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Additional visual feedback improves aiming movement performance with practice but may foster dependency in individuals with cerebellar dysfunction: a proof-of-principle study

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HIGHLIGHTS

- Visual feedback improved aiming accuracy and speed in cerebellar dysfunction
- Gains disappeared after feedback removal, suggesting no motor learning occurred
- Controls retained gains, highlighting cerebellar sensory–motor integration role
- Findings show reliance on cues in cerebellar dysfunction, urging rehab caution

ABBREVIATIONS

MMSE	Mini-mental state examination
SARA	Scale for the assessment and rating of Ataxia
BBT	Box and blocks test
IP	Initial position
MoCA	Montreal cognitive assessment
RT	Reaction time
MT	Movement time
TVP	Time to peak velocity
MU	Movement units
KR	Knowledge of results

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BACKGROUND: Cerebellar dysfunction impairs voluntary movement by disrupting sensorimotor integration, particularly the processing of somatosensory and visual information. External visual feedback has been proposed as a compensatory strategy, but its effectiveness in facilitating performance improvement with practice remains uncertain.
AIM: To determine whether additional visual feedback enhances performance in individuals with cerebellar dysfunction during upper limb aiming movements.
METHODS: This longitudinal crossover design study included 28 adults (14 with cerebellar dysfunction, 14 healthy controls) who practiced discrete aiming movements with and without additional visual feedback across two days of sessions, with practice blocks preceded and followed by brief pre- and post-tests. A 24–48 h washout period separated the sessions. Immediate performance outcomes, including planning and execution variables, were analyzed.
RESULTS: Participants with cerebellar dysfunction demonstrated shorter movement times, higher peak velocities, and smaller final position errors when provided with additional visual feedback. These improvements disappeared once feedback was withdrawn, indicating no retention of gains. Control participants showed improved performance through practice, regardless of the feedback condition.
INTERPRETATION: Additional visual feedback enhanced immediate performance in individuals with cerebellar dysfunction; however, no retention was observed. These findings highlight reliance on visual cues and underscore the need for caution when incorporating such strategies into rehabilitation protocols.

KEYWORDS: Cerebellar dysfunction | Ataxia | Visual feedback | Sensory integration | Motor learning

INTRODUCTION

Adequate motor performance and learning processes depend on the integration of cerebellar sensorimotor functions [1]. This integration is achieved through somatosensory information, which is directly used to regulate muscle forces and enhance the accuracy of multi-joint movements towards a target [2]. Visual information indirectly provides references about the object position in space necessary for aiming movement preparation and execution [3]. When movement is inaccurate, the somatosensory and visual information is used to make corrections. However, with practice, vision is processed more quickly and used to improve motor performance [4].

Individuals with hereditary cerebellar dysfunction, whether dominant or recessive, may experience a decline in upper limb performance over time [1]. One hallmark sign of cerebellar dysfunction is ataxia, which impacts posture and voluntary movement, leading to inaccurate and uncoordinated movements [5]. As the disease progresses, motor behavior worsens and becomes more variable [5]. Individuals with cerebellar dysfunction also exhibit longer initiation and execution times for movements compared to healthy individuals [5,6]. Additionally, aiming movements are less accurate, with more overshoot or undershoot depending on the target distance [7]. Therefore, providing additional visual feedback during the execution of aiming movements could be a helpful strategy to improve performance and facilitate retention in individuals with cerebellar dysfunction.

Different strategies can provide additional visual feedback during the execution of aiming movements [8]. Visual feedback can be related to external information about the goal of the movement (knowledge of results) or to how the movement performance was up to the goal (knowledge of performance) [9,10]. Knowledge of results can be provided by the final position reached toward the target. Knowledge of

performance can be provided by the characteristics of the movements, such as the trajectory drawn by the individual when using a pen on the digitizing table surface to reach a target.

Improvements in movement accuracy and reduced spatial variability were observed when individuals with cerebellar dysfunction performed upper limb aiming movements while receiving visual information about the movement trajectory by a cursor (knowledge of performance) [11]. It was suggested that this additional feedback may have helped the spatial organization of movement [11]. Tseng, Diedrichsen, Krakauer, Shadmehr, and Bastian [12] suggested that individuals with cerebellar dysfunction can improve their performance by using knowledge of results during practice of complex visuomotor coordination tasks. The influence of providing knowledge of performance on motor performance in these individuals remains unclear. However, it has been widely used in clinical settings as an intervention[13]. Additionally, it is unclear whether individuals with cerebellar dysfunction can retain performance improvements, particularly in movements that are more accurate and non-perturbed after receiving additional visual feedback.

