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Democratizing Health Care in the Metaverse: How Video Games can Monitor Eye Conditions Using the Vision Performance Index

A Pilot Study

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Objective: In a world where digital media is deeply engrained into our everyday lives, there lies an opportunity to leverage interactions with technology for health and wellness. The Vision Performance Index (VPI) leverages natural human−technology interaction to evaluate visual function using visual, cognitive, and motor psychometric data over 5 domains: field of view, accuracy, multitracking, endurance, and detection. The purpose of this study was to describe a novel method of evaluating holistic visual function through video game-derived VPI score data in patients with specific ocular pathology.

Design: Prospective comparative analysis.

Participants: Patients with dry eye, glaucoma, cataract, diabetic retinopathy (DR), age-related macular degeneration, and healthy individuals.

Methods: The Vizzario Inc software development kit was integrated into 2 video game applications, Balloon Pop and Picture Perfect, which allowed for generation of VPI scores. Study participants were instructed to play rounds of each video game, from which a VPI score was compiled.

Main Outcome Measures: The primary outcome was VPI overall score in each comparison group. Vision Performance Index component, subcomponent scores, and psychophysical inputs were also compared.

Results: Vision Performance Index scores were generated from 93 patients with macular degeneration (n = 10), cataract (n = 10), DR (n = 15), dry eye (n = 15), glaucoma (n = 16), and no ocular disease (n = 27). The VPI overall score was not significantly different across comparison groups. The VPI subcomponent “reaction accuracy” score was significantly greater in DR patients (106 ± 13.2) versus controls (96.9 ± 11.5), $P = 0.0220$. The VPI subcomponent “color detection” score was significantly lower in patients with DR (96.8 ± 2.5; p=0.0217) and glaucoma (98.5 ± 6.3; $P = 0.0093$) compared with controls (101 ± 11). Psychophysical measures were statistically significantly different from controls: proportion correct (lower in DR, age-related macular degeneration), contrast errors (higher in cataract, DR), and saturation errors (higher in dry eye).

Conclusions: Vision Performance Index scores can be generated from interactions of an ocular disease population with video games. The VPI may offer utility in monitoring select ocular diseases through evaluation of subcomponent and psychophysical input scores; however, future larger-scale studies must evaluate the validity of this tool.

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We live in the metaverse: a fusion of our physical and virtual worlds. Smartphone users have doubled over the span of the last decade, reaching nearly 6.4 billion people worldwide.[1] We use technology for work (e.g., Microsoft Teams), health care (e.g., Apple Watch), entertainment (e.g., League of Legends), school (e.g., Khan Academy), and much more. Each of these examples of how we interact in the metaverse involves some form of human-machine interface (HMI).[2]

The popularization of digital media presents an opportunity to better understand the human body and the brain−machine relationship. Computers, telephones, and tablets display and record responses and can therefore be used to gather useful, personalized data. New Apple

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Watches and FitBit models can passively track heart rate, sleep, and movement.[3] The passive collection of physiologic data sets has paved the way for leveraging HMIs to identify conditions affecting our health and wellness through evaluation of ocular, cognitive, and physical performance.

The intersection of virtual reality (VR), augmented reality (AR), and the metaverse in the world of ophthalmology is becoming more nuanced.[4,5] We have already seen HMIs being leveraged for simulation training (e.g., VR ophthalmoscopy),[6] diagnostic testing (e.g., VR goggles to assess activity limitation in glaucoma),[7] and therapeutics (NGenuity "heads-up" surgery).[8] The use of modalities like VR, AR, and digital media for visual function testing makes sense when we think of the dynamic and integrative nature of our visual sense. These modalities demonstrate a potential step toward evaluating vision in a more holistic manner.

The eyes are embryonically extensions of the brain.[9] We use sight to perceive, analyze, and engage with our environments through the eye−brain−body (EBB) relationship. In clinical practice, visual function testing is the starting point for investigating and diagnosing ocular pathology and commonly begins with visual acuity assessment.[10] Unfortunately, coarse measures like visual acuity do not measure visual function applicable to how humans live their daily lives and often neglect the cognitive-behavioral component of the EBB axis. The Vision Performance Index (VPI) is a dynamic, holistic measure of visual function which addresses these limitations of conventional vision assessment.[11] The VPI evaluates the EBB axis by incorporating visual, cognitive, and motor metrics through user engagement with digital media.

