Title
The impact of low vision on a strategic re-aiming task

Author
Cipleu, Mihai

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Introduction

Motor learning, an experience dependent improvement in motor performance (1), is not a unitary phenomenon. Motor learning involves both implicit and explicit processes. For instance, during motor adaptation, subjects deviate from an explicit strategy over time due to the force of implicit adaptation (2). Implicit adaptation is considered to be effortless, automatic, yet rigid. Explicit strategies are often effortful, deliberate, and flexible. For instance, we are able to adjust the angle at which we throw a basketball in order to attempt to make a shot from the different positions around a basketball hoop. If given verbal instructions about an explicit strategy to adopt, subjects can immediately alter their movements. However, directional errors due to implicit adaptation continue across movements (3).

Recent work has shown that implicit adaptation is sensitive to the quality of visual feedback. For example, larger uncertainty in feedback leads to slower adaptation (5, 6, 7). That being said, a recent set of studies in our lab has revealed additional constraints on this process, namely that visual uncertainty – induced extrinsically via a Gaussian cloud or intrinsically due to low vision – attenuates implicit adaptation in response to small errors but not large errors (8). Two previous studies in the lab compared behavior in individuals with low vision to that of matched controls, and similarly demonstrated that low vision attenuates implicit adaptation to small errors.

Taken together, these results suggest that, rather than weakening the motor system's sensitivity to errors of all sizes, visual uncertainty may instead add variability to the distribution of the perceived error location (8). That is, visual uncertainty may increase the likelihood that errors are mis-localized (i.e. to the wrong side of a target). This is opposed to other theories, such as the theory that level of visual uncertainty is used by the motor system to adjust the gain on motor output. However, by this theory, a larger error size would still reach the same saturation point under conditions of visual uncertainty (8).

On the other hand, the impact of low vision on the explicit processes underlying motor adaptation is currently unknown. A straightforward way to determine the impact of low vision on the explicit processes underlying motor adaptation would be to compare performance in low vision and control participants on a visuomotor adaptation task that isolated strategic re-aiming. However, to our knowledge, no study has carried out this comparison.

It has been shown that reaching is guided by spatial information and the information that is available before the movement (9). Additionally, it has been shown that low vision adults with amblyopia can generalize learning on a visual task to different locations and are relatively normal in planning reaches (9, 10). Taken together, this indicates that such individuals would not be impaired in strategic re-aiming.

More broadly, explicit re-aiming strategies are thought to depend on top-down cognitive control, rather than lower level factors like visual uncertainty. Discovering a new re-aiming strategy is thought to require mental simulation, that is, the ability to imagine the consequences of movements that were not enacted. Mental simulation abilities seem largely preserved in individuals with low vision, suggesting that these individuals would not be impaired in strategic re-aiming (11, 12). For instance, visually impaired participants perform similarly to controls when making a 180-degree mental rotation of a route (12).

Moreover, an important attribute of motor learning is strategy recall - which is a distinct learning process from the learning in implicit adaptation. In contrast to strategy discovery, strategy recall seems to depend more on memory retrieval, or the ability to recall recent items that are held in working memory (13, 14). There is a dissociation between strategy discovery and recall in participants with cerebellar degeneration, which supports that they are different processes (4).

Additionally, high working memory capacity is specifically associated with explicit re-aiming (15). Spatial working memory seems to be largely preserved in individuals with low vision, suggesting that strategy recall would be preserved on a visuomotor adaptation task (12, 16), and that no deficit in explicit re-aiming would be expected. For instance, individuals with congenital visual impairment are un-impaired relative to controls in memorizing target locations on tactile matrices (16).

However, many of these previous studies tested with inputs other than visual ones (e.g. tactile), or did not adopt visuomotor adaptation tasks that isolated strategic re-aiming. In sum, the currently available evidence is inadequate in order to determine the impact of low vision on the explicit processes underlying motor adaptation.

To explore the effect of low vision on strategic re-aiming, we adopted a visuomotor adaptation task that isolated strategic re-aiming. Specifically, participants were asked to control a visual cursor on their screen with the movements of their finger on a trackpad or the movement of a mouse - with the goal being to hit the visual target with their cursor. To to isolate explicit learning processes, our method was to provide cursor feedback a few seconds after the movement was completed - a manipulation shown to severely attenuate the degree of implicit adaptation (17, 23, 24, 25, 26). Specifically, when visual feedback was provided (either congruent or rotated), we imposed an 800 ms delay between the termination of movement (i.e., when the hand crosses the target distance) and the onset of visual feedback at the target amplitude. We integrated a block into our task designed to assess implicit adaptation - and expected participants to demonstrate no implicit learning. Our hypothesis for this study posits that participants with low vision will not show a deficit in magnitude of strategic re-aiming (discovery) or in strategy recall compared to controls.