Hence, the current study aimed 1) to verify the influence of the additional visual feedback during practice on aiming performance and 2) to evaluate the retention of a possible performance improvement using the additional visual feedback. It is predicted that additional visual feedback will improve aiming movement performance and facilitate retention process in individuals with cerebellar dysfunction. This knowledge may contribute to a better understanding of cerebellar functions and the impact of additional stimuli on voluntary movement performance, offering insights into the development of targeted interventions for individuals with cerebellar diseases.

METHODS

A cross-over study with a longitudinal design was conducted. The study was approved by the university's Ethics Committee (protocol number: 54775816.0.0000.0064). All participants received information about the procedures and signed the approved informed consent before participating. Recommendations by the Equator Network (STROBE) were followed [14].

Participants

The study recruited individuals with cerebellar dysfunction (cerebellar group) and healthy individuals (control group), who were matched for gender and age (between 18 and 70 years) and were at least 80% right-handed, as determined by the Edinburgh Inventory [15]. The cerebellar group was individuals with hereditary cerebellar neurodegenerative disease (spinocerebellar ataxias), diagnosed over six months. The study excluded individuals with a history of other neurological diseases or cerebellar disorders of etiologies other than degenerative ones. Individuals with Friedreich ataxia were excluded due to their specific signs and prognosis. In both groups, individuals with a Mini-Mental State Examination (MMSE) score below their schooling level [16], musculoskeletal disorders and/or upper limb pain, clinical instability, peripheral signs of diabetes mellitus, and visual impairments without correction were excluded.

A pilot study was conducted with three individuals with cerebellar dysfunction to determine the required sample size. The calculation was carried out using G-Power, with movement time as the primary outcome, an alpha error probability of 0.05, and a power of 0.80. A sample of 7 individuals per subgroup was found (control with and without additional visual feedback, and cerebellar with and without additional visual feedback), totaling 28 individuals.

Procedures

Individuals were evaluated on sociodemographic and clinical data. MMSE was used to assess individuals' cognitive function [17]. Palmar grip strength (manual dynamometer model HS5811, Saehan®) and pinch grip strength (Pinch Gauge dynamometer (Jamar®) were evaluated on both upper limbs. Procedures were standardized for all individuals [18]. The cerebellar group was further characterized by the time since cerebellar diagnosis and classified by the type of predominant cerebellar syndrome (middle line or hemispheric). The Scale for the Assessment and Rating of Ataxia (SARA) was used (19-21). The Box and Blocks Test (BBT) was used to assess the motor dexterity of both upper limbs in both groups. The most compromised upper limb by cerebellar dysfunction (assessed by the SARA scale and BBT) and the paired upper limb of the control group were used to perform the discrete aiming movements.

Participants were assessed in an illuminated and partially soundproofed room. They remained seated with the trunk stabilized by a vest fixed to the chair, preventing compensatory movements (Figure 1A). The shoulders were maintained in a neutral position next to the trunk for rotation, and the elbows were flexed at 90°. In front of the participants was a table on which a digitizing tablet (12 x 12 inches; Wacom Intuos Professional®) was placed. The participants were asked to perform aiming movements using a stylus on the tablet's sensitive surface according to stimuli displayed on a 15-inch monitor screen (Samsung®). The monitor was positioned at the individual's eye level. Movements started from the same initial position (IP; Figure 1B), indicated in the inferior and central part of the monitor screen as a 1-cm diameter circular shape. The target (1-cm diameter) was positioned 18 cm above the IP. A familiarization trial with the instrumental apparatus was allowed with cyclic movements between the two targets. The target position was calibrated by asking participants to hold the stylus for 2 seconds at the center of the IP and the target. The task was controlled, and the x- and y-coordinates of the stylus on the tablet surface were recorded using customized routines written in LabView® 9.0 Software.

All individuals performed the discrete aiming movements on blocks of trials. For all trials, the target's color on the monitor

changed from white to red (duration of 300 ms), indicating the target to be reached (indicative stimulus). Next, the target returned to white color. After a randomized interval (between 300 and 800 ms), the target changed from white to green (imperative stimulus), indicating that the participant could start the movement. Participants were instructed to "Execute the aiming movement as quickly as possible, trying to hit the center of the target." Individuals in the Cerebellar and Control groups were randomly allocated to subgroups that differed in the sequence of conditions (cross-over). Half of each group began with a condition that included additional visual feedback, in which the trajectory of the tracing was displayed on the screen during execution and remained visible until the end of the trial. The other half of the group began with the condition without the additional visual feedback, meaning that individuals had no information about the trajectory during the trial. The information about the final stylus position (knowledge of results) was always provided on the monitor screen at the end of each trial.