Because > 3.24 billion people play video games,[12] we chose to incorporate the VPI into a regular gaming environment. The aim of this study was to describe a novel method of evaluating visual function in individuals with ocular pathology, using video games as the vector for generating VPI visual, cognitive, and motor metrics.

Methods

Study Design

In this prospective comparative analysis, study participants were enrolled by means of a convenience sample. Scheduled patients at the Prism Eye Institute in Oakville, Canada with a confirmed diagnosis of dry eye disease, cataract, glaucoma, diabetic retinopathy (DR), macular degeneration, and patients with healthy eyes were recruited between June 2017, and June 2019. This study adhered to the tenets of the Declaration of Helsinki, and Trillium Health Partners research ethics board approval (Protocol #20170524-1) was obtained. To be considered for inclusion, patients aged ≥ 18 years with dry eye disease, glaucoma, cataract, DR, and age-related macular degeneration, as well as healthy patients without any previous ocular diagnoses, were required to have provided written informed consent. Exclusion criteria were as follows: (1) patients with an ocular condition other than the specific diagnoses sought after; (2) patients with a combination of ocular conditions; and (3) inability to perform video game tasks on a tablet computer.

Software Utilized

The Vizzario software development kit (SDK), which allows for the construction of VPI scores, was integrated into 2 video game applications: Balloon Pop (Fig 1A) and Picture Perfect (Fig 1B). These applications were specifically designed by Five Agency, under the direction of Vizzario Inc. In Balloon Pop, balloons of varying speed, size, color, and transparency move upwards on the screen. The user was instructed to correctly click on target balloons (i.e., striped balloons) among distractor balloons (i.e., solid balloons). In Picture Perfect, 2 variations of the same image are displayed side-by-side on the computer screen. The user was instructed to identically match a distorted image to a target image by adjusting simple image properties including hue, saturation, brightness, and contrast.

Data Collection

Data were collected from patients at Prism Eye Institute, with chart-documented diagnoses of either glaucoma, DR, macular degeneration, cataract, or dry eye, as well as healthy patients (controls). Study researchers provided video game instructions to each participant. Patients were then assigned to complete 2 rounds of Balloon Pop and 2 rounds of Picture Perfect, in an alternating fashion. The first game performed (either Balloon Pop or Picture Perfect) was randomized for each patient. All video game trials were performed using a 2015 model ASUS ZenPad 8.0 tablet.

VPI

Like the intelligence quotient (IQ), the VPI has a normal distribution among users, with a mean of 100 and a standard deviation of 15 (Fig 2),[11] with higher scores corresponding to better performance. A VPI score is compiled from 5 component and subcomponent scores: field of view (central and peripheral), accuracy (reaction and targeting), multitracking (focused and divided), endurance (fatigue and recovery), and detection (color, contrast, and acuity) (Fig 3).[11] The VPI component scores are formulated using subcomponent scores, which themselves are generated from VPI psychophysical inputs related to the 2 video game applications. Each of these VPI components and subcomponents evaluates different parts of the EBB relationship to assess visual, cognitive, and motor function. In simple terms, *field of view* is related to the ability to see what is in front of you and your surroundings. *Accuracy* involves perception, intent, and action; this component evaluates one's ability to identify targets from distractors, make a cognitive decision based on these visual inputs, and then physically react to these stimuli. *Multitracking* relates to an individual's cognitive processing and actions when one's attention is focused on a target or divided among multiple stimuli. *Endurance* involves the ability to perform these visual, cognitive, and motor skills over a period of time, and *detection* involves the ability to detect stimuli of varying characteristics. The VPI psychophysical inputs in Balloon Pop included "proportion correct," which refers to the percentage of correctly popped balloons. In Picture Perfect, psychophysical measures include "hue" (°), "saturation," "brightness," and "contrast," matching errors between the target and user-manipulated image. "Saturation," "brightness," and "contrast" errors are reported as arbitrary units rather than standard units of measure, as the latter requires use of a single, calibrated display in a completely dark environment. The desire to make the VPI experience easy to implement in a variety of settings justifies these arbitrary units. Gaming was chosen as the vector to generate VPI scores due to the parallels of the stimulus−decision−response