Materials and Methods

Ethics Statement

All participants gave written informed consent in accordance with policies approved by the UC Berkeley Institutional Review Board. Participation in the study was in exchange for monetary compensation.

Participants

Individuals with vision loss that cannot be corrected with glasses, contacts or surgery were recruited to participate in this study, whereas participants with correctable vision loss were excluded. Our criteria for inclusion was visual acuity worse than 20/60. We recruited 23 individuals that fit our criteria for inclusion from UC Berkeley's Optometry clinic, as well as from various participant registries for low vision individuals across the country (see Table 1 for group data and Table S1 for individual data). A few of the most common diagnoses were glaucoma and retinopathy. For those who agreed to participate, we obtained a medical history, and an evaluation of general cognitive status using the Montreal Cognitive Assessment Blind (i.e., MoCA-Blind; (18, 19)) through a phone call.

The MoCA-Blind is a version of the MoCA-Full which may be administered over the phone (20). The MoCA-Blind eliminates the visual items of the full test. As shown in Table S1, three of the low vision participants exhibited mild cognitive impairment (a MoCA score less than 18) (20). We opted to include these participants given our general interest in the contribution of low vision to cognitive processes, and here in this study, with a specific focus in testing the impact of low vision on strategic re-aiming. Note that half of the low vision participants reported using assistive technology to enhance their vision during the experiment (e.g. zoom text, screen magnification).

We recruited a sample of 23 matched controls. As shown in Table 1, Low vision and Control groups appeared to not show marked differences in terms of Sex, Handedness, Age, Years of Education, and MoCA scores.

Group	N	Handedness	Sex	Age	Education	MoCA Blind
Low Vision	23	21 R, 2 A	7M, 16F	50 (24 - 86)	17.6 ± 2.0	19.7 ± 1.4
Control	23	22 R, 1 A	7M, 16 F	49.7 (21 - 74)	16 ± 1.9	19.2 ± 2.2

Table 1: Low vision and matched Control participants. Participants self-reported as male (M) or female (F), or declined to specify (D); right-handed (R), left-handed (L), or ambidextrous (A). MoCA-Blind scores can range from 0 to 22 (where lower scores indicate greater impairment). Mean ± SD is provided.

Apparatus and General Procedures

For the entire one-hour session, the experimenter was present on the phone with the participant to provide task instructions. Participants used their own laptop or desktop computer to access a customized webpage that hosted the experiment (21). Participants used their computer trackpad or mouse to perform the reaching task (sampling rate typically ~60 Hz). The size and position of stimuli were scaled based on each participant's screen size. For ease of exposition, the stimuli parameters reported below are for a typical monitor size of 13'' with screen resolution of 1366 x 768 pixels (22).

Reaching movements were performed by using the computer trackpad or mouse to move the cursor across the monitor. Each trial involved a planar movement from the center of the workspace to a visual target. The center position was indicated by a white circle and the target location was indicated by a blue circle (both 0.5 cm in diameter). On the typical monitor, the radial distance from the start location to the target was 6 cm. However, for future studies, it would be as or more important to know the average movement distance. The target appeared at one of two locations on an invisible virtual circle (60˚ = upper right quadrant; 210° = lower left quadrant). The movement involved some combination of joint rotations about the arm, wrist, and/or finger depending on whether the trackpad or mouse was used. In our prior validation work using this online interface and procedure, the exact movement and the exact device used did not impact measures of performance or learning on visuomotor adaptation tasks (21).

To initiate each trial, the participant moved their cursor into a circle which was the starting location. The cursor was only visible when the white dot was moved within 2 cm of the starting location. This prevented the participants from adapting their hand angle on their return movement to the starting circle because they were unable to see where they had moved previously. Once the participant maintained their position in the starting circle for 500ms, the blue target would appear. The participant was instructed to reach, attempting to rapidly "slice" through the target, after they heard the go-cue (i.e., an auditory "beep").

We imposed a 1200 ms delay (with a 100 ms jitter) between the target appearance and the auditory go-cue. By imposing this mandatory temporal interval prior to movement initiation, we sought to equate the time allocated to movement preparation between groups, and as such, eliminate potential speed-accuracy differences. Participants heard the message "Wait for the tone!" if they initiated movements prior to the go-cue and heard the message "Move earlier!" if they initiated their movements 800 ms after the tone.

The visual feedback cursor during the center-out movement could take one of three forms: Congruent feedback, rotated feedback, and no-feedback. During congruent feedback trials, the position of the visual feedback was congruent with the direction of the hand and presented only at the endpoint of movement (i.e., at the target amplitude). During rotated feedback trials, the cursor was presented only at the endpoint of movement and at a 60 angular offset relative to the position of the participant's hand angle as it exceeds the target amplitude. The direction of this offset was either clockwise or counterclockwise (counterbalanced across participants and targets). During no-feedback trials, the feedback cursor was extinguished as soon as the hand left the start circle and remained off for the entire movement.