The experiment was performed in two days. On both days, pre- and post-tests were administered before and after the practice period, with one block of ten trials conducted without additional visual feedback. On the first day, considered "Learning", one subgroup performed four blocks with additional visual feedback, while the other subgroup performed four blocks without it. Each block had 20 trials, totaling 80 practice trials. After a 24- to 48-hour washout period, they were called back for the second day of practice. On the second day (the 'Cross Learning' day), crossover was applied, and the conditions between subgroups were reversed, considering the additional visual feedback. The timeline of data collection events is presented in Figure 1C. We applied distributed practice to promote more evident improvements in motor performance [22]. Distributed practice is characterized by a period of pause between blocks of practice greater than or equal to the time performed in practice [23]. Thus, we applied cognitive tasks between practice blocks to change attentional focus (Figure 1). Such cognitive tasks were related to attention, working memory, and cognitive abstraction. These tasks were adapted from components of the Montreal Cognitive Assessment (MoCA) [24, 25]. They included short exercises targeting sustained attention (e.g., digit vigilance), working memory (e.g., sequences of auditory number repetition), and cognitive abstraction (e.g., categorical similarity judgment). Each cognitive task lasted approximately one minute, matching the intended rest interval duration. The rationale for including these tasks was to minimize repetitive motor engagement, promote cognitive resetting between blocks, and maintain consistency with distributed practice principles. However, such tasks may introduce contextual interference or proactive/retroactive effects, although these potential influences were equivalent across all participants and conditions.

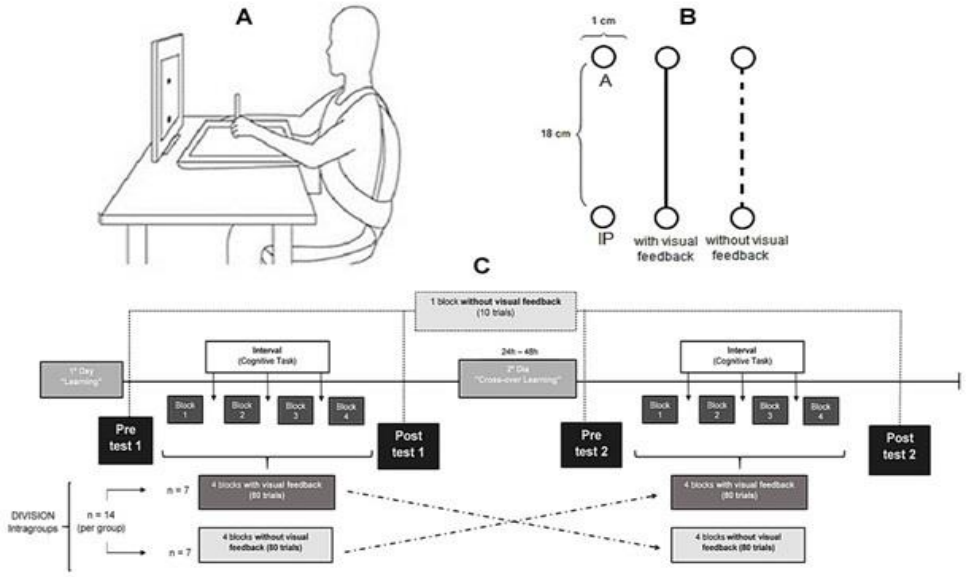

Figure 1. Positioning of the participant (A); representation of the targets shown on the computer screen and the practice conditions, with and without visual feedback (B); timeline of events for data collection (C).

Variables analyzed on aiming movements

The stylus trajectory on the digitizing tablet (X- and Y-coordinates) was recorded at a frequency of 300 Hz for two seconds and filtered with a second-order Butterworth low-pass filter at a frequency of 10 Hz. Trajectory data were used to calculate the linear velocity from the tip of the stylus. The peak velocity was considered the maximum linear velocity (in centimeters per second). 5% of the peak velocity was used to determine the beginning and the end of the movement.

In addition to peak velocity, temporal variables analyzed were reaction time (RT - interval between the imperative stimulus and the beginning of the movement, in milliseconds); movement time (MT - interval between the beginning and the end of the movement, in milliseconds) and time to peak velocity (TPV - interval in which the tip reaches the maximum tangential velocity, in milliseconds). Spatial

movement variables analyzed were: smoothness (number of times that acceleration curve changes direction, in movement units - MU); initial direction error (error in direction of the trajectory at the moment of the peak acceleration, in degrees); the final position error (resultant constant error in mild-lateral and anteroposterior directions, in degrees) and final point variability (average of all end of the trajectory position in the anteroposterior and mid-lateral directions, in degrees). The outcome variables were averaged across trials for each block and condition, and these averages were used for further analyses. Movement time [35,36], smoothness [35,36], and the final position error were considered the primary outcomes.

Data Analysis

The groups' sociodemographic, clinical, and functional data were analyzed through descriptive statistics. The data from each group were compared using the T-test for independent samples for continuous variables and through the Chi-square test for categorical variables. Data normality was verified using the Shapiro-Wilk test. In cases of non-normal distribution, a logarithmic transformation was performed before analysis, or nonparametric tests were applied.