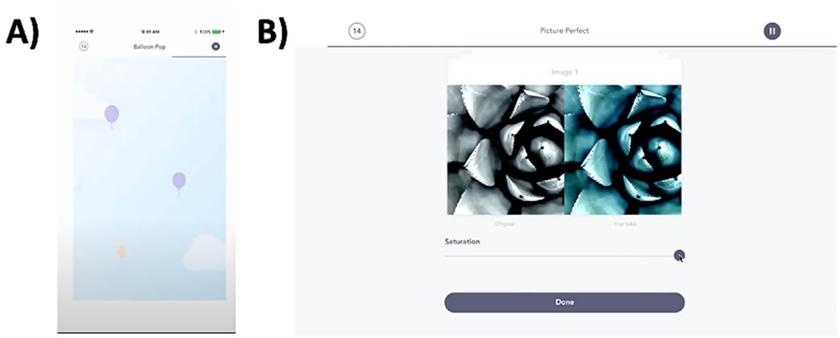

Figure 1. **A**, "Balloon Pop" and (**B**) "Picture Perfect" in-game user display. In Balloon Pop, the user attempts to click target balloons (those with stripes) and ignore distractor balloons (those without stripes). In Picture Perfect, the user attempts to adjust the saturation of the image on the right to match the "original" image on the left.

process native to game play and the perception—decision—action data capture native to the VPI.

Primary and Secondary Outcomes

The primary outcome of this study was the mean VPI overall score for control and specific ocular pathology groups (glaucoma, macular degeneration, DR, cataract, and dry eye). Secondary outcomes for this study were the mean VPI component and subcomponent scores as well as the VPI psychophysical measure values between pathology groups and the control group.

Statistical Analysis

Analysis of covariance and linear regression analyses were performed across primary and secondary outcomes, using participant age as the covariate to isolate and remove age effects, while looking for significant differences associated with diagnosed eye conditions. Pairwise analysis of covariances accounting for age effects were independently performed for each condition versus controls (healthy eyes). The Python statistical programming language (version 3.5.1; Python Software Foundation) was used to perform all statistical testing, with a *P* value of 0.05 used to indicate statistical significance.

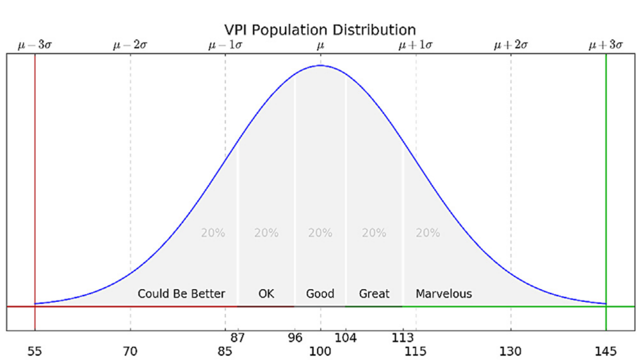

Figure 2. Distribution of Vision Performance Index (VPI) scores among a population. The VPI is modeled as a normal distribution with a mean of 100 and a standard deviation of 15. Shaded areas show regions with an equal area of 20%; scores < 87 (bottom 20%) are considered as abnormally low, while scores > 113 (top 20%) are considered as abnormally high. Figure obtained from Ahmed et al[11].

Results

A total of 93 patients met inclusion criteria and were included in analysis (Table 1). Mean age of study participants was 54.9 years (range, 20—87 years; Table 1) Of these participants, 10 had macular degeneration, 10 had cataract, 15 had DR, 15 had dry eye, 16 had glaucoma, and 27 were healthy (Table 2). A complete summary of mean VPI overall, component, and subcomponent scores as well as VPI psychophysical measure scores is found in Tables 2 and 3, respectively.

VPI Overall Score

Mean VPI overall scores for each comparison group, from highest (i.e., better) to lowest (i.e., worse), were: DR (102 ± 9.6), dry eye (101 ± 9.6), macular degeneration (101 ± 9.3), glaucoma (99.3 ± 9.8), healthy eyes (97.9 ± 11.7) and cataract (96.3 ± 9.8; Table 2). Mean VPI overall scores in each disease state were not statistically significantly different from healthy eyes.

VPI Component Scores

Mean VPI component scores in healthy eyes for *field of view*, *accuracy*, *multitracking*, *endurance*, and *detection* were not statistically significantly different in comparison to specific ocular pathology states (Table 2).

