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Eye Drop Instillation Success and Hand Function in Adults with Glaucoma

A Pilot Study

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Purpose: To investigate hand function and eye drop instillation success in adults with and without glaucoma.
Design: Cross-sectional pilot study.
Subjects: Adults aged ≥ 65 years with glaucoma who use eye drops daily and adults aged 65+ without glaucoma who do not regularly use eye drops.
Methods: Hand function was evaluated using the Saehan Hydraulic Pinch Gauge, Jamar Hand Dynamometer, Grooved Pegboard Test (GPT), Arthritis Hand Function Tests (AHFT), Semmes-Weinstein Monofilament Test, and a tactile pattern recognition device. Eye drop instillation success was analyzed through videography.
Main Outcome Measures: Proportion of successful eye drop instillation trials assessed by (1) overall success in getting at least one drop in the eye; (2) average number of drops dispensed; and (3) bottle tip contact with the eye, eyelashes, or skin. Hand function measures: mean pinch and grip strength, GPT and AHFT completion times, smallest detected monofilament, tactile pattern identification time, and accuracy.
Results: A total of 25 participants with glaucoma and 79 participants without glaucoma were included. There was no difference in the proportion of trials where at least one drop was successfully instilled, disregarding bottle tip contact (glaucoma: 0.95, nonglaucoma: 0.91; $P = 0.88$). Participants with glaucoma were more likely to make contact between the bottle tip and the eye, eyelashes, or skin compared with those without (glaucoma: 0.49, nonglaucoma: 0.28; $P = 0.01$). Participants with glaucoma dispensed a similar number of drops as those without (glaucoma: 1.37, nonglaucoma: 1.46; $P = 0.47$). Participants with glaucoma had significantly reduced pinch strength (glaucoma: 4.8 kg, nonglaucoma 6.1 kg, $P = 0.01$), grip strength (glaucoma: 23.4 kg, nonglaucoma: 27.7 kg, $P = 0.02$), longer completion times for the GPT (glaucoma: 113.5 seconds, nonglaucoma: 85.5 seconds, $P = 0.02$), and specific AHFT tasks of fastening/unfastening buttons (glaucoma: 36.6 seconds, nonglaucoma: 27.7 seconds, $P = 0.03$) and pinning/unpinning safety pins (glaucoma: 35.4 seconds, nonglaucoma: 27.3 seconds, $P = 0.02$), and worse tactile acuity on monofilament ($P = 0.04$) compared with participants without glaucoma.
Conclusions: Despite hand function deficits, in this exploratory pilot study, adults with glaucoma demonstrated eye drop instillation success comparable to those without glaucoma, though with higher rates of bottle tip contact with the eye, skin, or eyelashes, suggesting an increased risk of potential eye drop bottle contamination. These findings suggest that though regular practice may help mitigate the effects of hand function deficits on the targeted activity of getting the eye drop in the eye, the deficits may make this activity difficult.
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Supplemental material available at www.ophthalmologyglaucoma.org.

Glaucoma is a leading cause of irreversible blindness worldwide.[1] The global prevalence of glaucoma is expected to increase from 76 million cases in 2020 to approximately 111.8 million by 2040 in individuals aged 40 to 80 years.[2] The primary management for glaucoma involves the daily application of medicated eye drops to lower intraocular pressure.[3] However, adherence to the medication regimen remains a significant challenge, with rates of nonadherence ranging from 30% to 80% among patients.[4,5] Poor adherence to eye drop medications significantly impairs treatment effectiveness and accelerates disease progression. Notably, adherence rates < 80% are associated with an

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increased risk of severe visual field deficits and progressive visual field loss.[6,7]

Factors contributing to nonadherence include forgetfulness, side effects, medication costs, and difficulties in instilling eye drops, among others.[8] Even among individuals attempting to adhere to their prescribed eye drop regimen, a significant portion of adults with glaucoma still face challenges in self-administering their medication.[9,10] Approximately one third of glaucoma patients are unable to instill a single drop into their eye effectively,[11] with older patients facing greater difficulties.[11–14] Poor instillation technique may be associated with visual impairments[14] and physical limitations,[15] which can interfere with both squeezing the bottle and accurately targeting where the drop lands.

Hand function, essential for tasks requiring fine sensorimotor control such as instilling eye drops, is known to decline with age.[16,17] Given that the average age of onset for glaucoma is 66 years,[18] adults with glaucoma may experience age-related declines in hand function, which could affect their ability to administer eye drops. Although previous studies have highlighted the instillation challenges faced by adults with glaucoma,[11,19] there remains a significant gap in understanding how age-related sensorimotor deficits impact the ability to self-administer eye drops.

Comparative studies evaluating eye drop instillation success between adults with glaucoma who use chronic daily eye drops and adults without glaucoma who do not use daily eye drops are limited and are needed in order to understand the hand function learning curve associated with instilling drops. Understanding how hand function declines associated with aging may impact eye drop instillation success could potentially inform how to teach the best techniques to promote successful eye drop instillation when someone is newly diagnosed with glaucoma. A previous study compared eye drop instillation success among visually impaired older adults with either glaucoma or retinal disease, finding that both groups, who regularly used eye drops, faced significant challenges in self-administering their medication.[20] To date, only one study has specifically compared eye drop instillation success between older adults with glaucoma who use daily eye drops and adults of similar age without glaucoma who do not use eye drops,[21] which found that the participants with glaucoma had lower rates of successful instillation. Our study seeks to build upon this foundation by comparing hand function and eye drop instillation success between older adults with and without glaucoma. We hypothesize that those with glaucoma will have worse hand function and lower eye drop instillation success than those without glaucoma. We used standardized measures from the motor control literature to assess hand function.[22–26] This investigation is exploratory and will generate hypotheses as to how sensorimotor deficits associated with aging may impact eye drop instillation success.