It is important to note that blocking participants' vision of their reaching hand was not possible, unlike in a laboratory-based set up. However, we have previously shown that measures of explicit adaptation are similar between lab-settings and online settings (38). Additionally, informal observation has shown that participants attend to the screen throughout the experiment, limiting vision of the hand to the periphery.

Experimental Design

The experiment was designed to evaluate whether strategic re-aiming during motor adaptation requires high fidelity vision. 23 Low vision and 23 Control participants completed the experiment, consisting of three phases. First, participants watched a video that introduced the various manipulations in the task (i.e., the go-cue and the delayed cursor feedback). Second, participants completed 15 practice trials, familiarizing them to the web-based reaching environment as well as congruent and no-feedback conditions. Third, participants completed the main task, which entailed six blocks (80 movement cycles x 2 targets = 160 trials total): a baseline veridical feedback block (5 cycles), rotated contingent feedback block (i.e., "Discovery" block; 30 cycles), no-feedback aftereffect block (5 cycles), veridical feedback block (5 cycles), rotated contingent feedback block (i.e., "Recall" block; 30 cycles), no-feedback aftereffect block (5 cycles).

Before veridical feedback blocks, participants were provided the following instructions: "Please move your white cursor directly to the blue target immediately after the tone." Before rotated contingent feedback blocks, participants were provided the following instructions: "Your white cursor will appear at an offset from your movement. To hit the blue target with your white cursor, please reach somewhere differently than the blue target immediately after the tone." Before the no-feedback aftereffect blocks, participants were provided the following instructions: "Your white cursor will be hidden and no longer offset from where you moved. Please move directly and immediately to the blue target after the tone." As the experimenter was present on the phone with the participant, understanding of these instructions was gauged by asking the participant "Can you explain what you understand by this?." Participants were expected to restate the instructions in their own words. Note that no participants in either group were excluded based on this understanding check.

Data Analysis

All data and statistical analyses will be performed in R. The primary dependent variable was the endpoint hand angle on each trial (i.e., the angle of the hand, relative to when the movement amplitude reached a 6 cm radial distance from the start position). To aid visualization, the data were collapsed across two targets (i.e., movement cycles).

We compared hand angle between groups in three a priori defined epochs (27): Early adaptation, late adaptation, and aftereffect. Early adaptation was defined as the initial ten movement cycles after the rotation was introduced (Discovery block: cycles 7 – 16; Recall block: cycles 47 – 56). Late adaptation

was defined as the final ten movement cycles of the rotation blocks (Discovery block: cycles 31 – 40; Recall block: cycles 66 – 75). Aftereffect was defined as all movement cycles without visual feedback after the rotation was removed (following the Discovery block: cycles 41 – 45; following the Recall block: cycles 76 – 80).

Reaction time was defined as the time between the go-cue and the start of movement (operationalized as the time at which the hand movement exceeded 1 cm). Movement time was defined as the time from the initial movement to the time when the cursor reached 6 cm. Reaction time and movement time appear to not significantly differ between groups.

We will employ F-tests with the Satterthwaite method to evaluate whether the coefficients (i.e., beta values) obtained from the linear mixed effects model are statistically significant (R functions: lmer, lmerTest, ANOVA). Pairwise post-hoc two-tailed t-tests (or Wilcoxon sign-ranked test when parametric assumptions were violated) will be employed to evaluate whether hand angle and kinematic measures differ between groups. P-values will be adjusted for multiple comparisons using the Tukey method. The degrees of freedom will also be adjusted when the variances between groups aer not equal. Standard effect size measures will also be provided (D for between-participant comparisons; D for within-participant comparisons; η_p^2 for between-subjects ANOVA) (31).

Results

This experiment sought to investigate whether strategic re-aiming requires high fidelity vision. We tested this by recruiting participants with low vision and their matched controls (N = 23/group). Each performed a visuomotor rotation task. During the initial veridical feedback block, participants acquainted themselves with the task environment. Then, when a 60° visuomotor rotation was imposed, significant hand angle changes in the opposite direction of the rotation were seen in both groups, during both the Discovery and Recall blocks. These hand angle changes pulled the cursor nearer to the target to compensate for the rotation. During no-feedback aftereffect block, the participants switched off their strategies and re-aimed back to the target, as they were asked to do. To eliminate the use of implicit processes in motor adaptation, we delayed the visual feedback. This isolated the use of strategic re-aiming. Since minimal aftereffects were seen in both groups, hand angle changes in the opposite direction of the rotation represented the use of strategic re-aiming, not implicit adaptation. To quantify the amount of strategic re-aiming, we measured endpoint hand angle (i.e., the angle of the hand, relative to when the movement amplitude reached a 6 cm radial distance from the start position) during each trial. As a caveat, the results are currently based on our own visual inspection of the data, and our statistical analysis is a work in progress.