VPI Subcomponent Scores

The VPI subcomponent *reaction accuracy* score was statistically significantly greater in DR patients (106 ± 13.2) in comparison to controls (96.9 ± 11.5; $P = 0.0220$; Table 2). The VPI subcomponent *color detection* score was statistically significantly greater in healthy patients (101 ±

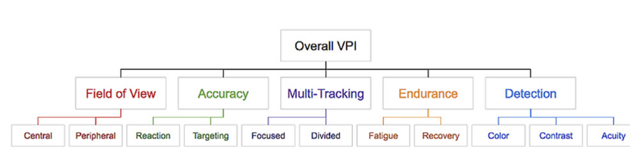

Figure 3. Vision Performance Index (VPI) components (second level) and subcomponents (third level). Figure obtained from Ahmed et al.[11]

Table 1. Demographics of Patients Included in Study Analysis (N = 93)

Characteristics	
Age (yrs), mean, (range)	54.9 (20–87)
Number of unique patients	93
Male, n, (percent)	43 (44.3)

11) in comparison to patients with DR (96.8 ± 2.5; $P = 0.0217$) or glaucoma (98.5 ± 6.3; $P = 0.0093$). All other VPI subcomponents scores were not statistically significantly different across ocular disease states compared with healthy eyes.

VPI Psychophysical Measures

"Proportion correct" among patients playing Balloon Pop was statistically significantly greater among those with healthy eyes (73.0 ± 7.03%) compared with individuals with DR (59.7 ± 13.3%; $P = 0.0033$) and macular degeneration (59.2 ± 11.5%; $P = 0.0433$; Table 3). Among individuals playing Picture Perfect, "contrast errors" were larger in individuals with cataract (0.226 ± 0.304; $P = 0.0399$) and DR (0.203 ± 0.124; $P < 0.0001$) compared with healthy patients (0.045 ± 0.036). "Saturation errors" were significantly greater in those with dry eyes (0.1300 ± 0.104; $P = 0.0357$) compared with the control group (0.0566 ± 0.0584). In healthy eyes, "brightness errors" (0.0652 ± 0.0574) and "hue errors" (12.1 ± 17.2°) were not statistically significantly different compared with specific ocular pathology states.

Discussion

To illustrate the practical applications of the VPI, this proof-of-concept, pilot study focused on a large-scale problem affecting > 2.2 billion individuals worldwide: visual impairment.[13] By embedding the Vizzario SDK into video game software, VPI data was passively captured as study participants played consecutive rounds of video games. Here, we exemplify how daily activities, like gaming, can be utilized to monitor conditions affecting visual, cognitive and motor performance (i.e., ocular disease).

VPI Overall, Component, and Subcomponent Measures

Clear trends in the VPI overall and component scores in the setting of specific ocular pathology were not seen. This was expected, as the VPI is an integration of numerous inputs. Unless one's *field of view*, *accuracy*, *multitracking*, *endurance*, and *detection* are all negatively impacted by the presence of an ocular condition, the VPI overall score will more-or-less be "average." Using the example of the IQ, which the VPI is modeled after, and autism spectrum disorder, we offer an explanation as to why global VPI was not statistically significantly affected in disease states. Decreased IQ score is not very strongly associated with autism spectrum disorder[14]; in fact, 42% of children in a

Table 2. VPI Overall, Component, and Subcomponent Scores across Comparison Groups.