First, the performance in aiming movements was compared between groups (cerebellar vs. control) at baseline (pre-test 1) using nonparametric comparisons of the Mann-Whitney U test for independent samples. Secondly, to ensure that the effects from the first day were not carried over to the second day, comparisons between the pre-tests (pre-test 1 vs. pre-test 2) and between the post-test on day 1 and the pre-test on day 2 were performed, separated by group, using nonparametric Wilcoxon paired samples tests.

A two-way repeated-measures ANOVA was performed, considering motor performance during practice with conditions (with vs. without visual feedback) versus block (B1–B4). Additionally, considering performance improvement with practice, the interaction between conditions (with vs. without visual feedback) and time (pre-test vs. post-test) was also examined. Post-hoc tests with Bonferroni adjustments were used when appropriate. Probability values were considered significant when p-values were smaller than 0.05.

Effect sizes were calculated to complement the interpretation of statistical results. For repeated-measures ANOVA tests, partial η^2 was derived from the corresponding F-values and degrees of freedom. For pre–post comparisons, Cohen's d was computed using pooled standard deviations. These additions provide a clearer understanding of the magnitude of observed effects.

RESULTS

Sociodemographic, clinical, and functional data

Fourteen individuals with cerebellar dysfunction and fourteen age and gender-matched healthy individuals were recruited. One participant with cerebellar dysfunction was excluded after baseline testing due to potential performance interference from concurrent medication use (anxiolytics, antidepressants, and muscle relaxants). The final socio-demographic and clinical characteristics of the sample are presented in Table 1.

Table 1. Socio-demographic and clinical data of individuals per group.

Variables	Control *(n = 14)*		Cerebellar *(n = 13)*	
			Median (SD)	
Age (years)	42(11)		42 (10)	
Motor Dominance (percent)	97 (2)		98 (0.04)	
MEEM (score)	29 (1)		26 (2)	
SARA (score)	-		17 (5)	
Diagnosis (years)	-		8 (6)	
Medications in use (quantity)	1(0.7)		1(2)	
	Paired		**(-) Affected**	**(+) Affected**
Palmar Strength (kgf)	31.5 (2.6)	31.7 (2.5)	27 (8)	26 (7)
Pinch Strength (kgf) [a]	4 (0.3)	4 (0.3)	2.5 (1.1)	2.5 (1.3)
Box and Block Test (blocks) [a]	54.7 (2.3)	54.5 (2.4)	29 (9)[b]	26 (8) [b]
			Frequency – n (%)	
Gender				
Female (%)	8 (57.1)		7 (53.8)	
Most affected side				
Right	-		5 (38.5)	
Left	-		8 (61.5)	
Schooling				
High School	-		9 (69.2)	
Undergraduate	7 (50)		4 (30.8)	
Graduate	7 (50)		-	
Ataxia (type)				
Axial	-		4 (30.8)	
Appendicular	-		9 (69.2)	

a = differences between groups e b= differences between sides

Individual characteristics of the participants from the Cerebellar group are described in Table 2.

Table 2. Individual socio-demographic and clinical characteristics of the Cerebellar group.

Participants	Gender (Male/Female)	Age (years)	Type of SCA	Most affected Side (Right/Left)	Right-handedness (%)	Symptom onset (years)	SARA (score)	MMSE (score)	Locomotion	Visual Correction	Type of cerebellar syndrome	MRI Findings	Extracerebellar signs (in general)
1	Male	58	SCA 7	Right	95	21	16	23	Independent	Farsightedness	Hemispherical	Cortex atrophy is mainly located in the cerebellar hemispheres	Yes
2	Female	57	SCA 3 - MJD	Right	100	5	8.5	28	Independent	Multifocal	Hemispherical	Cortex atrophy is mainly located in the cerebellar hemispheres	No
3	Male	30	SCA 3 - MJD	Right	100	4	18	25	Walking aid	-	Middle line	Atrophy on vermis	Yes
4	Male	37	SCA 3 - MJD	Left	95	7	10.5	27	Independent	-	Hemispherical	Unable to bring imaging exams (syndrome defined through clinical evaluation)	No
5	Female	46	SCA 3 - MJD	Left	95	13	20.5	22	Independent	Nearsightedness	Middle line	Atrophy on vermis	Yes
6	Female	38	SCA in investigation	Left	100	25	24.5	26	Wheelchair	-	Middle line	Atrophy on vermis	No
7	Female	40	SCA 3 - MJD	Left	100	1	9.5	30	Independent	Nearsightedness	Hemispherical	Cortex atrophy is mainly located in the cerebellar hemispheres	No
8	Male	36	SCA 3 - MJD	Right	95	15	22	27	Walking aid	-	Hemispherical	Cortex atrophy is mainly located in the cerebellar hemispheres	Yes
9	Female	25	SCA in investigation	Right	100	7	22	26	Walking aid	Farsightedness	Hemispherical	Unable to bring imaging exams (syndrome defined through clinical evaluation)	Yes
10	Male	29	SCA 3 - MJD	Left	100	22	16.5	30	Independent	Farsightedness	Hemispherical	Unable to bring imaging exams (syndrome defined through clinical evaluation)	Yes
11	Female	49	SCA 3 – MJD	Left	100	23	19.5	26	Walking aid	Farsightedness	Middle line	Unable to bring imaging exams (syndrome defined through clinical evaluation)	Yes
12	Male	48	SCA 3 - MJD	Left	95	16	12.5	27	Independent	Nearsightedness	Hemispherical	Cortex atrophy is mainly located in the cerebellar hemispheres	No
13	Female	52	SCA 3 - MJD	Left	100	6	22.5	26	Walking aid	Farsightedness	Hemispherical	Unable to bring imaging exams (syndrome defined through clinical evaluation)	No