Figure 1b-c show the mean hand angle for Control and Low vision groups. Hand angles appear to have deviated significantly from baseline in both Control and Low vision participants, during late adaptation in the Discovery block, but not during early adaptation in the Discovery block. This suggests that both groups of participants are similar relative to one another in discovering the strategy to nullify the rotation.

Upon participants' second exposure to the same imposed visuomotor rotation, we wanted to determine whether there was a change in adaptation. We looked at "savings" - an increase in adaptation upon second exposure due to more rapid recall of a learned strategic re-aiming approach rather than increased implicit adaptation (29, 30, 33). We looked at the main effect of block for both early and late epochs and found that there is possibly a main effect. This suggests that there was an increase in hand angles in the Recall Block relative to the Discovery Block.

To address our main question of whether strategic re-aiming requires high fidelity vision, we looked at the effect of group during early adaptation. During all adaptation phases, it appears there was no main effect of group. This suggests that low vision participants were not impaired on strategy discovery or recall, two elements of strategic re-aiming. We also looked at the effect of group during late adaptation and possibly found none. Taken together, both of these results indicate that low vision participants were not impaired on strategy discovery or recall.

We then were interested in ascertaining the extent of strategic recall. Here, we calculated a "recall ratio" that quantifies the extent to which learning during late adaptation in the Discovery block was recalled during early adaptation in the Recall block. In this case, a recall ratio of 1 signifies complete strategic recall, below 1 signifies partial strategic recall, and above 1 signifies additional learning upon second exposure to the visuomotor rotation. Figure 1d shows that both groups had successful recall. For low vision participants, the recall ratio appeared to be 1.1. For control participants, the recall ratio appeared to be 1. The recall ratio appeared to not significantly differ between the two groups, which suggests that low vision participants were not impaired in strategic recall.

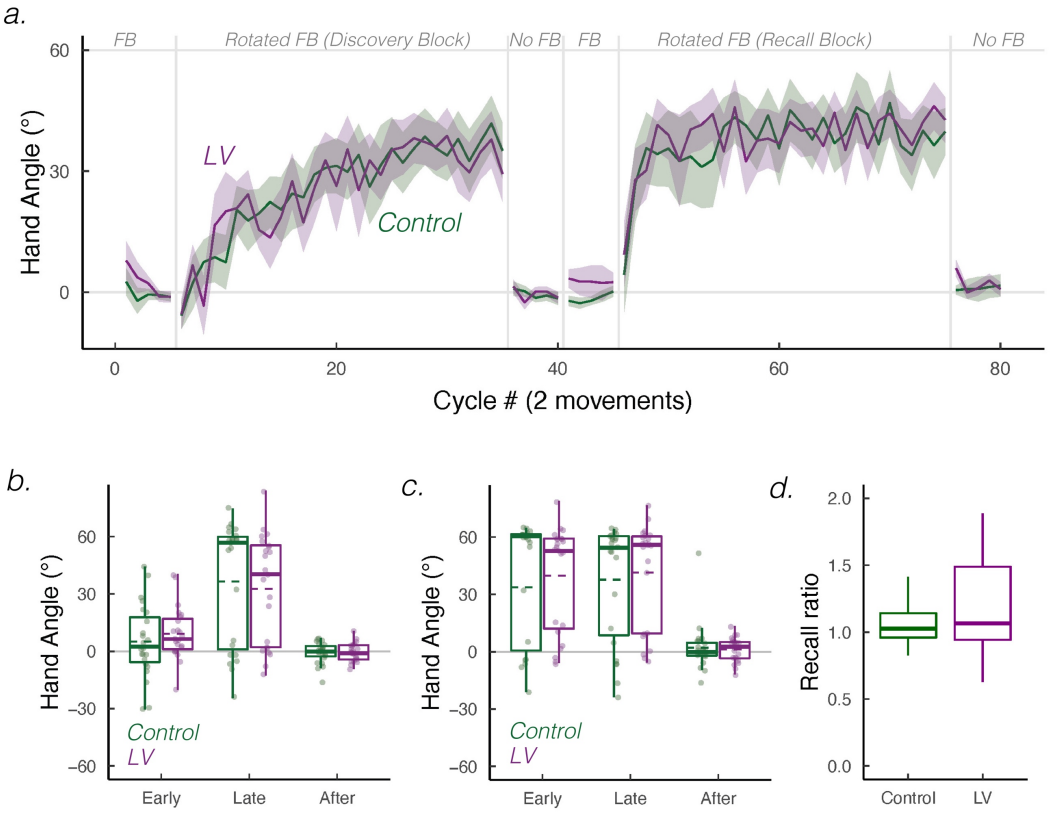

Figure 1: Low vision does not impair strategy discovery or strategy recall. (a) Mean hand angle for Control (green) and Low vision (purple) groups. Hand angle is shown across a cycle (2 trials) and is presented relative to the target (0°) during veridical feedback (cycles 1- 5), rotated feedback (cycles 6 - 35), and no-feedback aftereffect trials (cycles 36 – 40). Grey horizontal bars indicate early, late and aftereffect phases of adaptation. **(b)-(c)** Mean hand angle during the discovery **(b)** and recall **(c)** phase. Box plot denotes the mean (dashed line) and median (solid line) hand angle, 1st/3rd IQR, and min/max.

