methods for all the domains ($p > 0.05$, $t(74) = 3.201$, $t(74) = -0.772$, $t(74) = 0.64$, $t(74) = 1.346$, $t(74) = 1.346$, $t(74) = -1.297$, $t(74) = -0.321$, $t(74) = -0.957$, respectively). Similarly, no significant difference was found between the administration methods for all domains in the CA group ($p > 0.05$, $t(178) = 7.088$, $t(178) = -0.127$, $t(178) = 2.12$, $t(178) = 0.038$, $t(178) = 0.744$, $t(178) = -1.545$, $t(178) = 0.824$, respectively).

4. Discussion

In this study, we assessed the reliability and validity of administering the modified MoCA-VC to both NH individuals and a large cohort of those with CA. Our comprehensive analysis across 20 previous in-person findings revealed that the CA group received lower MoCA scores compared to the NH group when the test was administered in-person. Consistent with this comprehensive finding, we found that our online CA group scored lower than our online NH group, demonstrating the construct validity of the online administration. Furthermore, support for the reliability of the online approach was found. The MoCA-VC scores were not significantly different from our in-person MoCA scores both in the NH and CA groups. When looking at the specific MoCA domains, no differences were observed when comparing administration methods within each group. This experimental design allowed us to establish the validity and reliability of the MoCA-VC in people with a rare and progressive neurodegenerative condition.

The current work has several advantages and limitations. In terms of limitations, this study primarily compared NH participants to those with CA. Future research could extend this comparison to other patient groups, such as those with Parkinson's disease. Also, our total patient sample size comprised 186 participants, with 83 participating online and 103 in-person. Although the heterogeneity of this sample could be viewed as an advantage, the division into subgroups limits our ability to thoroughly assess cognitive abilities within each specific disease type, such as SCA3. Future research could benefit from utilizing the MoCA-VC to recruit larger sample sizes for

Table 2. Comparison of the MoCA domains scores (Mean [*SD*]) between groups and administration method.

	CA ($n = 180$)				NH ($n = 76$)				Across Methods ($n = 256$)				
Domain	In-person	Online	*p*	Hedges' g	In-person	Online	*p*	Hedges' g	CA	NH	*p*	Hedges' g	Overall
MoCA total	26.0 [2.2]	26.4 [2.4]	1	−0.172	27.7 [1.1]	27.9 [1.6]	1	−0.167	26.2 [2.3]	27.8 [1.4]	<.001	−0.883	27.0 [1.8]
Visuospatial/ Executive	4.2 [1]	3.9 [1.2]	.920	0.236	4.4 [0.8]	4.8 [1]	.544	−0.423	3.7 [1.1]	4.1 [0.8]	.003	−0.355	3.9 [0.9]
Naming	3.0 [0.2]	3.0 [0.2]	1	−0.019	2.9 [0.2]	3.0 [0.2]	1	−0.176	3.0 [0.2]	3.0 [0.2]	.508	0.003	3.0 [0.2]
Attention	5.4 [1]	5.6 [0.6]	.280	−0.316	5.9 [0.4]	5.8 [0.5]	1	0.146	5.5 [0.8]	5.8 [0.5]	<.001	−0.498	5.65 [0.6]
Language	2.2 [0.9]	2.2 [0.9]	1	0.006	2.7 [0.4]	2.5 [0.7]	1	0.307	2.2 [0.9]	2.6 [0.6]	<.001	−0.544	2.4 [0.7]
Abstraction	1.8 [0.5]	1.8 [0.5]	1	0.111	1.9 [0.4]	2.0 [0.2]	1	−0.296	1.8 [0.5]	1.9 [0.3]	.053	−0.205	1.85 [0.4]
Memory	3.5 [1.4]	3.8 [1.2]	.992	−0.230	4 [0.9]	4.1 [1]	1	−0.073	3.6 [1.3]	4.0 [1]	.001	−0.390	3.8 [1.1]
Orientation	5.9 [0.3]	5.9 [0.7]	1	0.123	5.9 [0.3]	6.0 [0.3]	1	−0.219	5.9 [0.5]	5.9 [0.3]	.344	−0.050	5.9 [0.4]

CA = Cerebellar ataxia, NH = Neurotypical healthy, MoCA = Montreal Cognitive Assessment.

each subgroup. This would provide a more nuanced understanding of the impact of specific CA types on the MoCA. Moreover, there can be large variance between home environments, including heterogeneity in background noises and computers screen size, as seen in other VC-based assessments (Brearly et al., 2017).