MJD - Machado-Joseph disease; SCA - Spinocerebellar Ataxia; SARA - Scale for the Assessment and Rating of Ataxia; MMSE - Mini Mental Status Examination; MRI - Magnetic Resonance Imaging; UL – Upper Limb.

The cerebellar and control groups did not differ in age ($t(26) = –0.26$, $p = 0.80$) or gender distribution ($p = 1.0$). Compared with controls, the cerebellar group demonstrated significantly lower pinch strength ($t(25) = 1.35$, $p = 0.001$) and poorer manual dexterity on the Box and Block Test ($t(25) = 7.37$, $p < 0.00001$) bilaterally. Within the cerebellar group, the most affected limb showed markedly reduced dexterity compared to the less affected side ($t(12) = 11.6$, $p < 0.0001$).

Differences between groups and carry-over effects analysis

The trajectories of the aiming movements from two participants of the control group and two individuals with cerebellar dysfunction under the tested conditions (with and without additional visual feedback) are presented in Figure 2. Note that the trajectories performed by cerebellar individuals were less smooth than those of controls and showed larger initial direction errors and corrections when the visual feedback was not available, compared to the condition with visual feedback.

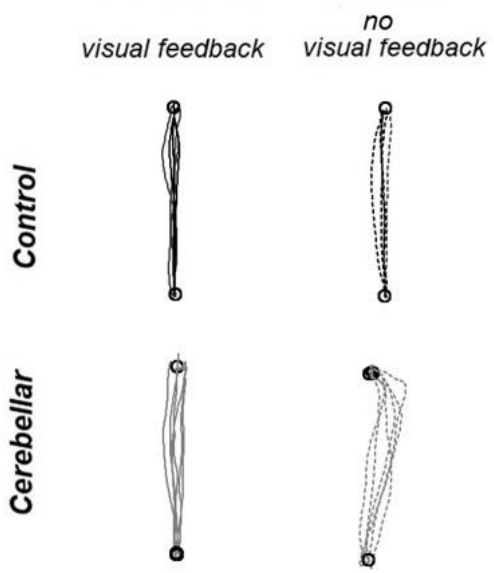

Figure 2. Movement trajectories of two individuals of the control group and two individuals of the cerebellar Group, on the first day, in the two conditions of practice (with and without visual feedback).

There were no carry-over effects due to the different days of practice. For the control and cerebellar groups, there were no differences between the pre-test on day 1 and the pre-test on day 2, or between the post-test on day 1 and the pre-test on day 2, for all analyzed variables ($p \geq 0.05$). Overall, individuals with cerebellar dysfunction exhibited longer reaction and movement times, lower peak velocity, longer time to peak velocity, greater initial direction and final position errors, reduced smoothness, and higher endpoint variability compared with controls ($p < 0.006$ across all assessments: pre-test, practice blocks, and post-test; Figures 3 and 4).

Motor performance on blocks and visual feedback conditions

In the cerebellar group, significant effects were found across practice blocks for final position error ($F(3,36) = 37.8$, $p < 0.0001$, $\eta p^2 = 0.76$; Figure 4C) and final position variability ($F(3,36) = 6.4$, $p = 0.001$, $\eta p^2 = 0.35$; Figure 4D). The highest final position error occurred in B1 (0.84 ± 0.12°), which was greater than in B2 (0.80 ± 0.10°), B3 (0.70 ± 0.09°), and B4 (0.80 ± 0.13°). Similarly, final position variability was greater in B1 (1.07 ± 0.14°) compared with B3 (0.80 ± 0.07°) and B4 (0.80 ± 0.08°).