Individual participants are denoted by translucent dots. **(d)** Recall ratio, quantifying the degree to which late adaptation in the Discovery block was recalled during early adaptation of the Recall block.

Figure 1b-c shows that there were substantial individual differences in re-aiming within each group. It is possible that these differences may be due to a generic cognitive deficit (i.e., a deficit in attention) in participants that did not discover a re-aiming strategy throughout the experiment (i.e., individuals whose late adaptation did not significantly differ from baseline in both blocks; see (32, 33)). We have termed these participants "non-learners" as they exhibit no learning or recall. Specifically, there were 14 "learners" and 9 "non-learners" in the Low vision group and 15 "learners" and 8 "non-learners" in the Control group.

We then sought to determine whether our key findings would replicate when looking at "learners" (i.e. the subset of participants who did discover a re-aiming strategy throughout the course of the experiment). Figure 2 shows that our key comparisons appeared to be replicated. Adaptation in the Control and Low vision groups appeared to not differ in any of the epochs. Additionally, the recall ratio appeared to not differ between the two groups. Overall, this suggests that strategic re-aiming does not require high fidelity vision.

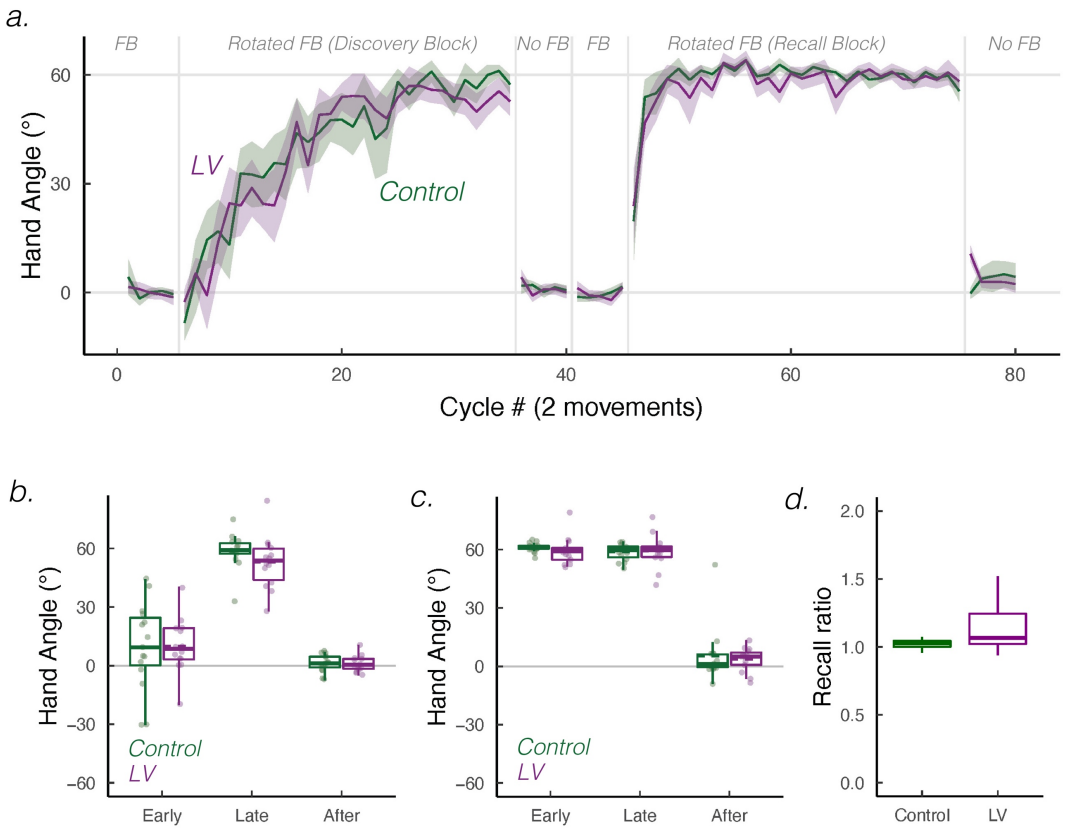

Figure 2: Low vision does not impair strategy discovery or strategy recall for learners. (a) Mean hand angle for Control (green) and Low vision (purple) groups. Hand angle is shown across a cycle (2

trials) and is presented relative to the target (0°) during veridical feedback (cycles 1- 5), rotated feedback (cycles 6 - 35), and no-feedback aftereffect trials (cycles 36 – 40). Grey horizontal bars indicate early, late and aftereffect phases of adaptation. **(b)-(c)** Mean hand angle during the discovery **(b)** and recall **(c)** phase. Box plot denotes the mean (dashed line) and median (solid line) hand angle, 1st/3rd IQR, and min/max. Individual participants are denoted by translucent dots. **(d)** Recall ratio, quantifying the degree to which late adaptation in the Discovery block was recalled during early adaptation of the Recall block.