Group	VPI Overall	Field of View			Accuracy			Multitracking			Endurance		Detection			
		Combined	*Central*	*Peripheral*	*Combined*	*Reaction*	*Targeting*	*Combined*	*Focused*	*Divided*	*Combined*	*Fatigue*	*Combined*	*Color*	*Contrast*	*Acuity*
Control (n = 27)	97.9 ± 11.7 -	102 ± 12.8 -	100 ± 14.9 -	101 ± 10.6 -	97.6 ± 11.6 -	96.9 ± 11.5 -	99.9 ± 13.7 -	100 ± 12.8 -	101 ± 13.1 -	100 ± 12.7 -	98.4 ± 18.7 -	98.1 ± 19.2 -	99.6 ± 6.88 -	101 ± 11.0 -	99.3 ± 8.75 -	100 ± 7.24 -
Cataract (n = 10)	96.3 ± 9.77 *P* = 0.7389	92 ± 9.12 *P* = 0.2624	97.8 ± 9.49 *P* = 0.3140	93.9 ± 8.87 *P* = 0.5880	99.4 ± 7.63 *P* = 0.5744	100 ± 9.94 *P* = 0.3866	99.9 ± 13.9 *P* = 0.8653	98.1 ± 11.4 *P* = 0.2678	94.5 ± 13.7 *P* = 0.9066	98.8 ± 5.28 *P* = 0.9675	97.2 ± 11.7 *P* = 0.3993	97.3 ± 11.4 *P* = 0.4113	100 ± 5.84 *P* = 0.3236	110 ± 9.23 *P* = 0.9590	98 ± 7.58 *P* = 0.5669	99.1 ± 9.15 *P* = 0.4344
Diabetic retinopathy (n = 15)	102 ± 9.6 *P* = 0.1677	93.9 ± 7.41 *P* = 0.1757	93 ± 12.3 *P* = 0.6435	95.5 ± 10.3 *P* = 0.4793	106 ± 12.3 *P* = 0.0555	106 ± 13.2 *P* = 0.0220	99 ± 16.2 *P* = 0.5902	98.6 ± 8.58 *P* = 0.3782	95 ± 10.2 *P* = 0.5280	92.3 ± 15.4 *P* = 0.2602	101 ± 15.2 *P* = 0.8802	101 ± 15.1 *P* = 0.9101	98.3 ± 4.9 *P* = 0.9746	97.3 ± 9.65 *P* = 0.0217	104 ± 7.9 *P* = 0.2381	102 ± 11.5 *P* = 0.5703
Dry eye (n = 15)	101 ± 9.57 *P* = 0.4763	105 ± 11.4 *P* = 0.6942	108 ± 10.2 *P* = 0.1640	104 ± 13.1 *P* = 0.4650	100 ± 10.5 *P* = 0.5069	100 ± 9.76 *P* = 0.4037	101 ± 11.6 *P* = 0.7832	103 ± 12 *P* = 0.4269	106 ± 14.8 *P* = 0.5092	106 ± 10.9 *P* = 0.2428	94.5 ± 12.4 *P* = 0.5468	94.6 ± 12.6 *P* = 0.6116	104 ± 5.42 *P* = 0.0559	96.2 ± 7.51 *P* = 0.3494	99.8 ± 5.81 *P* = 0.8167	101 ± 8.42 *P* = 0.7887
Glaucoma (n = 16)	99.3 ± 9.75 *P* = 0.2397	99.7 ± 13.9 *P* = 0.7482	101±9.97 *P* = 0.1120	98.1 ± 14.6 *P* = 0.6312	95.1 ± 8.58 *P* = 0.7456	97.8 ± 9.96 *P* = 0.5626	101 ± 12 *P* = 0.7463	96.3 ± 14.7 *P* = 0.3751	99.1 ± 15.1 *P* = 0.3588	99.9 ± 10.3 *P* = 0.6498	106 ± 12.4 *P* = 0.4005	106 ± 12.5 *P* = 0.3987	98.4 ± 10.2 *P* = 0.9819	98.5 ± 6.26 *P* = 0.0093	101 ± 4.71 *P* = 0.7780	97.2 ± 10.3 *P* = 0.2348
Macular degeneration (n = 10)	101 ± 9.27 *P* = 0.1767	94.7 ± 13.6 *P* = 0.5956	92.5 ± 11 *P* = 0.7714	96 ± 11.2 *P* = 0.9547	99.7 ± 7.44 *P* = 0.5633	99.2 ± 9.06 *P* = 0.4371	96.3 ± 6.84 *P* = 0.2897	99.9 ± 12.3 *P* = 0.4820	92.6 ± 6.52 *P* = 0.7619	94.9 ± 9.1 *P* = 0.5902	101 ± 10.6 *P* = 0.6768	101 ± 10.8 *P* = 0.6740	103 ± 7.55 *P* = 0.0848	106 ± 10.3 *P* = 0.5269	106 ± 11.4 *P* = 0.1705	102 ± 8.26 *P* = 0.8165

VPI = Vision Performance Index.
Data are listed as mean VPI score ± standard deviation.
P-values are the pairwise analysis of covariance tests comparing each ocular condition to the control group and are listed below mean VPI values.

Table 3. VPI Psychophysical Measure Scores across Comparison Groups.

