USAARL Report No. 2018-15

Dynamic Visual Acuity and Gaze Stabilization in a Clinically Normal Population of Military-Trained Aviators

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United States Army Aeromedical Research Laboratory

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July 2018

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE *(DD-MM-YYYY)* 26-07-2018	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)* October 2015 to December 2017

4. TITLE AND SUBTITLE Dynamic Visual Acuity and Gaze Stabilization in a Clinically Normal Population of Military-Trained Aviators	**5a. CONTRACT NUMBER** N/A
	5b. GRANT NUMBER N/A
	5c. PROGRAM ELEMENT NUMBER N/A
6. AUTHOR(S) Karch, Stephanie J. Milam, Lana S. Staton, Robert N.	**5d. PROJECT NUMBER** N/A
	5e. TASK NUMBER N/A
	5f. WORK UNIT NUMBER N/A
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Aeromedical Research Laboratory P.O. Box 620577 Fort Rucker, AL 36362	**8. PERFORMING ORGANIZATION REPORT NUMBER** USAARL 2018-15
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command 810 Schreider Street Fort Detrick, MD 21702-5000	**10. SPONSOR/MONITOR'S ACRONYM(S)** USAMRMC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) N/A

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

Laulima Government Solutions, LLC

14. ABSTRACT

The dynamic visual acuity (DVA) test and gaze stabilization test (GST) are functional assessments of the vestibuloocular reflex. Both the DVA test and GST have shown great sensitivity/specificity in the identification of unilateral and bilateral peripheral vestibular deficits. The DVA test is recommended for inclusion in fitness-for-duty evaluations for military occupations, like that of aviators. The goal of the current study was establish a reference dataset for clinically normal military aviators on both the DVA test and GST. Forty-four military trained aviators completed the informed consent process and participated in this study. The data from 40 participants were analyzed. Results of this study suggest that military aviators are high-performers when compared to the publically available results from populations of clinically normal adults. The results from this study may provide the practicing clinician a comparative normal cohort when analyzing and interpreting the VOR function in military aviators.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Loraine St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	26	**19b. TELEPHONE NUMBER** *(Include area code)* 334-255-6906

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Acknowledgements

The authors would like to thank the following people for their contributions to this project:

- Dr. Ben Lawson for his guidance and foresight in study design.
- Dr. Robert N. Staton for his assistance with data collection.
- SGT Cierrah Azcona and Mr. Christopher Latin, Jr. for their assistance with both data collection and data entry.

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Introduction

The vestibulo-ocular reflex (VOR) is a compensatory and automatic reflex that provides visual stability during dynamic head movements. Simplistically, the peripheral vestibular end organs detect and encode head movement for central processing, which then excite/inhibit the extraocular muscles stabilizing the eyes on a target image. When functioning normally, the VOR moves the eyes in the opposite direction of the head movement and at the same speed, or velocity (i.e., gain). Thus, allowing the eyes to maintain connection to the target of interest, maintaining a clear visual scene and preventing retinal slip. A VOR gain of 1.0 is normal, and indicates the velocity of the eyes are equal and opposite of the head (Demer, Honrubia, & Baloh, 1994). Peripheral vestibular loss or dysfunction can result in a loss of VOR abilities (Goebel, Tungsiripat, Sinks, & Carmody, 2007), resulting in unstable and blurry visual images or oscillopsia due to excessive retinal motion (Clark, 1998; M. Y. Lee, Kim, & Park, 2004; Riska & Hall, 2016; Stott, 2013).

Functional tests of the VOR or tests of gaze stability include the dynamic visual acuity (DVA) test and gaze stabilization test (GST). Both the DVA test and GST assess similar yet distinct manifestations of gaze stability in peripheral vestibular deficits and are described later in greater detail (Goebel et al., 2007). Additionally, C. Lee and Honaker (2013) recommended use of the DVA test and GST in the clinical workup of individuals with vestibular hypofunction.