Methods

Participants

The study sample included 25 adults ≥ 65 years of age with any type of glaucoma using medicated drops and 79 adults ≥ 65 years of age without glaucoma who do not regularly use eye drops, defined as using eye drops less than once per week. Because this was a pilot study, the sample size was based on feasibility, with the primary focus on generating hypotheses for future studies. We excluded individuals with a history of allergic reaction to over-the-counter eye drops and any individuals with glaucoma who did not self-administer their drops. Approval for this study was obtained from the Michigan Medicine Institutional Review Board, and written informed consent was obtained for each participant. The study adhered to all the tenets of the Declaration of Helsinki. All participants were recruited from the University of Michigan research participant registry (https://umhealthresearch.org) and via community and university flyer postings. Participants were not recruited from eye clinics.

Standardized Assessments

Participants completed standardized assessments of visual acuity, physical activity, grip and pinch strength, dexterity, and tactile registration. Visual acuity was evaluated using a standardized Snellen Chart, and better-eye scores were converted to logMAR for analysis. Participants were assessed for physical activity using the Physical Activity Scale for the Elderly.[27] Grip and three-point pinch strength were measured 3 times each in the dominant hand using a Jamar Hand Dynamometer and a Saehan Hydraulic Pinch Gauge. Assessments of dexterity included both the Jamar Grooved Pegboard Test (GPT) and the Arthritis Hand Function Test (AHFT). The GPT, one of many pegboard tests, is a commonly used standardized test of manual dexterity[28] that is particularly effective in correlating with activities of daily living and quantifying changes in hand function among older adults.[22–24] In this test, participants are timed while using their dominant hand to manipulate grooved pegs into a board with holes of varied orientations. The AHFT, originally designed for patients with arthritis and related conditions, includes simulated functional tasks that are commonly encountered in daily life, such as lacing shoes and buttoning clothing. This test was selected because it requires the dexterous use of both hands, a skill required for eye drop bottle use.[25,26] In this test, participants were timed while completing bimanual simulated activities of daily living, including buttoning a button board, lacing up a shoe and tying a bow, pinning safety pins to fabric, placing coins into a slot, and cutting a piece of clay with a fork and knife. Tactile registration was assessed in the index and ring fingers of the dominant hand using the Semmes-Weinstein Monofilament Test.[29] In the Semmes-Weinstein Monofilament Test, participants were asked to close their eyes while monofilaments of various sizes were applied to their finger pads and indicate when they perceived a touch. The smallest detectable monofilament size was recorded for each finger.

Experimental Assessments

Tactile Discrimination. Tactile discrimination was evaluated using a custom-designed pattern recognition device. While seated in front of the device, participants were given 5 seconds to feel a visually concealed pattern of raised dots with one finger. After

5 seconds, participants removed their finger from the pattern and used a touchscreen display to select the pattern they felt from a choice of 4 patterns. Participants completed 4 trials each with their dominant index and ring fingers, for a total of 8 trials in the dominant hand. Patterns were randomly selected for each trial from a set of 12 unique patterns. Outcome measures included the amount of time taken to identify the perceived pattern and accuracy rate of correct identifications.

Assessment of Eye Drop Instillation. Participants completed 3 eye drop instillation trials for each eye across 3 different postural configurations (seated, standing, and supine), starting with the right eye in each position. During each trial, participants were instructed to administer 1 eye drop into their eye, dispensing as many drops as needed to achieve this goal. Participants used a 15 mL bottle of Refresh Tears Lubricant Eye Drops (Allergan) for all trials. No instruction was provided for instillation technique; participants self-selected which hand they preferred to hold the bottle with, whether they used their other hand for support, and whether they used a mirror during instillation. Trials were recorded using an iPod touch (seventh generation) with high-definition video (8-megapixel camera with 1080p HD video recording). The camera was positioned close to the side of the participant's eye for clear visualization. The video recordings were transferred to a laptop computer for review. The recordings were carefully reviewed by pausing, zooming in, and, when necessary, slowing down the footage frame by frame to accurately assess the number of drops dispensed and determine if the trial was successful. Each trial video was reviewed by a research associate who did not take the video recording, although they were not masked to participant glaucoma status. The following measures were collected and managed in a secure research database (UM1TR004404)[30,31]: location of eye drop instillation, number of drops used to instill 1 drop, and whether the tip of the eye drop bottle touched the ocular surface, eyelashes, or skin. In rare cases where the solution was dispensed as a stream instead of individual drops, it was counted as 4 drops if a clear start and end of the stream could be determined. A single research associate reviewed each video. To assess the reliability of the eye drop instillation success measures graded from videos (location of eye drop, number of drops dispensed, bottle tip contact with the ocular surface, skin, or eyelashes), a 10% random sample of videos was selected, stratified by grader, position, and eye, with an oversampling of videos where more than 1 eye drop was dispensed. This sample was regraded by additional research associates masked to the initial grading. Intergrader agreement of measures obtained from videos was good and ranged from 86.9% to 95.6% (Table S1, available at www.ophthalmologyglaucoma.org).