An additional limitation is the high education levels of the participants (>16(. This is compatible with known biases in online neuropsychological evaluations (Binoy, Lithwick Algon, et al., 2024). Additionally, an optimal validation study would use a counterbalanced design to administer the test in both administration methods to the same participants. However, due to the practice effect/carryover effect inherent to the MoCA repeated testing and the progressive nature of the disease, we wanted to avoid any potential impact of those factors on the scores. Therefore, each participant was tested using only one administration method. Future research can evaluate the MoCA-VC on different clinical populations using a counterbalanced design (e.g. using parallel versions of the test).

Finally, this study did not include the Trail Making Test (TMT) item of the MoCA, but rather prorated the final score to be in accordance with the in-person MoCA range of scores. The written version (W-TMT) item may be biased due to its reliance on motor skills. This dependency on graphomotor skills may result in the underestimation of the cognitive abilities of people with CA who have motor impairments. The Oral Trail Making Test (O-TMT) was designed to be the clinical analog of the W-TMT. However, there is debate about whether the measurement of processing speed and set-shifting is fully equivalent between versions (Fox-Fuller et al., 2023; Mrazik et al., 2010). Additionally, given the sparse literature on the TMT in CA, it remains unclear whether the O-TMT and the W-TMT are fully comparable in this population. Despite this, and in line with recent papers (Loring et al., 2023; Binoy, Monstaser-Kouhsari, et al., 2024), we now recommend incorporating the O-TMT item into the online administration in future research in order to assess generalizability.

Despite these limitations, one of the primary advantages of this study lies in its robust CA sample size, which is particularly noteworthy given that CA is a rare disease (Farghaly et al., 2011). This large patient sample size ($n = 186$, online = 83) supports the validity and reliability of the MoCA-VC. Furthermore, the study design itself presents an advantage. Implementing both in-person and online testing methods allows for the assessment of reliability, as opposed to relying solely on literature values for indirect comparison (Binoy et al., 2023).

Our study has important implications for researchers and clinicians using the MoCA and for those interested in remote neuropsychological testing more broadly. Our results hold implications for both research and clinical communities, particularly in enhancing the patients' and the experts' (e.g. neurologists and neuropsychologists) comfort. The administration of the MoCA online, facilitated through VC, allows testing to be conducted within the comfort of a patient's home. Enabling remote assessments reduces the financial strain and logistical challenges linked to traveling to research labs or clinical facilities. Additionally, it helps alleviate potential physical or mental distress for patients, particularly when multiple sessions are necessary for disease management.

From a research perspective, this online method presents an efficient and cost-effective approach to data collection. It opens new avenues for researchers to conduct studies, potentially leading to increased sample sizes and direct access to patient populations. Thus, online patient testing can increase neuropsychological knowledge faster (Gray et al., 2020; Loring et al., 2023; Nayak & Narayan, 2019).

To conclude, in large samples of older adults who underwent in-person or a remote cognitive screening test (i.e. MoCA), we demonstrated good validity of the remote test. Across 20 in-person findings, we found that the typical pattern of results in the MoCA scores was comparable between administration methods. Overall, our results suggest that MoCA data collected from in-person and remote sessions are comparable. More broadly, our results converged with previous conclusions that remote administration of cognitive tests is feasible and valid, even in a large sample of individuals with CA, who have motor impairments and mobility restrictions.

However, it is pertinent to question whether online testing is universally applicable to all neuropsychological assessments. While it may be suitable for some screening tests such as the MoCA, its efficacy for more complex tasks like the Rey Complex Figure Test, which relies on process over product for diagnostic value, remains uncertain. Similarly, the applicability of online testing across all patient populations warrants discussion. For instance, individuals diagnosed with ADHD may require an in-person setting to maintain focus and ensure reliable test performance. Future studies assessing other tests or comparing between other populations could provide valuable insights into the reliability and validity of online testing for different tests and groups, thereby informing clinical practice.

Broadly speaking, remote neuropsychological testing has broadened the horizons of accessibility. We hope it will pave the way for binational or multinational studies, enabling the comparison of multiple domains across diverse populations. Future research could focus on validating the MoCA-VC across different languages and patient populations, such as those with Alzheimer's. Moreover, the potential for online administration of other neuropsychological assessments in various patient populations warrants exploration. Our promising results underscore the ability of technological advancements to revolutionize research and clinical communities. We hope that neuropsychological assessment developments continue to evolve in tandem with technological capabilities, ultimately benefiting patients worldwide.

Ethics approval

The study was approved by the Ethics Committee of Tel Aviv University (# 0005713-4).

Authors' contributions

YDP, ALA, and WS contributed to the conception and design of the study. YDP conducted the analyses, and IA collected the meta-analysis data. All authors wrote the manuscript and contributed to the manuscript revision.

Disclosure statement

All authors declare no financial or non-financial competing interests.

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Data availability statement

The datasets analyzed during the current study are not publicly available because they contain information that could compromise the privacy of research participants.

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