While our main results indicate that strategic re-aiming does not differ between low vision participants and controls, when we compared behavior in participants with congenital visual impairments to that of participants with acquired visual impairments, it appeared that participants with acquired visual impairments had poorer performance. There were 9 participants in the acquired group, and 14 participants in the congenital group (see Table S2 for individual data). Additionally, there was 1 participant with acquired visual impairments that showed a mild cognitive impairment (a MoCA score less than 18) and 2 participants with congenital visual impairments that showed mild cognitive impairments. Figure 3b-c show the mean hand angle for Acquired and Congenital groups. Adaptation in the Acquired group appeared to be impaired in the late epoch of the Discovery block, and both epochs of the Recall block.

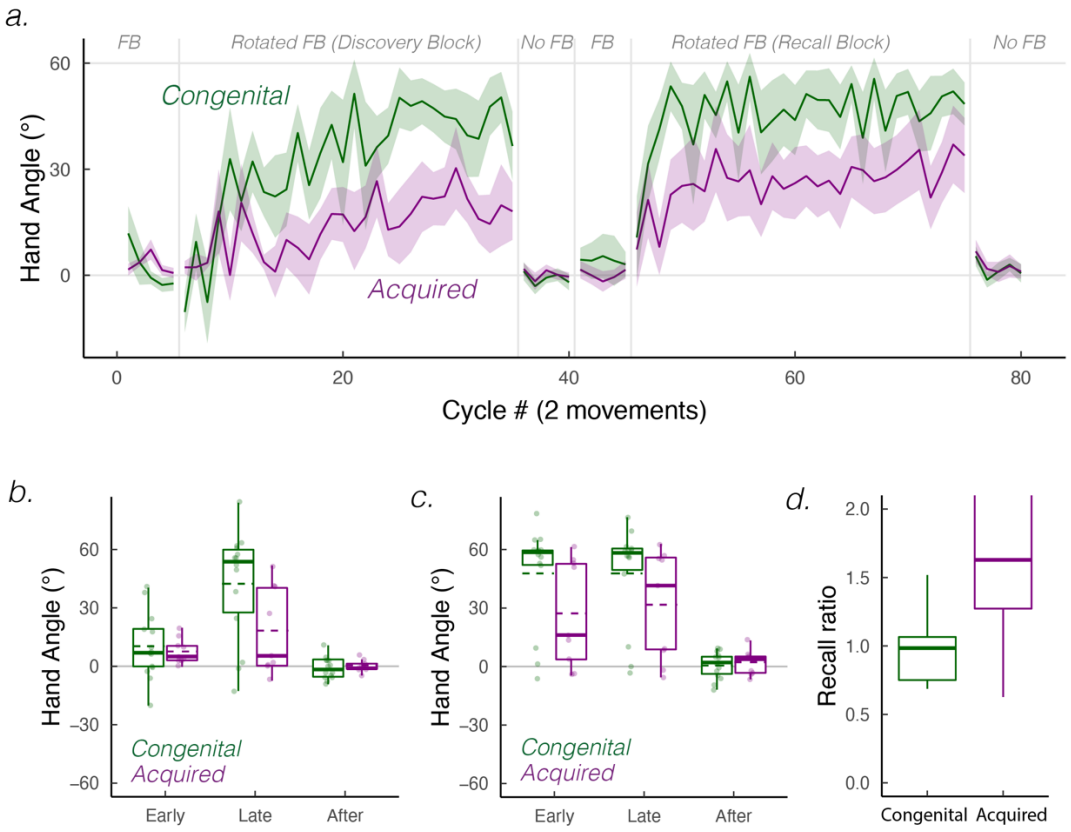

Figure 3: Acquired visual impairment attenuates explicit adaptation. (a) Mean hand angle for Control (green) and Low vision (purple) groups. Hand angle is shown across a cycle (2 trials) and is presented relative to the target (0°) during veridical feedback (cycles 1- 5), rotated feedback (cycles 6 - 35), and no-feedback aftereffect trials (cycles 36 – 40). Grey horizontal bars indicate early, late and aftereffect phases of adaptation. **(b)-(c)** Mean hand angle during the discovery **(b)** and recall **(c)** phase. Box plot denotes the mean (dashed line) and median (solid line) hand angle, 1st/3rd IQR, and min/max.