Statistical Analysis

Characteristics of the sample (participant demographics, eye drop instillation success, and sensorimotor function) were summarized with descriptive statistics, including mean and standard deviation for continuous measures and frequency and percentage for categorical measures. Six measures of eye drop instillation success were calculated and aggregated over all 18 trials, including (1) proportion of trials with no bottle tip contact with the eye, eyelashes, or skin, (2) proportion of trials with only one drop dispensed, (3) mean number of drops dispensed to instill a single drop, (4) proportion of trials with at least 1 drop successfully placed in the eye, (5) proportion of trials with at least 1 drop successfully placed in the eye with no bottle tip contact, and (6) proportion of trails with exactly 1 drop successfully placed in the eye with no bottle tip contact. Participants with and without glaucoma were compared for differences in demographic characteristics, eye drop instillation success, and sensorimotor function with 2-sample *t*-tests (for normally distributed continuous measures), 2-sample Wilcoxon tests (for non-normally distributed continuous measures), chi-square tests (for categorical measures with expected counts ≥ 5), or Fisher exact tests (for categorical measures with expected counts < 5). Linear regression was used to estimate the differences in eye drop success and sensorimotor function between participants with and without glaucoma, adjusting for age and diabetes. Model results are reported with regression estimates and 95% confidence intervals (CIs). Because of the limited variability in monofilament detection in the sample, models adjusted for age and diabetes could not be performed for this outcome. SAS version 9.4 (SAS Institute) was used for all statistical analysis.

Results

A total of 25 glaucoma participants and 79 participants without glaucoma were studied. Participants with glaucoma reported using 1 (n = 9; 36.0%), 2 (n = 11; 44.0%), or 3 (n = 5; 20.0%) daily eye drop medications to control their disease for durations that were less than 1 year (n = 1; 4.0%), 1 to 5 years (n = 10; 40.0%), 6 to 10 years (n = 7; 28.0%), or > 10 years (n = 7; 28.0%). Those without glaucoma reported using over-the-counter eye drops either weekly (n = 6; 7.6%), monthly (n = 11; 13.9%), rarely (n = 31; 39.2%), or never (n = 31; 39.2%). Glaucoma participants (n = 25) had significantly worse vision than nonglaucoma participants (n = 79). Specifically, glaucoma participants had an average logMAR visual acuity of 0.45 (Snellen equivalent 20/57; median 20/30), whereas nonglaucoma participants had an average logMAR visual acuity of 0.12 (Snellen equivalent 20/26; median 20/25; $P = 0.0007$). No significant demographic differences were found between participants with vs. without glaucoma for age (mean of 75.3 years, [standard deviation (SD) = 1.8] vs. 73.3 years [SD = 5.8], $P = 0.15$), sex (45.8% male vs. 44.9%; $P = 0.93$), race (80.0% White vs. 85.5%; $P = 0.50$), ethnicity (0.0% Hispanic vs. 1.3%; $P = 1.00$), education ($P = 0.42$), and income ($P = 0.81$) (Table 2). Further, no significant difference between groups was found with respect to physical activity (mean Physical Activity Scale for the Elderly score 150.6 [SD = 73.7] vs. 155.7 [SD = 73.3]; $P = 0.76$). However, a larger percentage of glaucoma participants reported having diabetes than participants without glaucoma (20.8% vs. 5.1%; $P = 0.03$). For the reduced sample with tactile measures, no significant demographic differences were observed between those with and without glaucoma (Table S3, available at www.ophthalmologyglaucoma.org).

Participants showed differing success with eye drop instillation measures (Table 4). Bottle tip contact with the eye, eyelashes, or skin was the largest hurdle to successful eye drop instillation with an average rate of noncontact of 0.51 for glaucoma participants (SD = 0.55; median = 0.67), which was significantly worse than the average rate of 0.72 for participants without glaucoma (SD = 0.36; median = 0.94; $P = 0.01$; Fig 1A). The rate of dispensing only one drop from the bottle was similar between glaucoma (mean = 0.76; SD = 0.17; median = 0.78) and nonglaucoma groups (mean = 0.72; SD = 0.23; median = 0.72; $P = 0.59$; Fig 1B). There was no difference in the number of drops dispensed to successfully instill a single drop in the eye among those with and without glaucoma (glaucoma: mean = 1.37, SD = 0.31, median = 1.28; nonglaucoma: mean = 1.46, SD = 0.41;

Table 2. Sample Descriptives Stratified by Glaucoma Status

	Glaucoma (n = 25)		No Glaucoma (n = 79)		
Continuous Variable	*Mean (SD)*	*Median*	*Mean (SD)*	*Median*	**P Value***
Age (yrs)	75.3 (6.2)	74.0	73.3 (5.8)	72.0	0.1503
PASE score	150.6 (73.7)	147.0	155.7 (73.3)	151.0	0.7623