Visual acuity (specific to this study) is the ability to correctly identify the orientation (i.e., up, down, right, left) of the equipment test optotype ('E') from a distance of 10 feet. The DVA test quantifies the impairment (i.e., acuity loss) an individual experiences due to head movement. The total visual acuity lost (i.e., DVA loss) due to dynamic movement of the head is calculated by identifying the total difference in visual acuity between dynamic and static conditions (i.e., DVA – static visual acuity [SVA]). It is well regarded that in individuals with normal functioning VORs, minimal loss of visual acuity occurs between dynamic and static conditions (C. Lee & Honaker, 2013; Natus, 2013). Although not a test to identify the site of lesion, the DVA test is significantly reduced in patients with vestibular deficits such as unilateral vestibular hypofunction and bilateral vestibular dysfunction (Dannenbaum, Paquet, Chilingaryan, & Fung, 2009; Herdman et al., 1998; Ward, Mohammad, Whitney, Marchetti, & Furman, 2010). The DVA test has also been shown to measure the severity or degree of vestibular deficit (Herdman et al., 1998).

The GST identifies the maximum head velocity (degrees per sec, or deg/s) an individual can achieve while maintaining a visual acuity of the test optotype. This would suggest that the GST can identify when retinal slip occurs (Ward et al., 2010). Unlike the DVA test, the GST utilizes a fixed optotype, therefore eliminating the effect any pre-existing visual condition (e.g., cataracts, refraction error, macular degeneration, diabetic retinopathy) would have on test results (Goebel et al., 2007; Pritcher, Whitney, Marchetti, & Furman, 2008).

Both the DVA test and the GST can evaluate baseline function, measure impairment after vestibular insult or injury, and monitor vestibular compensation post-injury (Clark, 1998; Honaker, Criter, Patterson, & Jones, 2015; Pritcher et al., 2008). Normative values for commercially available computerized tests of the DVA test and the GST are limited (Clark, 1998; Kaufman, Puckett, & Smith, 2013; Mohammad et al., 2011; Pritcher et al., 2008; Rine et al., 2012; Riska & Hall, 2016; Voelker, Lucisano, Kallogjeri, Sinks, & Goebel, 2014; Ward et al., 2010). This is particularly true for occupations that involve a high degree of physical performance. Additionally, the DVA test can be used to assist in fitness-for-duty (FFD) evaluations for military occupation series, including aviation (Clark, 1998). At this time, the DVA test is thought to provide information for return-to-duty (RTD) determinations, although the implications related to test results and occupational performance have not been established (Kelley, Estrada, Crowley, Marion, Karch, Truong et al., 2017). This is also true for the GST.

In-flight operational tasks that require the coordination and interaction of the visual-vestibular systems include monitoring an instrument panel or helmet mounted display and spatial orientation. Similarly, this anatomical coordination occurs in grounded troops when driving a motorized vehicle or walking (Clark, 1998; Kline et al., 1992; Hillman, Bloomberg, McDonald & Cohen, 1999; Lawson & Rupert, 2010; McKnight, Shinar, & Hilburn, 1991; Sekuler, Kleine, & Kismukes, 1982). While not specific to operational performance for military aviators, activities such as reading in a lighted (or dimly lit) environment while in movement or driving a motorized vehicle also require use of the visual-vestibular systems (Kline et al., 1992; Lawson & Rupert, 2010; McKnight et al., 1991).

Clark and Rupert (1992) detail the influence of the visual-vestibular function in aviators. That is, the visual-vestibular function assists in spatial orientation and the maintenance of spatial awareness. Therefore, an abnormal or dysfunctional DVA is associated with spatial disorientation during instrument flight (Clark & Rupert, 1992). Tests of the DVA can consequently be used to screen for visual-vestibular system deficits that may contribute to spatial disorientation (Clark, 1998). Previous reports of DVA function among aviators and/or military personnel have utilized either experimental methods or non-computerized visual stimuli. These includes topics such as the effects of: fatigue (Behar, Kimball, & Anderson, 1976), minimal peak velocity (M. H. Lee, Durnford, Crowley, & Rupert, 1996), and vestibular neuronitis (Shupak et al., 2003). Despite repeated literature searches, published research regarding the GST in either a military pilot or aviator cohort was not found.