Individual participants are denoted by translucent dots. **(d)** Recall ratio, quantifying the degree to which late adaptation in the Discovery block was recalled during early adaptation of the Recall block.

Discussion

Implicit and explicit processes are both part of motor learning - with implicit adaptation being considered to be effortless, automatic, yet rigid, while explicit adaptation is often effortful, deliberate, and flexible (2). Recent work has shown that implicit adaptation is sensitive to the quality of visual feedback (5, 6, 7). However, whether strategic re-aiming is sensitive to the quality of visual feedback is largely unknown. To examine this, we compared behavior in individuals with low vision to that of their matched controls on a visuomotor adaptation task that isolated strategic re-aiming. We measured endpoint hand angle on each trial and it appeared that the Low vision group was not impaired in any epoch. Given that explicit re-aiming strategies are thought to depend on strategy discovery and strategy recall, this suggests that strategy discovery and strategy recall are not sensitive to the quality of visual feedback.

Our experiment may provide evidence in support of the hypothesis that low vision participants will not show a deficit in strategic re-aiming compared to controls. This hypothesis appeared to be supported in two main ways. Firstly, during all adaptation phases, it seemed that there was no main effect of group. This suggests that low vision participants are not impaired on strategy discovery or recall, two elements of strategic re-aiming. Secondly, the recall ratio (i.e. the extent to which learning during late adaptation in the Discovery block was recalled during early adaptation in the Recall block) seemed to not differ between the two groups. Both groups showed an increase in adaptation upon second exposure to the same visuomotor rotation, which is known as “savings.”

Our main results appeared to demonstrate that there was no difference in strategic re-aiming between low vision participants and controls. However, participants with acquired visual impairments appeared to show poorer performance compared to participants with congenital visual impairments. Due to brain plasticity, earlier acquisition of skills provides a bigger benefit as one becomes an adult (34). In the case of vision, low vision can be an acquired impairment - something that one develops later in life after already having a normal visual schema. In order to successfully adapt on our visuomotor task, participants must have the ability to discover the strategy and recall the strategy. However, our results suggest that participants with acquired visual impairments have a less accurate perceptual estimate of the rotation size, as they are not able to fully compensate for the rotation. If true, this indicates that participants with acquired visual impairments are not able to refine their existing visual schema enough in order to accurately represent the environment.

This is consistent with previous evidence that patients with early childhood experience of inaccurate visual perception develop compensatory strategies for better accuracy (9, 35, 37). For instance, some low vision adults with amblyopia are better and more confident at certain parts of a reaching task (i.e. programming the grasp) compared to adults with normal vision (9). Additionally, it has been shown that fixational stability becomes better throughout development in low vision children with amblyopia (35). Furthermore, childhood experience of inaccurate visual perception is associated with an alteration of the speed-accuracy trade-off function (35). Specifically, low vision children with amblyopia use slower movements to increase precision (35). However, in our experiment, movement time did not significantly differ between participants with congenital visual impairments and participants with acquired visual impairments.

Previous studies also show that a compensatory mechanism employed by low vision patients with amblyopia is the use of corrective saccades. Taking all the above into account, it is not clear what

compensatory strategy participants with congenital visual impairments in our study could be employing. It seems plausible the strategy participants could be using was something along the lines of corrective saccades. However, the evidence for this compensatory mechanism comes from literature looking specifically at low vision patients with amblyopia rather than low vision patients in general. Additionally, the participants were not observed face to face as they completed the experiment. To our knowledge, as there is not much work examining possible compensatory mechanisms in low vision patients in general, further studies must be done to examine this. In sum, our results suggest that if one is able to develop a visual schema earlier in life, they might protect themselves in the future.

With that being said, it is also possible that the duration of disease in participants with congenital visual impairments could be a confounding result in our study. This alternative explanation can be demonstrated by the possibility that ability to perceptually estimate the rotation size is related to disease duration, or how much experience one has without vision. For example, all of the participants with acquired visual impairments could share a similar number of years from disease onset, or could vary widely in number of years from disease onset. If true, this suggests that duration of disease impacts one's ability to refine their existing visual schema enough in order to accurately represent the environment. Based on our demographic data, the participants with acquired visual impairments did indeed vary within-group in terms of number of years from disease onset.

This alternative explanation is consistent with previous studies suggesting that perceptual ability increases with duration of disease in low vision patients with amblyopia. For instance, in amblyopic children, there is an enhancement of hand-eye coordination skills with age (37). Specifically, more of the movement time is spent in the visual feedback phase of the reach at an older age and error rates are more similar to matched controls at an older age (37). Thus, our results may also support the alternative explanation, which implies that one's visual schema can improve over the duration of their disease.