Categorical variable	**Frequency (Percent)**	**Frequency (Percent)**	**P Value†**
Sex-male	11 (45.8)	35 (44.9)	0.9340
Race			
White	20 (80.0)	65 (85.5)	0.5043
Black	4 (16.0)	6 (7.9)	
Asian	1 (4.0)	5 (6.6)	
Ethnicity-Hispanic/Latino	0 (0.0)	1 (1.3)	1.0000
Education			
High School/GED	3 (12.0)	2 (2.5)	0.4201
Vocational/Technical	0 (0.0)	1 (1.3)	
Some College/Associate Degree	5 (20.0)	15 (19.0)	
College Graduate	7 (28.0)	25 (31.7)	
Graduate/Professional Degree	10 (40.0)	36 (45.6)	
Income			
< $20k	1 (4.6)	3 (4.4)	0.8059
$20k–$39k	3 (13.6)	14 (20.3)	
$40k–$59k	3 (13.6)	8 (11.6)	
$60k–$79k	2 (9.1)	8 (11.6)	
$80k–$99k	1 (4.6)	8 (11.6)	
$100k–$119k	5 (22.7)	11 (15.9)	
$120k–$139k	1 (4.6)	6 (8.7)	
$140k–$160k	1 (4.6)	5 (7.3)	
> $160k	5 (22.7)	6 (8.7)	
Handed			
Right-handed	22 (88.0)	70 (88.6)	0.8674
Left-handed	2 (8.0)	5 (6.3)	
Both	1 (4.0)	4 (5.1)	
Comorbidities			
Cardiac	8 (33.3)	16 (20.8)	0.2071
Vascular	16 (64.0)	37 (48.1)	0.1655
Pulmonary	3 (12.0)	5 (6.4)	0.3981
Neurologic	0 (0.0)	1 (1.3)	1.0000
Endocrine/diabetes	5 (20.8)	4 (5.1)	0.0314
Renal	3 (12.5)	6 (7.7)	0.4360
Hepatic	0 (0.0)	1 (1.3)	1.0000
Gastrointestinal	0 (0.0)	5 (5.1)	0.5704
Mental	1 (4.2)	6 (7.9)	1.0000
Osteoarthritis	16 (66.7)	41 (55.4)	0.3311
Immunocompromised	3 (12.0)	8 (10.3)	0.7257
Blood disorder	1 (4.0)	1 (1.3)	0.4283

PASE = Physical Activity Score for Elderly; GED = General Education Diploma; k = $1000.
*Two-sample *t*-test.
†Chi-square or Fisher exact test; percentages are reported on the nonmissing sample.

median = 1.39; *P* = 0.47; Fig 1C). The average proportion of trials that glaucoma participants successfully placed at least 1 drop in their eye was high at 0.95 (SD = 0.07; median = 0.94), which was similar to the average proportion for participants without glaucoma of 0.91 (SD = 0.17; median = 1.00; *P* = 0.88; Fig 1D). However, when accounting for bottle tip contact, these rates decreased and were significantly different between groups such that those with glaucoma had an average rate of instilling at least 1 drop in the eye without contacting the bottle tip of 0.49 (SD = 0.42; median = 0.56) compared with 0.68 for those without glaucoma (SD = 0.36; median = 0.83; *P* = 0.03; Fig 1E). These rates were reduced further when also requiring only a single drop be instilled, although no significant difference was observed between those with and without glaucoma (glaucoma: mean = 0.39, SD = 0.36, median = 0.44; nonglaucoma: mean = 0.53, SD = 0.34, median = 0.56; *P* = 0.06; Fig 1F). After adjusting for age and diabetes status, though the directionality of the estimated differences in instillation success between participants with and without glaucoma remained the same, the results were no longer statistically significant (Table 5).

Table 4. Comparison of Eyedrop Instillation Success and Sensorimotor Function Between Participants With and Without Glaucoma

Outcome	Glaucoma (n = 25)				No Glaucoma (n = 79)				P Value*
	n	*Mean*	*SD*	*Median*	*n*	*Mean*	*SD*	*Median*	
Eyedrop instillation									
Proportion of trials with no contamination	25	0.51	0.44	0.67	79	0.72	0.36	0.94	0.0128
Proportion of trials with only 1 drop dispensed	25	0.76	0.17	0.78	79	0.72	0.23	0.72	0.5899
Average number of drops used to instill one over all trials	25	1.37	0.31	1.28	79	1.46	0.41	1.39	0.4686
Proportion of trials with ≥ 1 drop in the eye	25	0.95	0.07	0.94	79	0.91	0.17	1.00	0.8829
Proportion of trials with ≥ 1 drop in the eye and no contamination	25	0.49	0.42	0.56	79	0.68	0.36	0.83	0.0301
Proportion of trials with only 1 drop in the eye and no contamination	25	0.39	0.36	0.44	79	0.53	0.34	0.56	0.0631
Sensorimotor function									
Median pinch force - Dominant Hand (kg)	25	4.8	2.1	5.0	79	6.1	2.1	6.0	0.0098
Median grip strength - Dominant Hand (kg)	25	23.4	10.7	20.0	79	27.7	10.6	24.0	0.0185
Time to complete Grooved Pegboard - Dominant Hand (sec)	23	113.4	52.3	93.0	79	85.8	23.4	80.0	0.0166
AHF fasten/unfasten 4 buttons (sec)	25	36.6	19.0	30.0	79	27.7	8.2	26.0	0.0324
AHF lacing shoe and tying bow (sec)	24	49.6	18.1	44.0	79	42.2	12.0	39.0	0.0718
AHF pinning/unpinning 2 safety pins (sec)	23	35.4	17.5	32.0	79	27.3	7.4	26.0	0.0214
AHF picking up/manipulating 4 coins into a slot (sec)	24	14.4	5.3	12.0	79	12.6	4.6	12.0	0.1510
AHF cutting putty into 4 pieces with knife (sec)	23	13.3	4.5	12.0	77	12.6	3.5	12.0	0.6924
AHF sum all times (sec)	23	143.2	49.2	127.0	77	121.3	23.3	120.0	0.0647
Median time to complete tactile testing (sec)	20	5.1	2.3	4.4	41	4.2	1.9	3.9	0.0986
Percent tactile accuracy	20	43.7	24.1	40.2	41	52.1	20.9	50.0	0.1972