Group	Balloon Pop	Picture Perfect			
	Proportion Correct (%)	*Hue Errors (°)*	*Saturation Errors*	*Brightness Errors*	*Contrast Errors*
Control (n = 27)	73.0 ± 7.03 -	12.1 ± 17.2 -	0.0566 ± 0.0584 -	0.0652 ± 0.0574 -	0.0449 ± 0.036 -
Cataract (n = 10)	66.7 ± 8.25 *P* = 0.7356	8.59 ± 7.31 *P* = 0.1238	0.0819 ± 0.0923 *P* = 0.0861	0.0694 ± 0.0393 *P* = 0.1894	0.226 ± 0.304 *P* = 0.0399
Diabetic retinopathy (n = 15)	59.7 ±13.3 *P* = 0.0033	44.7 ± 48 *P* = 0.1459	0.0741 ± 0.0599 *P* = 0.2590	0.0674 ± 0.0541 *P* = 0.1685	0.203 ± 0.124 *P* < 0.0001
Dry eye (n = 15)	74.9 ± 4.96 *P* = 0.9999	5.84 ± 5.31 *P* = 0.5718	0.1300 ± 0.104 *P* = 0.0357	0.0561 ± 0.0478 *P* = 0.6261	0.0534 ± 0.0456 *P* = 0.7041
Glaucoma (n = 16)	68.6 ± 7.43 *P* = 0.6065	11.7 ± 20.8 *P* = 0.3794	0.0651 ± 0.0522 *P* = 0.2713	0.0788 ± 0.0893 *P* = 0.3496	0.0662 ± 0.0898 *P* = 0.9999
Macular degeneration (n = 10)	59.2 ± 11.5 *P* = 0.0433	17.3 ± 20.8 *P* = 0.2632	0.0948 ± 0.0665 *P* = 0.1717	0.0948 ± 0.0777 *P* = 0.3606	0.0813 ± 0.0399 *P* = 0.2680

VPI = Vision Performance Index.
Data are listed as mean ± standard deviation.
P values are listed below each mean ± standard deviation value and are the pairwise analysis of covariance tests comparing each ocular condition to the control group.

study conducted by the Centers for Disease Control and Prevention had an "average" or "higher-than-average" range.[15] One must evaluate specific components which formulate the global IQ score to find more meaningful trends. For example, verbal IQ is more statistically significantly decreased compared with nonverbal IQ in autism spectrum disorder,[16] whereas spatial reasoning may be seen as an autistic strength.[17] The "global" score of normalized indexes, like IQ and the VPI, are often average; *all* components which formulate the global score are usually not negatively or positively affected. One must evaluate specific components, subcomponents, and more granular metrics to derive more meaningful trends. Similarly, we expected more meaningful trends to be seen in the VPI component, subcomponent, and psychophysical measure scores.

Visual Performance Index subcomponent *reaction accuracy* ($P = 0.0220$) and *color detection* ($P = 0.0217$) scores were statistically significantly higher and lower, respectively, in DR patients compared with controls. Although the effect of chance and type 1 error cannot be ruled out (see Study Limitations), decreased color vision is a well-known finding in patients with DR.[18–20] Patients with glaucoma performed poorer than controls with respect to the VPI subcomponent *color detection* score ($P = 0.0093$); this is consistent with the known effects of glaucomatous disease, causing decreased color discrimination in its early stage.[21,22] Glaucoma also results in peripheral visual field loss as the disease becomes more severe. Although the VPI subcomponent *peripheral field of view* score was not negatively affected in these patients, this may be explained by the majority early-stage glaucoma patients in our study sample.

VPI Psychophysical Measures

The most heavily impacted metrics obtained from the Vizzario SDK were found at the most granular level of the VPI: the psychophysical measures. Psychophysical measures, such as "proportion correct," "reaction time," and "matching errors," evaluate one's visual, cognitive, and motor responses. These inputs contribute to a combination of different VPI components and subcomponents.

The basic objective of Balloon Pop was to pop target balloons from distractor balloons. In this video game, the VPI psychophysical measure "proportion correct" referred to the percentage of correctly popped balloons and ultimately reflected one's performance in the game. "Proportion correct" contributes to all VPI components (field of view, accuracy, multitracking, endurance, and detection). For example, the VPI component *field of view* score evaluates a user's "proportion correct" when stimuli are located centrally or in the periphery. Similarly, the VPI component *multitracking* score incorporates a user's "proportion correct" based on the varying number of stimuli on the screen. "Proportion correct" was statistically significantly lower among patients with DR (59.7 ± 13.3%; $P = 0.0033$) and macular degeneration (59.2 ± 11.5%; $P = 0.0433$) compared with healthy eyes (73.0 ± 7.03%). Extrapolating these results into a practical example, individuals with these conditions may have difficulty identifying a friend among a crowd of people.