Additionally, condition analysis revealed that movements performed with additional visual feedback resulted in lower final position error (0.70 ± 0.10°) compared to no-feedback trials (0.80 ± 0.17°; $F(1,12) = 9.3$, $p = 0.01$, $\eta p^2 = 0.44$). Significant interactions were observed between practice blocks and feedback conditions for movement time ($F(3,36) = 5.1$, $p = 0.005$, $\eta p^2 = 0.30$; Figure 3B), peak velocity ($F(3,36) = 3.3$, $p = 0.03$, $\eta p^2 = 0.22$; Figure 3D), and final position error ($F(3,36) = 42.4$, $p < 0.001$, $\eta p^2 = 0.78$; Figure 4C). Post-hoc analyses indicated that in B3, individuals with cerebellar dysfunction performed faster (723 ± 19.4 ms) and had higher peak velocity (60 ± 3 cm/s) under the additional feedback condition than in no-feedback trials (802 ± 45 ms and 53 ± 3 cm/s, respectively). In B1, the final position error was also lower with additional feedback (0.70 ± 0.14°) than without feedback (0.90 ± 0.20°).

The control group showed differences across practice blocks for movement time ($F(3,39) = 3.0$, $p = 0.044$, $\eta p^2 = 0.19$) and smoothness ($F(3,39) = 6.0$, $p = 0.002$, $\eta p^2 = 0.32$). Post-hoc analyses did not identify specific blocks contributing to the movement time effect but revealed that smoothness was lower in B1 (2.8 ± 0.2 MU) than in B3 (2.2 ± 0.15 MU, $p = 0.02$; Figure 4A).

Immediate effects and visual feedback conditions

Considering pre- and post-tests, no significant differences were observed in the cerebellar group for any variable ($p > 0.05$). Differently, the control group demonstrated significant improvements in reaction time ($F(1,13) = 13.3$, $p = 0.003$, $\eta p^2 = 0.51$) and final position variability ($F(1,13) = 10.5$, $p = 0.006$, $\eta p^2 = 0.45$) (Figures 3A and 4D, respectively). Specifically, reaction time decreased from 536 ± 15 ms at pre-test to 495 ± 13 ms at post-test, while final position variability decreased from 0.50 ± 0.03° to 0.40 ± 0.03°. These changes correspond to large effect sizes for pre–post differences in the control group (reaction time: $d \approx 2.9$; final position variability: $d \approx 3.3$). All participant data are provided in Supplementary Material 1.