	Frequency (Column Percent)	Frequency (Column Percent)	P Value†
Smallest monofilament detected - Index finger, Dominant Hand			
2.83	0 (0.0)	5 (6.3)	0.1761
3.61	22 (88.0)	70 (88.6)	
4.31	2 (8.0)	4 (5.1)	
4.56	1 (4.0)	0 (0.0)	
Smallest monofilament detected - Ring finger, Dominant Hand			
2.83	2 (8.0)	16 (20.3)	0.0360
3.61	19 (76.0)	61 (77.2)	
4.31	3 (12.0)	2 (2.5)	
4.56	1 (4.0)	0 (0.0)	

AHF = Arthritis Hand Function; SD = standard deviation.
*2-sample t-test (pinch force) or 2-sample Wilcoxon test (all other outcomes). † Fisher exact test.

Several differences in sensorimotor function were observed between participants with and without glaucoma (Table 4). Participants with versus without glaucoma showed significantly reduced pinch force (mean of 4.8 kg [SD = 4.8] vs. 6.1 kg [SD = 2.1]; *P* = 0.01; Fig 2A) and grip strength (mean of 23.4 kg [SD = 10.7] vs. 27.7 kg [SD = 10.6]; *P* = 0.02; Fig 2B). Additionally, participants with glaucoma took significantly longer than those without glaucoma to complete the GPT (mean of 113.5 seconds [SD = 52.3] vs. 85.5 seconds [SD = 23.4]; *P* = 0.02; Fig 2C) and individual activities from the AHFT, including fastening/unfastening 4 buttons (mean of 36.6 seconds [SD = 19.0] vs. 27.7 seconds [SD = 8.2]; *P* = 0.03) and pinning/unpinning 2 safety pins (mean of 35.4 seconds vs. 27.3 seconds [SD = 7.4]; *P* = 0.02; Fig 2D). No significant differences were observed between participants with and without glaucoma for time to complete the tasks of lacing a shoe and tying a bow, picking up and manipulating 4 coins into a slot, and cutting putty into 4 pieces with a knife (all $P > 0.05$; Table 4). A significantly smaller percentage of participants with glaucoma were able to detect the smallest monofilaments compared with those without glaucoma (2.83 monofilament: 8.0% vs. 20.3%; 3.61 monofilament: 67.0% vs. 77.2%; *P* = 0.04; Fig 2E). Lastly, there was also a marginally significant difference in time to complete tactile testing (Fig 2F), in that those with glaucoma took longer than those without glaucoma (mean of 5.1 seconds [SD = 2.3] vs. 4.2 seconds [SD = 1.9]; *P* = 0.10), but there was no difference in tactile accuracy (mean of 43.7% accurate [SD = 24.1] vs. 52.1% [SD = 20.9]; *P* = 0.20; Table 4).

After adjusting for age and diabetes status, differences between participants with and without glaucoma on sensorimotor function measurements remained significant or remained with a trend in the hypothesized direction (Table 5). Participants with glaucoma were estimated to have weaker pinch force than participants without glaucoma by 0.9 kg (95% CI: −1.9 to 0.1; *P* = 0.07), took 22.7 seconds longer to complete the GPT (95% CI: 8.2−37.3; *P* = 0.003), and took 1.0 second longer to complete tactile testing (95% CI: −0.1 to 2.1; *P* = 0.08). Participants with glaucoma also took longer to complete the AHFT, including an estimated additional 6.6 seconds to finish fastening/unfastening 4 buttons (95% CI: 1.2−12.1; *P* = 0.02), an additional 5.6 seconds to finish lacing a shoe and tying a bow (95% CI: −0.7 to 11.9; *P* = 0.08), and an additional 7.4 seconds to finish pinning/unpinning 2 safety pins (95% CI: 2.3−12.6; *P* = 0.005).