Reported findings in the arena of sports medicine (i.e., recent emphasis on return to play after an on field concussion) often influence return to duty (RTD) determinations after a neurosensory injury (Haran et al., 2016; Scherer, Weightman, Radomski, Davidson, & McCulloch, 2013; Schmidt, Register-Mihalik, Mihalik, Kerr, & Guskiewicz, 2012). Kaufman et al. (2013) report that the DVA test is a reliable test among collegiate football players in the recognition of vestibular deficits associated with head injury, and with return-to-play determinations. Additionally, Honaker et al. (2015) state the GST has excellent specificity (96%) in identifying collegiate football players with a history of concussion.

The goal of the current study was to define normal functional values for commercially available computerized tests of dynamic vision (i.e., DVA test and GST) in a cohort of clinically normal military-trained aviators (i.e., pilots and flight students). This is in line with the direct recommendation by Gottshall and Hoffer (2010) to develop and use normative visual-vestibular data sets for in RTD and/or return to physical activity evaluations in military cohorts. The study's defined functional range of performance for these dynamic vision tests could therefore assist in a clinician’s interpretation of test results as a comparative normal cohort.

Methods and Materials

Participants

The goal of this study was to define normal function for 40 U.S. military-trained aviators for both the DVA test and the GST. To reach this goal, 44 (43 male; 2 female) military-trained aviators (Active Duty, Reserve, and National Guard) consented to participate in this study. All participants were rated rotary-wing pilots or flight students who held military medical clearance for flight operations. Study exclusion criteria is provided in Figure 1. Data was excluded from analysis due to withdrawal from the study (*n* = 1) and invalid test recordings (*n* = 3).

- Aviator not trained by the U.S. Military
- Not between the ages of 19 to 40
- Does hold current military medical clearance for flight activities
- Unable to turn one’s head left and right in the yaw axis
- > 1 episode of dizziness or lightheadedness within the previous month
- “Whiplash” or other serious neck injury within the past 5 years (or not fully recovered)
- ≥ 2 unexplained falls within the past 6 months
- Head injury or concussion with reported symptoms within the past 6 months
- Lower limb injury/surgery within the past 6 months
- Exposure to high-level blast within the past 5 years (or not fully recovered)
- Self-reported confirmed or possible pregnancy
- Diabetes
- Known disorder of hearing or balance, including but not limited to:
    - Ménière's disease
    - Chronic migraine headaches
    - Multiple Sclerosis
    - Vestibular neuritis
    - Vestibular schwannoma
    - Major cerebrovascular disorders
    - Sudden sensorineural hearing loss
- Systemic disorder (e.g., chronic renal failure, cirrhosis of the liver)

Figure 1. Study exclusion criteria.

Equipment

The NeuroCom[*] *in*Vision™ system and software version 9.3 (Natus Medical Incorporated, Clackamas, OR) was used. A head mounted (InterSense Intertia™ Cube^{2}) 3-axis integrating gyro mounted on an adjustable headband was used to monitor location and velocity

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[*] See manufacturer’s list.

of the participant's head movement.

Procedure

The procedure presented herein is a subset of the Institutional Review Board (IRB) approved protocol to define the range of vestibular function in a sample of military Aviators. This protocol included use of computerized dynamic posturography (CDP) and the assessment of dynamic visual acuity and gaze stabilization. To avoid order effect, the presentation of tests were counterbalanced and then randomized. Participant study number counterbalanced the test block (i.e., CDP or dynamic vision) order, and the test order within each test block was pseudo-randomized. Pre-test measures of SVA and perception time test (PTT) were completed prior to either test. The presentation order for the DVA test and the GST was randomized for each subject. The procedure and results of the CDP test block are reported elsewhere.

Participants were required to complete a questionnaire and survey. The questionnaire included questions concerning basic demographic information (e.g., gender, birth year, height, branch of service), flight/aviator status (e.g., total flight-hours, type of aircraft rated/training to fly), and medical history (e.g., history of balance or dizziness, known medical diagnoses, medication use). The participant's responses to the questionnaire were compared to the inclusion/exclusion criteria to ensure eligibility. Next, the Dizziness Handicap Inventory (DHI) (Jacobson & Newman, 1990) was completed.