The difficulty of our task is a possible limitation. It is reported that increased difficulty of visuomotor tasks may compound impaired performance due to conditions like amblyopia (37). Therefore, it is possible that our task was too difficult. However, there were more learners than "non-learners" (i.e., individuals whose late adaptation did not significantly differ from baseline in both blocks) in both the Low vision and Control groups - indicating that the majority of participants were able to understand the task. Additionally, we acknowledge that only initial evidence of the influence of low vision on strategic re-aiming has been presented through our web-based task. To study this previously unexplored issue, we wanted to collect participants that would be more representative of the diversity of low vision disorders – and thus had a heterogenous low vision sample. However, future research may home in on specific deficits of low vision individuals (e.g., loss of peripheral vision, color vision, pressure, etc.). Finally, it is possible that the effects observed between the two groups stem from a difference in the personal set up of each participant (e.g., different distance from the screen, different brightness level). We have tried our best to standardize our setup to diminish this concern. With the experimenter speaking to the participant over the phone during the experiment, it was easier to ensure that the participants were not employing a compensatory viewing strategy.

In sum, we put forward that re-aiming strategies, specifically strategy discovery and strategy recall, are not sensitive to the quality of visual feedback.

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Supplemental Materials

Low vision (n = 23)							Control (n = 23)					
ID	**Hand**	**Sex**	**Age**	**YOE**	**Diagnosis**	**MoCA Blind**	**ID**	**Hand**	**Sex**	**Age**	**YOE**	**MoCA Blind**
1	R	F	47	18	Retinopathy of prematurity	21	1	R	F	39	16	18
2	R	M	34	22	Achromatopsia	21	2	R	M	37	12	16
3	Both	F	61	18	Rieger Syndrome	17	3	R	F	59	13	21
4	Both	F	60	18	Cerebral Visual Impairment	19	4	R	F	60	16	21
5	R	M	70	18	Glaucoma	20	5	R	M	67	18	19
6	R	F	29	18	Retinopathy of prematurity	19	6	R	M	32	16	18
7	R	M	86	16	Glaucoma	19	7	R	M	74	18	20
8	R	M	29	18	Glaucoma	21	8	R	F	30	13	20
9	R	F	70	18	Juvenile Macular Degeneration	17	9	R	F	71	16	22
10	R	F	24	16	Albinism	21	10	R	F	21	15	19
11	R	F	26	16	Genetic Disorder	20	11	R	F	30	18	20
12	R	M	79	18	Myopia	19	12	Both	F	74	18	20
13	R	F	62	16	Glaucoma	21	13	R	F	64	16	20
14	R	F	60	18	Retinitis Pigmentosa	20	14	R	F	65	16	21
15	R	F	28	18	Nystagmus	20	15	R	F	28	16	18
16	R	F	44	18	Terson's syndrone	20	16	R	F	40	18	21
17	R	F	33	18	Genetic / Developmental	20	17	R	M	36	16	13
18	R	M	63	19	Achromatopsia	21	18	R	M	69	18	21
19	R	F	69	22	Stargardt's Disease	20	19	R	F	68	18	21
20	R	F	44	12	Pseudotumor cerebri	19	20	R	F	41	12	19
21	R	M	59	16	Diabetic Retinopathy	17	21	R	M	62	16	17
22	R	F	38	16	Genetic / Developmental	20	22	R	F	42	18	21
23	R	F	34	18	Rod Cone Dystrophy	22	23	R	F	33	16	16

Table S1: Demographics for the individual participants in the Low vision and matched control group. Participant Identification, Handedness, Sex, Age, Years of Education (YOE), and scores for the MoCA-Blind are reported for all participants. MoCA scores ≥ 18 indicate no cognitive impairment.

ID	Low vision onset	Visual acuity right eye	Visual acuity left eye	MoCA Blind
1	C	20/400	20/25	21
2	C	20/160	20/160	21
3	C	20/200	None (prosthetic eye)	17
4	C	20/50	20/50	19
5	C	U	U	20
6	C	20/600	U	19
7	A	None	20/200	19
8	A	20/400	20/100	21
9	C	20/160	20/160	17
10	C	20/300	20/300	21
11	A	U	20/165	20
12	C	20/70-80	20/70-80	19
13	A	20/100	20/80	21
14	A	20/400	20/400	20
15	C	20/60	20/70	20
16	A	20/20-2	20/15	20
17	C	20/200	20/200	20
18	C	20/200	20/200	21
19	A	20/60	20/70	20
20	A	20/200	20/200	19
21	A	U	U	17
22	C	20/100	20/80	20
23	C	20/300	20/1000	22

Table S2: Demographics for the individual participants in the Low vision group with congenital vs. acquired dimension. Participant Identification, Disease onset, Visual acuity for each eye, and scores for the MoCA-Blind are reported for all participants. MoCA scores ≥ 18 indicate no cognitive impairment. Disease onset is denoted as congenital (C) or acquired (A). U denotes unknown.