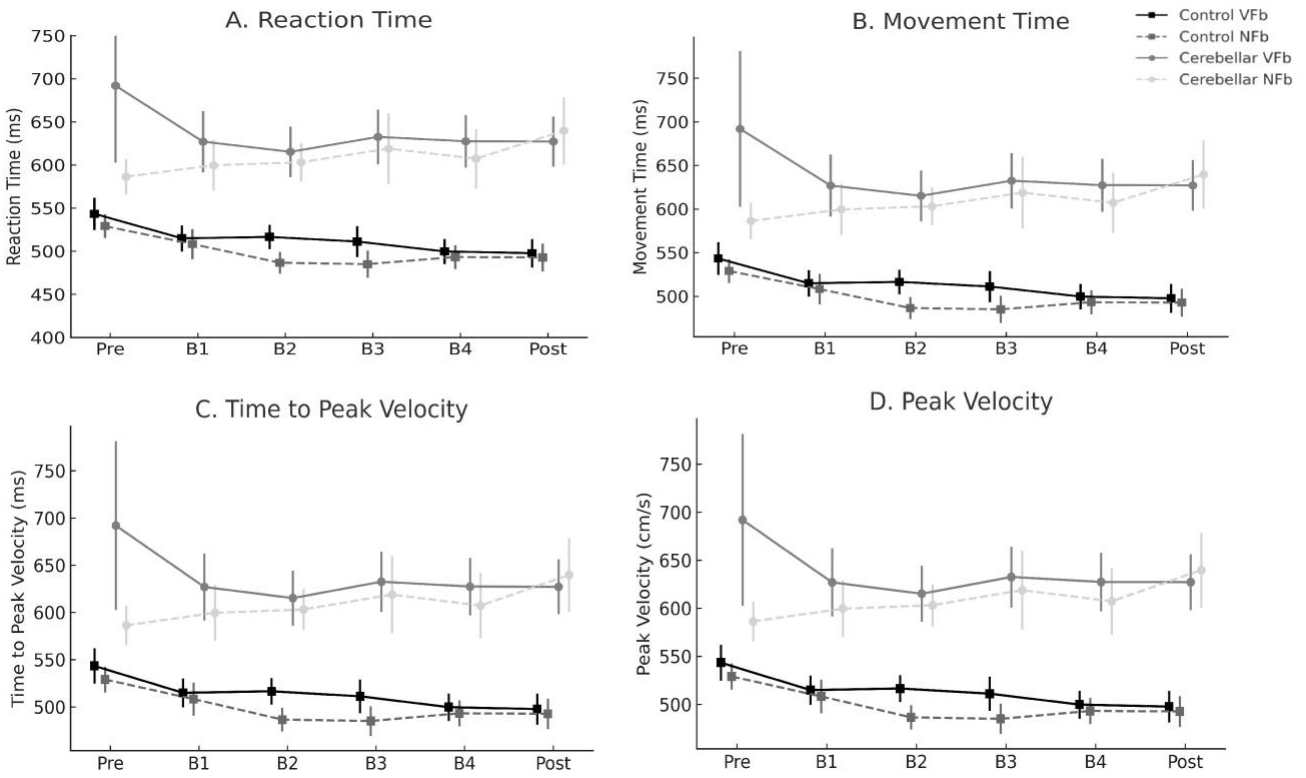

Figure 3. Means and Standard Error of the reaction time (A), in milliseconds (ms); movement time (B), in milliseconds (ms); time to peak velocity (C), in milliseconds (ms); and the peak velocity (D), in centimeters per second (cm/s) of Control groups (with and without visual feedback) and Cerebellar group (with and without visual feedback) during aiming movements.

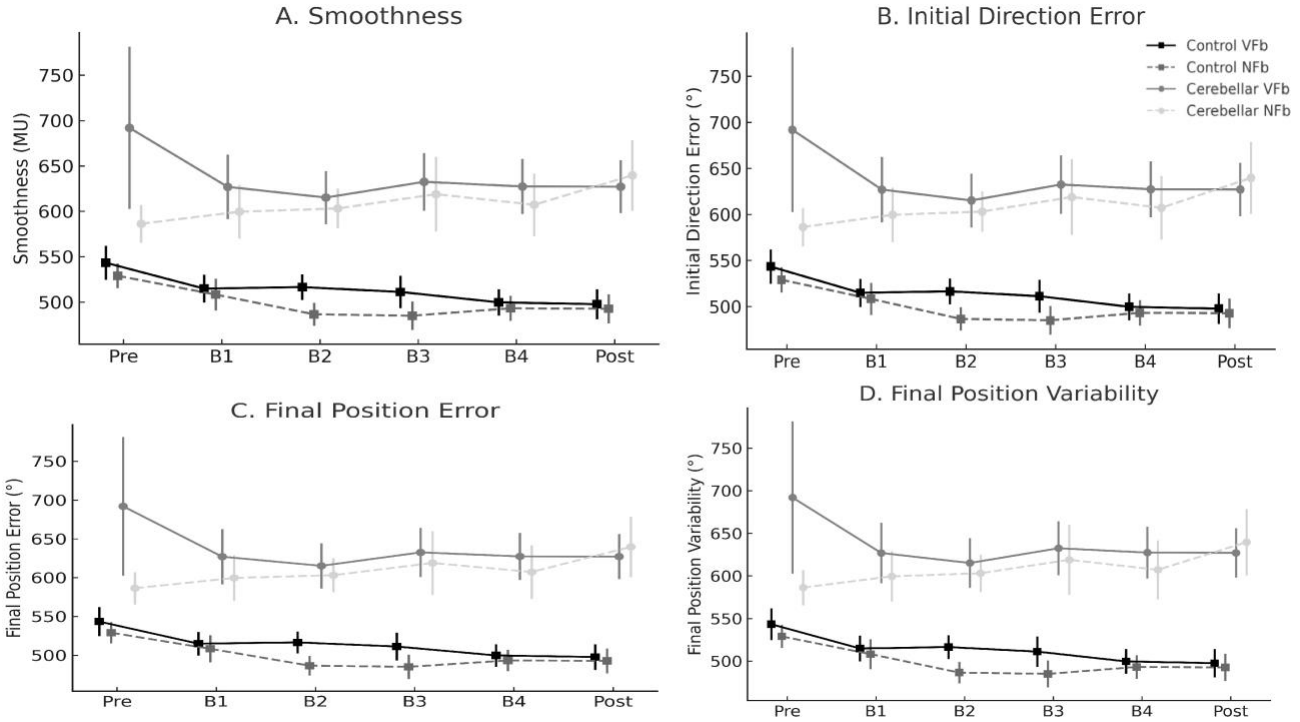

Figure 4. Means and standard error of the smoothness (A), in movement units (um); initial direction error (B), in degrees (°); final position error (C), in degrees (°); and final position variability (D), in degrees (°) of Control groups (with and without visual feedback) and Cerebellar groups (with and without visual feedback) during aiming movements.

DISCUSSION

This study investigated the impact of additional visual feedback on motor performance and learning of aiming movements in individuals with cerebellar dysfunction. The results showed that these individuals could use supplementary visual information to enhance their performance, particularly after repeated trials. However, once the feedback was withdrawn, the improvements were not retained, indicating a dependency on the external visual cues. The improvements observed during practice reflect immediate performance gains rather than motor learning. This pattern suggests that the observed changes reflected temporary, feedback-dependent performance enhancement.