Participants were seated in a well-lit room at a distance of 10 feet (ft) from the computer monitor. Slight adjustments were made to the height of both computer monitor and chair, so the participant would be eye level to the visual target. The head tracker was calibrated on a flat surface prior to placement on the participant's head. All participants were encouraged to don any necessary single-lens eyewear during testing.

Static Visual Acuity (SVA)

The SVA is the smallest optotype (i.e., 'E') the participant can correctly recognize and identify its orientation (i.e., up, down, right, or left). The unit of measure for SVA is the log of the minimal angle of resolution (logMAR). Participants were asked to look straight ahead and to verbally state the perceived orientation of the optotype. The optotype size increases if the response is incorrect and decreases if the response is correct. All participants were encouraged to guess the direction if they did not know. The SVA test automatically stops when a correct response is given three out of five times at the same logMAR level. Testing for SVA included logMAR scores below 0.00. A measure of 0.00 logMAR is equivalent to a Snellen visual acuity score of 20/20. Negative logMAR scores represent visual acuity better than 20/20 (Table 1).

Table 1. Comparison of Visual Acuity Measures.

logMAR	Snellen
+0.30	20/40
+0.20	20/32
+0.10	20/26

0.00	20/20
-0.10	20/15
-0.20	20/13
-0.30	20/10

Note. Adapted from NeuroCom$^{®}$ Clinical Integration Lab Manual (Natus, 2013).

Perception Time Test (PTT)

The PTT is the minimum amount of time (in ms) an optotype must be displayed for an individual to correctly recognize and identify it when the head is stationary. Participants were asked to look straight ahead and to verbally state the perceived optotype orientation. The optotype size fixed at 0.2 logMAR above the participant's measured SVA throughout testing. Testing is continuous, but automatically ends at the shortest duration in which 60% accuracy is achieved (i.e., three of five correct responses). Natus (2013) reports the normal limits for this test is between 20 to 50 ms. In cases in which a PTT score of ≤ 60 ms was measured, participants were reinstructed and retested. If results remain ≤ 60 ms, the participant's data was not included in the overall group analysis.

Gaze Stabilization Test (GST)

The goal of the GST is to identify the maximum head velocity (in deg/s) in which visual acuity remains intact. All participants were asked to move their head smoothly back and forth in the horizontal (i.e., yaw) plane while attempting to identify the direction of the presented optotype. The optotype size remained fixed (i.e., 0.2 logMAR larger than the participants measured SVA), presentation time was based on measured PTT, and the target head velocity ranged from 10 to 150 deg/s. The target head velocity was varied to determine the maximum velocity at which the participant could maintain visual accuracy. The desired range of head movement was 20 deg to the right and left of midline. Once the participant's headshake matched the target head velocity, the optotype appeared. All participants practiced both the desired head movement and targeted velocities until he or she felt comfortable with the required task. If the direction of the optotype was uncertain, the participant was encouraged to guess.

The GST automatically stops once three incorrect responses are provided in both the right and left head turns at the same velocity. The outcome measure reported is the average achieved velocity for both rightward and leftward head movement (Natus, 2013). Testing was not completed in either the vertical plane, nor using the high performance paradigm.

Natus reports average abilities range from 75 to 105 deg/s, with high performance exceeding 160 deg/s (Natus, 2013). Also reported is the velocity symmetry, or the percentage difference in the average gaze velocity between the rightward and leftward head turns. Honaker et al. (2015) suggests a calculated asymmetry of greater than 13% is indicative of a previous (sports related) concussion.