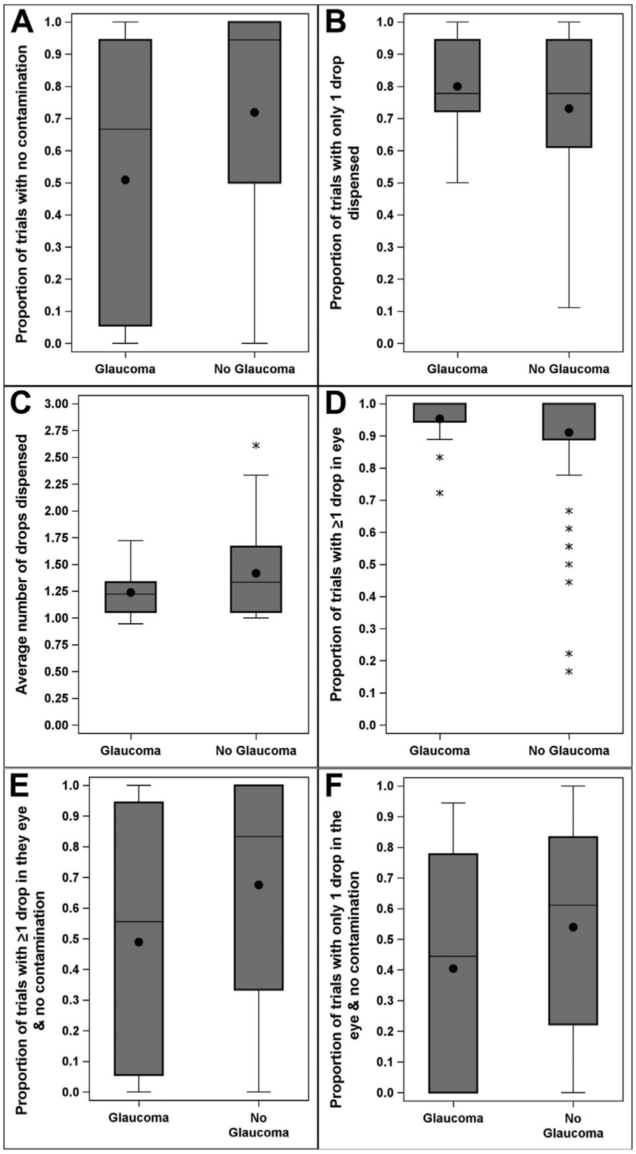

Figure 1. Boxplots displaying the distribution of eye drop instillation success measures, stratified by glaucoma status, including (**A**) proportion of trials with no eye drop bottle tip contact with the eye, eyelashes, or skin, (**B**) proportion of trials with only one drop dispensed, (**C**) mean number of drops dispensed to instill a single drop, (**D**) proportion of trials with at least one drop successfully placed in the eye, (**E**) proportion of trials with at least one drop successfully placed in the eye with no bottle tip contact, and (**F**) proportion of trials with exactly one drop successfully placed in the eye with no bottle tip contact.

Discussion

In this study, we explored specific hand function testing and eye drop instillation success among adults with glaucoma who regularly use medicated eye drops compared to adults without glaucoma who do not use eye drops regularly. Although we had hypothesized that people with glaucoma would have worse hand function and lower success instilling eye drops compared to people without glaucoma, we did not find this in our study. We found that although participants with glaucoma had reduced hand function including decreased grip and pinch strength, decreased manual dexterity, and decreased tactile acuity compared to adults who do not use eye drops regularly, they achieved similar success in eye drop instillation as the nonglaucoma participants, although with a higher incidence of bottle tip contact with the eye, skin, or eyelashes, suggesting an increased risk of potential bottle contamination.

These findings suggest that the individuals with glaucoma may have developed adaptive strategies to compensate for their hand function deficits, potentially through the routine and repetitive task of daily eye drop use. Among glaucoma participants in our study, 96% had been using drops for over a year, and 56% for over 6 years. It may be possible that regular practice of the specific task of eye drop instillation over time enables refinement of skills compared to other activities involving precise control of hand movements. Although the transfer of motor skill learning from one arm to the other has been demonstrated,[32] it has also been demonstrated that the generalizability of more complex movements involving the coordination of different joints is poor[33,34] and independent of the intensity of training.[35] This literature suggests that learning to do a very specific task well, like instilling eye drops, may not generalize to being able to do other tasks requiring good hand function well. These observations support earlier work demonstrating that transfer of motor skill learning is most effective when tasks share similar joint configurations[36] rather than end-point control of body segments, as in what is necessary to hold the eye drop bottle above the eye and dispense a drop. Thus, in the present study, the ability to successfully instill an eye drop in the eye despite poor hand function may be an example of nontransferable task-specific training.

The question remains, however, as to why glaucoma patients had poor hand function on standardized measures of dexterity. Both the grooved pegboard test and the arthritis hand function test require visual monitoring of hand movements. Although research on hand function in the glaucoma population is limited, prior research suggests that adults with glaucoma may experience impaired eye-hand coordination compared to adults without glaucoma.[37,38] Of particular interest, Zwierko et al[37] found that adults with moderate to advanced glaucoma exhibited eye-hand coordination deficits that could not be entirely attributed to visual field defects. They suggested that other factors, such as accelerated age-related changes in visuomotor processing and reduced physical activity, may be contributing to these findings. While previous research suggests that adults with glaucoma are less physically active than their nonglaucoma counterparts,[39] our study found no significant differences in overall physical activity levels between the 2 groups, though our measure of physical activity was through self-report. The participants with glaucoma did have significantly worse visual acuity than the participants without glaucoma. Poor visual acuity in adults with glaucoma has been associated with restricted participation in activities of daily living,[40] many of which require skilled hand use. A reduction in hand use over time could contribute to

Table 5. Linear Regression Estimates for Differences Between Participants With and Without Glaucoma on Eyedrop Instillation Success and Sensorimotor Function Outcomes, Adjusted for Age and Diabetes