Individuals with cerebellar dysfunction exhibited worse performance in most outcomes compared to healthy paired controls, including pinch strength, BBT, and aiming movements, but not in palmar grip strength, a gross motor task. As expected, the diminished pinch strength and impaired motor dexterity on the BBT and in aiming movements can be ascribed to deficits in the coordination and modulation of muscular forces required for the manipulation, transportation, and elevation of objects set of functions intricately linked with fine motor tasks [7,26,27].

The present findings confirm that additional visual feedback temporarily enhanced performance in individuals with cerebellar dysfunction. Similar improvements in accuracy and reduced spatial variability have been reported when visual information is available [28]. Nevertheless, performance in the cerebellar group remained consistently below that of controls, indicating that supplementary feedback only partially compensates for deficits in sensory integration and predictive motor control.

The benefits of additional visual feedback for individuals with cerebellar dysfunction emerged only after extended practice. Previous studies have shown that changes in motor performance are more evident in tasks of greater complexity, which impose higher demands on the performer [22,29-31]. The relatively simple task used in this study may not have been challenging enough to reveal improvements during the initial trials. After approximately 60–70 repetitions, however, additional feedback promoted gains in temporal and spatial variables, leading to faster, more accurate, and less variable movements. Notably, performance deteriorated in block 4, particularly for spatial measures, which may reflect the effects of fatigue in prolonged practice.

The progressive improvements observed with additional visual feedback may reflect a process of sensory reweighting, in which individuals with cerebellar dysfunction rely more heavily on visual cues to compensate for unreliable somatosensory information. This strategy has been extensively described in postural control, where healthy individuals adjust their sway in response to visual input [43,44], and patients with cerebellar disorders show a marked dependence on vision, exhibiting larger sway when deprived of it [32,33]. A similar pattern was evident in the present study: once visual feedback was removed, the performance improvements were not sustained, and the pre- and post-test results were similar. These findings suggest that visual feedback facilitated short-term compensatory strategies but did not promote retention, potentially fostering dependency on external cues.

Another interpretation of the observed improvement in condition with visual feedback is a shift in attentional focus toward external visual cues rather than a genuine compensatory mechanism within the sensorimotor system. The positive influence of an external focus on motor performance has been consistently reported, regardless of health condition, including accuracy and speed outcomes [33]. Our results showed that individuals with cerebellar dysfunction benefit from a salient external visual reference, possibly due to enhanced automaticity and efficiency of movement associated with an external focus. However, such attentional reallocation does not necessarily engage the internal predictive mechanisms required for long-term adaptation, consistent with the lack of retention following the removal of visual feedback [33].

Day and Thompson [11] evaluated arm aiming movements in patients with ataxic syndromes of different etiologies under conditions with or without visual knowledge of results (KR). They found that KR improved spatial parameters, such as movement length and direction, but compromised temporal control, likely due to overreliance on external visual cues. Importantly, performance improvement with practice was not assessed in that study. These findings are consistent with the present results, in which additional visual feedback supported spatial accuracy in the cerebellar group but did not translate into durable learning [11].

Taking all together, these results challenge the common rehabilitation practice of using additional visual feedback as a guiding strategy for individuals with cerebellar dysfunction. Although such feedback improved spatial performance during practice, participants also developed dependency and failed to retain gains. Therefore, visual feedback should be applied with caution and with clearly defined therapeutic objectives. Future studies should explore its effects across different levels of cerebellar impairment and investigate alternative feedback modalities that may better support long-term learning.

LIMITATION

This study has limitations. Individuals with different degrees of cerebellar impairment were included, and some had extra-cerebellar involvement, which may have influenced the results. However, examining the individual curves developed during practice, all individuals with cerebellar dysfunction exhibited similar performances. The procedures used to stabilize the trunk, as well as the use of the stylus, may have promoted stabilization points that influenced performance. Additionally, the given instructions, which aimed to ensure both velocity ("do the movement as fast as possible") and movement accuracy ("hit the center of the target"), may have had

unintended consequences on performance. It is well established that movement speed affects the performance of individuals with cerebellar dysfunction. Future studies should consider controlling movement speed during practice in these individuals.

Another remark concerns the crossover design used, which may have introduced learning transfer effects between conditions. Although we did not find any carryover effect, participants experienced both feedback environments; improvements observed on the second day may partially reflect practice from the first day, making it difficult to isolate the specific contribution of additional visual feedback. This issue should be considered when interpreting the results, as it may limit the strength of conclusions regarding feedback-related performance changes.

CONCLUSION

Additional visual feedback improved aiming movement performance in individuals with cerebellar dysfunction. These gains, however, disappeared once feedback was withdrawn, indicating the absence of retention and reliance on external cues.

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