Dynamic Visual Acuity (DVA) Test

The DVA test aims to identify the smallest optotype (in logMAR) in which visual acuity can be maintained during dynamic head movement. This was accomplished by asking the participant to identify the direction of the optotype while moving his or her head. The desired range of head movement was 20 deg to the right and left of midline. The targeted minimum head velocity was 85 deg/s and the optotype size varied based on participant performance. The start of each test utilized an optotype size 0.2 logMAR larger than the measured SVA. Once the minimum target head velocity was achieved, then the optotype would appear. Each participant was allowed to practice both the desired head movement and targeted velocities until he or she felt comfortable with the task at hand. If the direction of the optotype was uncertain, the participant was encouraged to guess. The DVA test automatically stops once three incorrect responses are given in both the right and left head turns at the same acuity level (Natus, 2013). Testing in the vertical plane was not completed.

The information this test provides includes visual acuity loss for both the leftward and rightward direction. Natus reports little DVA loss indicates normal function (Natus, 2013). While not reported here, visual acuity (with corresponding Snellen fraction) and average head velocity for both the leftward and rightward head turns were also calculated.

Statistical Analysis

Descriptive statistics were used to describe performance on the pre-test measures of PTT and SVA, and the tests of dynamic vision: the DVA test and GST. That is, the mean (M), standard deviation (SD), median (Mdn), and interquartile range (IQR) for each test was analyzed for general trends. IBM® SPSS® Statistics version 23 was used for all analyses (Armonk, NY).

Results

Forty (38 male; 2 female) military-trained aviators aged 25 to 40 years (32.3 ± 3.8) participated and were included for analysis. All participants were rated rotary-wing pilots or flight students. A description of general characteristics is provided in Table 2. The average DHI score was zero, indicating no perceived impairment on daily life due to dizziness for the overall cohort. The average time (PTT) required for accurate identification of the optotype direction was 21.00 ± 3.04 ms. Mean static visual acuity (SVA) was -0.27 ± 0.06 logMAR.

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Table 2. Participant Characteristics.

Characteristic		Population
Age (yr)		
	M (SD)	32.3 (3.8)
	Range	25 to 40
Gender		
	Male/Female	38/2
First rotary-wing aircraft listed		
	UH-60	18
	CH-46	6
	AH-64	11
	OH-58	1
	UH-72	1
	Unknown	3
Range of total flight hours		
	0 to 20	1
	20 to 200	3
	200 to 300	2
	300 to 1000	18
	1000 to 2000	13
	2000+	3
Also rated/trained a fixed-wing aircraft		7
Rated/trained to fly > 1 rotary-wing aircraft		8

Note. Participants were asked to list the aircrafts they are rated or training to fly. The first item listed was what is provided herein.

Table 3 summarizes the findings for the GST. Mean logMAR for the DVA test during leftward head movement was -0.16 ± 0.12 and -0.16 ± 0.12 logMAR during rightward head movement. The mean loss of acuity (Figure 2) due to head movement (i.e., DVA loss) was 0.11 ± 0.10 logMAR during leftward head turns and 0.12 ± 0.09 logMAR during rightward head turns.

Table 3. Descriptive Results for DVA and DVA loss

		M	SD	Mdn	IQR
DVA (logMAR)					
	Left	-0.16	0.12	-0.18	-0.28 to -0.09
	Right	-0.16	0.12	-0.18	-0.25 to -0.08
DVA loss (logMAR)					
	Left	0.11	0.10	0.09	0.02 to 0.20
	Right	0.12	0.09	0.10	0.04 to 0.21

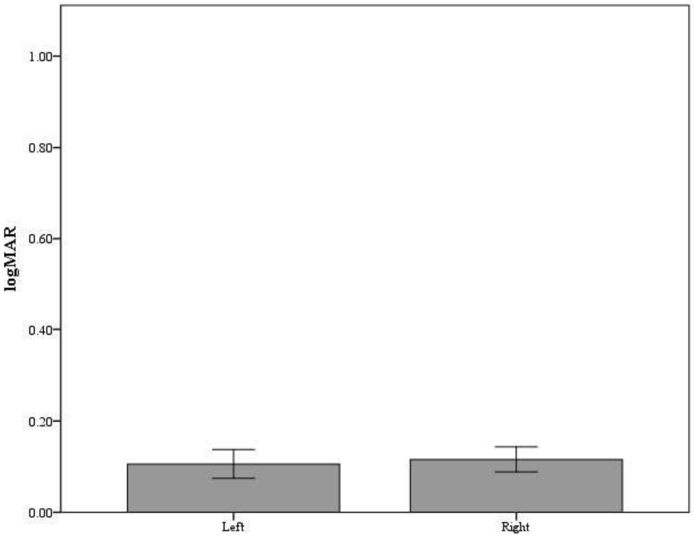

Figure 2. Average DVA loss for left and right movements. Graphic includes 95% Confidence Interval (CI) error bars.