In the video game Picture Perfect, the basic objective was to match an altered image to a target image. The VPI psychophysical measures which experienced the greatest change in the presence of ocular pathology were "contrast errors" and "saturation errors." These VPI psychophysical measures contribute to the VPI component "detection" score. For example, "contrast errors" (0.226 ± 0.304) were statistically significantly increased in cataract patients compared with healthy eyes (0.045 ± 0.036), $P = 0.0399$. This phenomenon was expected, as reduced contrast sensitivity is a common complaint among those with cataracts.[23,24] The VPI results suggest that those with cataracts may have difficulties with tasks requiring contrast detection, such as avoiding obstacles while walking around one's house at night. "Saturation errors" were statistically significantly increased only in patients with dry eye (0.130 ± 0.104; $P = 0.0357$). A photographer complaining of decreased vibrance of colors while capturing a sunset may similarly have increased saturation errors and may in fact have dry eye. Trends in VPI subcomponent and psychophysical measures across ocular diseases may allow for correlation of symptoms to objective data and help us better understand the context of a patient's health complaints.

A Holistic Way to Measure Visual Function

Visual function, in its holistic sense, involves perceiving, decision making, and action. Humans use visual stimuli to inform our mental and physical actions within our environments through the EBB connection. Take the example of a driver, who is moving into an adjacent car lane on the highway. The driver sees another car in their peripheral field of view and moves their head and eyes to confirm another vehicle in their blind spot. Consequently, they make the decision (i.e., cognitive domain) to resteer (i.e., motor domain) their wheel to move back into their original road lane while ensuring that a different car has not moved into their original lane. Conventional clinical parameters like visual acuity and visual field testing do not truly convey much insight into practical, functional vision. For example, glaucoma negatively impacts hand−eye coordination and may be associated with delayed hazard response time.[25−27] Patients with glaucoma may also demonstrate decreased contrast sensitivity on conventional clinical testing.[28,29] Glaucomatous disease clearly affects the cognitive and motor domains of the EBB as well. The negative impact of ocular disease affecting all components of the EBB relationship, illustrated through everyday activities like driving, walking, reading, and more, are also well documented.[30−34] We should be utilizing diagnostic modalities that give us practical insights of one's functional vision, rather than siloed results of the processes that may be affected by ocular conditions.

Therein lies in the utility of the VPI. Using the example of a driver with severe glaucoma changing car lanes, multiple VPI components, subcomponents, and psychophysical measures may be affected. Perhaps the driver reacts too slowly and nearly hits the car in their periphery? Response time and hand−eye coordination are poorer in glaucomatous disease,[25−27] possibly relating to decreased VPI inputs into the component scores for detection, accuracy, and field of view. Perhaps the driver cannot track multiple cars in front or behind of them as they are making the decision to turn back into their lane? The VPI component score for multitracking could possibly be decreased in this driver. Statistically significant differences in these VPI component, subcomponent scores were not seen in this study; however, this was certainly limited by type 2 error. Validity of these metrics was not the primary objective of this study, but the authors appreciate the necessity for evaluating this in the future.

The opportunity to identify how these visual, cognitive, and motor metrics differ in the presence of health conditions before visual symptoms or structural changes may allow for therapeutic intervention further upstream in a disease state. Conversely, if structural abnormalities exist, correlating the degree of disease with areas of visual dysfunction or compensatory states may allow for the development of therapeutics to address the areas of dysfunctions. Future investigations, correlating VPI scores and their inputs to structural anatomic testing (e.g., optical coherence technology) and clinical examination findings, are warranted to further explore this possibility.

Beyond the scope of ocular pathology, the VPI may theoretically offer screening or diagnostic utility for other health conditions. Neurocognitive disorders like Alzheimer's disease are characterized by distinct cognitive and behavioral changes, marked by impairment in executive functions involving attention, multitasking, and planning.[35,36] Psychiatric diagnoses such as major depressive disorder often result in decreased concentration, fatigue, and psychomotor slowing.[37] These often-subtle manifestations of disease can conceivably be evaluated through the VPI's visual, cognitive/behavioral, and motor metrics. It is not beyond the realm of possibility to screen for a myriad of different medical conditions every time an individual uses their mobile device, plays a video game, or watches a movie in VR. Future evaluation of the VPI's utility across a wider array of health conditions is an area of future interest.

Democratizing Healthcase in the Metaverse

The novel coronavirus disease 2019 pandemic has revolutionized the way we practice medicine, prompting a shift toward innovative virtual care modalities to continue servicing patients. Leveraging consumer technology for health and wellness is not a foreign idea.[5] New-generation Apple Watches infer contextual interpretations of health and wellness through correlation of heart rate variability with the wearer's daily actions.[38] For example, an elevated heart rate has a much different meaning if the user is sitting on a couch versus running. Similarly, the field of ophthalmology could benefit from the functionalities offered by the metaverse, AR, and VR. Virtual reality/AR assistive devices are making their way into the delivery of standard ophthalmic tests including visual field, contrast sensitivity testing, and more.[39−42] Furthermore, this technology has been shown to permit for comprehensive and more functional assessments of vision and visual impairment. The use of VR goggles to assess activity limitation in glaucoma patients has shown promise.[7,43] Lam et al[43] exposed patients with glaucoma to VR simulations of natural environments (e.g., navigating a city center during daytime and night) and found that vision-related disability among glaucoma patients was associated with task and lighting conditions. These findings demonstrated the benefit of augmenting classical assessments of vision to better understand how visual impairment affects daily function.