Outcome	Age and Diabetes Adjusted Estimate		
	Estimate	*95% CI*	P *Value*
Eyedrop instillation			
Proportion of trials with no contamination	−0.13	−0.31 to 0.05	0.1506
Proportion of trials with only 1 drop dispensed	0.05	−0.05 to 0.16	0.3257
Average number of drops used to instill one over all trials	−0.17	−0.30 to 0.08	0.2454
Proportion of trials with ≥ 1 drop in the eye	0.07	−0.01 to 0.14	0.0747
Proportion of trials with ≥ 1 drop in the eye and no contamination	−0.11	−0.28 to 0.07	0.2228
Proportion of trials with only 1 drop in the eye and no contamination	−0.07	−0.23 to 0.09	0.4098
Sensorimotor function			
Median pinch force - Dominant Hand (kg)	−0.9	−1.9 to 0.1	0.0661
Median grip strength - Dominant Hand (kg)	−3.7	−8.9 to 1.4	0.1527
Time to complete Grooved Pegboard - Dominant Hand (sec)	22.7	8.2 to 37.3	0.0026
AHF fasten/unfasten 4 buttons (sec)	6.6	1.2 to 12.1	0.0182
AHF lacing shoe and tying bow (sec)	5.6	−0.7 to 11.9	0.0787
AHF pinning/unpinning 2 safety pins (sec)	7.4	2.3 to 12.6	0.0049
AHF picking up/manipulating 4 coins into a slot (sec)	1.2	−0.9 to 3.4	0.2649
AHF cutting putty into 4 pieces with knife (sec)	0.6	−1.1 to 2.3	0.4931
AHF sum all times (sec)	17.8	3.2 to 32.4	0.0177
Median time to complete tactile testing (sec)	1.0	−0.1 to 2.1	0.0760
Percent tactile accuracy	−8.5	−20.7 to 3.7	0.1671

AHF = Arthritis Hand Function; CI = confidence interval.

diminished hand strength and dexterity, potentially leading to difficulties in tasks requiring fine sensorimotor control, such as manipulating an eye drop bottle. It is thus reasonable to hypothesize that the impaired hand function observed in the glaucoma group may reflect a decline in overall hand use because of impairments in visual acuity. This impaired hand function may be why we see an increase in bottle tip contact among those with glaucoma alongside the increased success in getting a drop in the eye.

Previous studies have highlighted the challenges faced by adults with glaucoma in self-administering eye drops. A review of 15 observational studies indicates that up to 61% of glaucoma patients struggle to dispense the correct dosage of 1 drop, as many as 37% miss the eye entirely, and up to 80% contaminate their eye drop bottles.[9] A study by Naito et al[21] compared eye drop instillation success, defined as the deposition of 1 drop onto the ocular surface on the first attempt without any bottle tip contact with the eye, skin, or eyelashes, between volunteers with and without glaucoma. They found that the adults with glaucoma had lower success rates (38.5%) compared with adults without glaucoma (56.5%). Using a similar definition of success, we observed a marginally significant difference between groups in the proportion of trials with instillation of only 1 drop into the eye and no contact between the bottle tip and eye or ocular adnexae (glaucoma: 0.39; nonglaucoma: 0.53; $P = 0.06$). When success was defined less stringently as the instillation of ≥ 1 drops into the eye and no eye drop bottle tip contact, the glaucoma group had significantly fewer successful trials (glaucoma: 0.49; nonglaucoma: 0.68; $P = 0.03$). Under our broadest definition of success, getting at least 1 drop into the eye irrespective of eye drop bottle tip contact, both groups had similar success (glaucoma: 0.95; nonglaucoma: 0.91; $P = 0.88$). Potential contamination of the bottle tip through contact with the eye or ocular adnexae was more prevalent among the glaucoma participants, with a smaller proportion of their trials having no contact (glaucoma: 0.51; nonglaucoma: 0.72; $P = 0.013$). Although regular practice of instilling eye drops daily may enable glaucoma participants to administer drops successfully, their ability to perform the finer movements necessary to prevent bottle tip contact may be impaired by their reduced hand function.

Both groups demonstrated comparable success in instilling at least 1 drop into their eye. Participants with glaucoma used an average of 1.37 drops, and nonglaucoma participants used an average of 1.46 drops to successfully instill a single drop into their eye, and this difference was not statistically significant ($P = 0.47$). Although the excess usage beyond a single drop for both groups may appear minor, it translates into notable medication waste over time, particularly for patients requiring multiple daily instillations. This can result in a shortage before the next refill is available that will be covered by insurance, leading people to pay out of pocket for the medication or have a gap in eye drop usage. Further, this study used a 15 mL artificial tear bottle that was likely more pliable and easier to squeeze than many of the bottles of glaucoma medications, which likely underestimated difficulties with eye drop instillation. Several researchers have demonstrated that the force required to squeeze the different glaucoma medication bottles is highly variable, based on bottle shape, pliability of the bottle material, orientation of the bottle, and the number of drops left in the bottle.[41,42] Drew and Wolffsohn demonstrated that average pinch grip strength among