Table 4 summarizes the descriptive results for the GST. The mean velocity (deg/s) during head turns to the left was 153.0 ± 29.6 and 158.2 ± 31.1 to the right. This can also be seen in Figure 3. The mean percent asymmetry between left and right head turns was 6.35 ± 6.62.

Table 4. Descriptive results for GST velocity and asymmetry.

	M	SD	Mdn	IQR
GST Velocity (deg/s)				
Left	153.0	29.6	160.0	134.5 to 173.8
Right	158.2	31.1	161.5	144.5 to 182.0
GST Asymmetry (%)	6.4	6.6	4.0	2.0 to 7.8

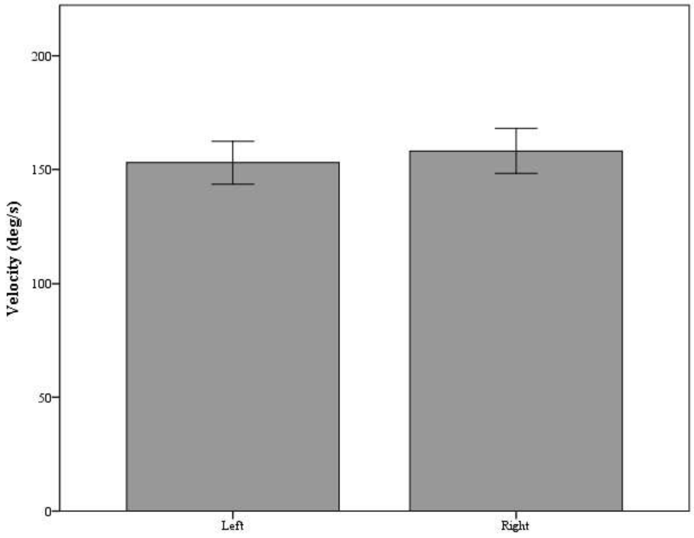

Figure 3. Average GST head velocity for left and right head turns. Graphic includes 95% CI error bars.

Discussion

The goal of this study was to define the range of function for a population of clinically normal military-trained aviators utilizing commercially available computerized tests of gaze stability. This included the DVA test and the GST. It is to the best of our knowledge that no other published normative values for military rotary-wing aviators exist.

Caution is warranted when comparing test results to those readily available in peer-reviewed published literature as both methodology and instrumentation vary significantly (Demer et al., 1994; Gotshall & Hoffer, 2010; Herdman et al., 1998; Hillman et al., 1999; C. Lee & Honaker, 2013; Marquez, Lininger, & Raab, 2017; Pritcher, Whitney, Marchetti, & Furman, 2008; Mohammad et al., 2011; Schneiders, Sullivan, Rathbone, Thayer, Wallis, & Wilson, 2010; Ward et al., 2010). Additionally, limited information is available regarding performance values for populations of clinically normal adults. Typically, these findings are reported as a control cohort in a comparative study evaluating test specificity and/or sensitivity in either sub-clinical populations of vestibular deficits (Dannenbaum et al., 2009; Goebel et al., 2007; Gotshall & Hoffer, 2010; Hillman et al., 1999; Pritcher et al., 2008; Voelker et al., 2014) or populations thought to be high performers (Ishigaki & Miyao, 1993; Marquez, Lininger, & Raab, 2017; Rouse, DeLand, Christian, & Hawley, 1988; Schneiders et al., 2010).