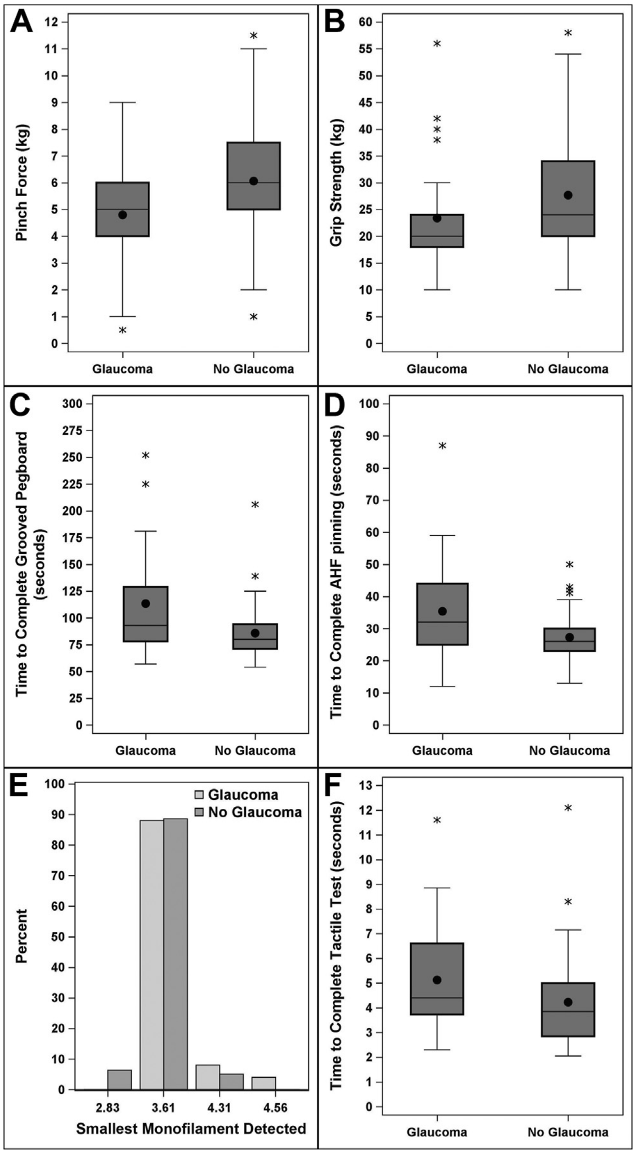

Figure 2. Plots (boxplots and bar chart) displaying the distribution of motor function measures, stratified by glaucoma status, including (**A**) pinch force, (**B**) grip strength, (**C**) time to complete the grooved pegboard test, (**D**) time to complete the arthritis hand function pinning/unpinning 4 safety pins test, (**E**) smallest monofilament detected with the index finger of the dominant hand, and (**F**) median time to complete tactile testing. AHF = Arthritis hand function.

people with glaucoma was not always sufficiently forceful to dispense a drop from the glaucoma medication bottle, leading them to conclude that many glaucoma patients likely struggle with the force required to dispense an eye drop from several of the bottle designs.[41]

Considering that hand function continues to decline with advancing age,[43] there may be a threshold at which the combined effects of hand function deficits and vision loss from glaucoma significantly impair the ability to administer eye drops, thereby affecting the overall effectiveness of the treatment. This highlights the need for developing targeted interventions to address instillation challenges, particularly for individuals newly diagnosed with glaucoma, those $\geq$ 65 years of age who are more likely to experience motor control deficits, and anyone with decreased hand function. Furthermore, because hand function continues to decline with age, it brings to light the potential that targeted interventions to improve hand function overall might impact not only the ability to instill eye drops but also the ability to engage with more activities of daily living. Additionally, identifying older patients with hand function deficits who may struggle with eye drop instillation could help guide clinicians toward considering alternative treatment options such as selective laser trabeculoplasty or surgical interventions, which may reduce the drop burden for patients who have difficulty utilizing topical medications.

The strengths of this study include its targeted focus on older adults and the prospective assessment of hand function using standardized methods. Our study has limitations. Given its exploratory nature, no sample size calculations were conducted, and the study was not powered to detect differences across all outcomes. Because this is a pilot study, the results should be seen as hypothesis-generating rather than hypothesis-testing. Eye drop instillation success was assessed using artificial tear bottles, which typically require less squeezing force than glaucoma medication bottles. The artificial tear bottles utilized in this study had a volume of 15 mL, in contrast to the average 5 mL volume of typical glaucoma medication bottles, which could result in the artificial tear bottles being more pliable and underestimating the difficulty people may have instilling glaucoma medication. We did not assess whether nonglaucoma participants faced limitations that would prevent them from self-administering eye drops, an exclusion criterion for the glaucoma participants. Consequently, the glaucoma group may consist of individuals more adept at administering their own drops, while the nonglaucoma group could include those who require assistance. There were few instances where participants dispensed a stream of eye drops, and the number of drops was not countable, and so we counted these instances as 4 drops; this involved 2.4% of the 1979 trials. Contrast sensitivity was not assessed, which could have provided further insight into the visual factors affecting hand function. The accessibility of this study was limited to individuals able to drive to the research location, potentially introducing a healthy volunteer bias into our findings, though this would be present across both groups. Additionally, participants were recruited from a restricted geographic area characterized by high income and education levels, which does not reflect the broader population. Future studies should address whether these differences exist in more diverse settings.

Our study highlights the critical need to understand the factors that contribute to successful eye drop instillation, with a particular focus on hand function deficits that may impact one's ability to effectively administer eye drops. Such information could be utilized to develop personalized and timely educational interventions aimed at refining eye drop instillation techniques, particularly among those newly diagnosed with glaucoma. However, with projected workforce shortages among ophthalmologists,[44] combined with the aging US population and subsequent increasing prevalence of glaucoma,[2] ophthalmologists may be constrained in their ability to provide such instruction. Novel strategies are needed to address this gap in glaucoma care. By standardizing assessment and coaching techniques, perhaps ophthalmic technicians could play a crucial role in filling this gap. Additionally, through standardized assessment, those with difficulties instilling eye drops could be identified and potentially referred to occupational therapy for additional coaching and strengthening, and/or the physician could identify alternative approaches for intraocular pressure management.

Footnotes and Disclosures

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Abbreviations and Acronyms:
AHFT = Arthritis Hand Function Test; **CI** = confidence interval; **GPT** = Grooved Pegboard Test.

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