Riska and Hall (2016) aimed to define normative values to act as a reference for the DVA test in young (18 to 30 years old) and older adults (60+ years old) utilizing the same equipment and methodology as the current study. Although the desired young adult age range was 18 to 30 years old, t the study cohort was 23 healthy young adults aged 19 to 26 years (22.4 ± 1.9) with normal vestibular function. Mean static acuity scores suggest that the military aviator population (-0.27 logMAR) has superior visual acuity than the healthy young adult population (-0.24 logMAR). Additionally, when comparing the mean DVA loss between study cohorts, the military aviator population exhibited less loss of visual acuity with head movement. The difference between the cohorts was 0.07 logMAR for leftward head movements and 0.06 logMAR for rightward head movements. Dynamic visual acuity (DVA) scores have been reported to be affected by age (Herdman et al, 1998), thus the Riska and Hall (2016) non-aviator young adult values (less than 30 years old) may not be a valid comparison to the current study cohort of 40 healthy adults whose mean age is 32.3 years who are military aviators. However, Sekuler et al. (1982) report the effect of age on dynamic visual acuity DVA among pilots is unknown. A brief literature search failed to find any publications regarding age effects on DVA in pilots or aviators.

While the methodology and testing environment varied slightly, Lee and Honaker (2013) reported mean SVA and GST values using the same commercially available equipment among a sample of 20 clinically normal adults between 20 to 40 years old. In this study, participants were asked to complete SVA and GST in accordance with the NeuroCom inVision™ protocol over two test sessions to determine test-retest reliability. The mean SVA for both sessions was -0.20 logMAR. When comparing this finding to that of the current study mean SVA, we find that the aviator population has greater visual acuity, with a measured SVA of -0.27 logMAR. Similarly, the average GST over the course of the two test sessions was 148.0 deg/s while the current study mean GST score was 153.0 deg/s. This suggests the current study cohort was able to achieve a higher degree of head rotation prior to retinal slip than that of a sample of a clinically normal population.

Schneiders et al. (2010) and Marquez et al. (2017) both completed studies of athletes that utilized similar instrumentation. Schneiders et al. (2010) evaluated a small cohort of motorsport athletes and a control group of age-matched non-athletes on the PTT, SVA and DVA test and GST. Marquez et al. (2017) evaluated collegiate football players using the PTT, SVA, and DVA test. The current study's population mean PTT (21.00 ms) was found to be more like that of Schneiders et al.'s (2010) motorsport athletes (21.11 ms) and Marquez et al.'s (2017) cohort of collegiate football players (20.1 ms) than that of Schneiders et al.'s (2010) non-athlete control cohort (28.99 ms). Comparison of the SVA between cohorts revealed a slightly better visual acuity among the military aviator population (-0.27 logMAR) compared to the young motorsport athlete population (-0.25 logMAR). Similarly, the current study population had an average SVA better than the mean SVA for collegiate football players (-0.23) as reported by Marquez et al. (2017). However, due to varying test parameters for both the DVA and the GST, direct comparison between the cohorts was not completed for either study.

Evidence suggests that high performance populations, like that of athletes (i.e., baseball, badminton, and tennis) and elite motorsport athletes, have greater visual acuity (i.e., DVA) during head movement from that of the general population (Ishigaki & Miyao, 1993; Rouse, DeLand, Christian & Hawley, 1988; Schneiders et al., 2010). Whether or not this skill is trainable or transferable has yet to be conclusively determined (Schneiders et al., 2010). Schneiders et al. (2010) utilized a DVA test paradigm with a minimum peak velocity of 150 deg/sec, compared to our own use of a minimum peak velocity of 85 deg/sec. Thus, a direct comparison of the two study cohorts could not be completed.

Schneiders et al. (2010) also reported GST results utilizing similar instrumentation with differing methodology, as they utilized a test paradigm suitable for high performers. That is, an extended range of headshake velocities of 70 to 300 deg/s was used compared to our own use of the standard test paradigm of 10 to 150 deg/s. This difference in velocity ranges prevented any comparison between the two studies. It should be noted that 73% (29 of 40 participants) of the current study population was identified as not completing testing at the higher head velocities in at least one head-turn direction. This is yet another limitation of the current study, as the highest reported velocity measured may be an inaccurate representation of individual performance. That is, by utilizing the standard velocity range of 10 to 150 deg/s, high performers may hit a performance ceiling due to a restricted range of speed. Future efforts evaluating gaze stabilization abilities among military-trained aviators should include test paradigms that would allow for higher ranges of performance both in the clinical and research settings.

An additional noted limitation is the reliance upon self-report for exclusionary criteria. That is, both inclusion and exclusion criteria. were assessed a demographic/medical history questionnaire and the DHI, and relied on self-report of symptoms and medical history. Reported medical history was not verified (e.g., consulting with individual medical record) prior to inclusion in this study. Consequently, the nondisclosure of an injury or medical condition that affects the vestibular system and/or VOR is possible. Such medical events include a history concussion (head injury) greater than 6 months from the day of participation, head/neck injury from which they have not fully recovered,; and exposure to high-pressure blasts greater than 5 years from the time of participation.

Head and neck injuries which result in either a concussion or traumatic brain injury (TBI) have known effects on (although not limited to) balance and visual-vestibular function (Honaker, Criter, Patterson, & Jones, 2015). Difficulties with balance and vestibular function are one of the most frequently reported symptoms of mild TBI (Fausti, Wilmington, Gallun, Myers, & Henry, 2009). Participants in the current study were excluded if there was a self-reported exposure to at least one high-pressure blast within the past 5 years and who did not recover to pre-blast exposure function. Any self-reported history of blast exposure or head/neck injury should be noted. At this time, it is unclear the effects of blast variables (e.g., amount of pressure, distance from detonation, side of body primarily exposed) on not only vestibular function but also the function of the VOR, even if the incident was considered medically minor and the individual has fully recovered (i.e., no longer expressing any symptoms of injury).

Additional known limitations of the current study include the fact that participants were not screened for baseline oculomotor function prior to inclusion and participation in this study. Rather, participants were asked to self-identify and self-exclude if they had a known eye motor difficulty. Like that of Mohammad et al. (2011), the test order was randomized in order to reduce the possibility of test effect. Kaufman et al. (2013) also suggest both mental and physical fatigue can decrease the reliability of GST. Participants were offered breaks between tests; however, these breaks were not mandatory and were rarely accepted by the participants. Lastly, the current study is not a comparative study. Therefore, a control group (i.e., non-aviator Service Members and/or non-aviator non-military personnel) was not included. Therefore, we cannot comment to the nature of how the performance of military-trained aviators differs from that of military non-aviators or the general population.

Conclusions and Recommendations

The results of this study suggest that military pilots and flight students are a high performance population. This is demonstrated with a higher measure of mean head turn velocity (GST) and greater visual acuity (DVA) with fewer lines of acuity loss (DVA loss) during head turns compared to published values from clinically normal young adults. Therefore, high performance measures and test paradigms should always be considered and utilized when evaluating a patient or population of military-trained aviators.

Future research efforts should focus on further establishment of GST normative values using head velocities exceeding 150 deg/s (i.e., a high performance test paradigm). Continued efforts should extend identifying range of function for both the DVA test and GST in the pitch (vertical) plane. The current study utilized a sample comprised of military-trained rotary-wing aviators; therefore, a comparative study of fixed-wing to rotary-wing pilots should be completed to determine if occupational and operational demands influence gaze stability. A study should also be completed that evaluates gaze stability utilizing a commercially available set of dynamic vision tests in military aviators with prior history of concussion or blast exposure, who have otherwise fully recovered and exhibit no continual symptoms. Additionally, age is known to affect both DVA (Herdman et al., 1998) and GST (Honaker & Shepard, 2010). A study aimed at identifying the correlation and/or effect of age on head velocity and visual acuity among older pilots should also be completed.

The main objective of this study was to establish a reference normative data set for functional balance and the VOR utilizing a cohort of healthy military trained aviators. The results from this study will assist those medical service providers administering and/or interpreting any one of the previously mentioned tests, as the results from this study can serve as a comparison cohort either for patients who are military aviators. These results may also assist in determining individual function for either RTD or FFD evaluation for aviators and possibly other high-performing military populations.

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