Similarly, holistic and practical comprehensive assessment of visual function is the intent of the VPI. The Vizzario SDK collects and analyzes data through HMIs to generate meaningful interpretations of individuals' behaviors (i.e., VPI scores), thereby democratizing EBB wellness through software. The appeal of the VPI and the delivery of other metaverse-based diagnostic testing is in that modalities meet users in the context of their everyday life. One can simply play a video game, type at their computer, or scroll on their telephone (i.e., an activity a user may already be doing). With the emergence of the metaverse, VR and AR are becoming mainstream. These types of technologies permit more multimodal inputs, including proprioceptive movements, limb acceleration, eye movements, and more, to be collected and analyzed using the SDK. From these inputs, a more comprehensive VPI score can be generated for more robust evaluations of human performance.

The VPI also presents an opportunity for more accessible, large-scale monitoring of disease, as demonstrated through the example of ocular pathology. In this study, with the Vizzario SDK integrated in a video game software, we demonstrate that a VPI score can be passively generated from virtually any HMI. With this accessibility, a patient can be prescribed to play Fortnite (Epic Games), a video game played by > 350 million individuals worldwide,[44] to potentially monitor ocular disease. The Kardia Mobile and Apple Watch allow patients to electronically send electrocardiogram readings taken from the device to their cardiologist if there are irregularities.[45,46] Similarly, if abnormal psychophysical measures or subcomponent scores are generated through rounds of Fortnite, one's physician can be automatically notified and consider further workup.

The involvement of digital media in our lives is well underway, and its transformation into health care and ophthalmology are no exceptions. There is an opportunity to leverage the metaverse to revolutionize medical care by means of providing more comprehensive and efficient testing, while increasing accessibility of services to ultimately improve the health of patients. The VPI may represent one such opportunity.

Study Limitations

The small sample size of patients limits the strength of conclusions that we can draw from the data. The authors also recognize that varying severity of respective ocular disease likely impacted VPI outcomes. The aim of this pilot study was to introduce the VPI and demonstrate its ability to evaluate vision performance metrics across ocular diseases states as a proof-of-concept. We are not able to conclude, with the support of rigorous statistical analyses, that specific VPI metrics are associated with certain ocular conditions. However, this was not the intended objective of this study. Limitations in statistical conclusions were due to the small sample size (N = 93), wide age range, and lack of control of basic stimulus characteristics including size, luminance, contrast, spatial frequency, and color (which were not recorded in absolute terms).

Study authors considered conducting a controlled experiment with simplistic stimuli exploring 1 narrowly defined measure at a time. However, this was not done as the controlled elements required for this to take place would have contradicted the intended use of the VPI. The VPI permits for broader and more abundant data collection and evaluation in a natural manner; it bypasses the medical clinic to bring clinical sciences to the masses. By conducting highly controlled experiments with simplistic stimuli, 1 measure at a time, we would have negated the translatability of our findings with respect to the target audience and scenarios where the VPI would be used. The authors accept the limitations of varying results and test-retest variability given the lack of standardization in basic stimulus testing parameters. The more appropriate conclusion we can derive from the results of this study is that the VPI may possibly demonstrate utility in performing out-of-clinic screening for and monitoring of specific eye diseases, which may prompt referral for formal testing of individual simplistic stimuli and ocular examination if needed.

Furthermore, the lack of statistically significant findings across ocular disease states among VPI components and subcomponents was likely heavily impacted by type 2 error. Conversely, many statistically significant findings in our study were undoubtedly driven by type 1 error and random chance; this is expected when there are many statistical comparisons made across different groups. The authors also recognize that varying severity of respective ocular disease likely impacted VPI outcomes. We appreciate the need to evaluate the validity and reliability of VPI metrics; this will be a primary goal of future studies. We plan to significantly expand the sample size and stratify outcomes by disease severity in future, larger-scale studies.

Lastly, performance-based psychophysical measures may have been influenced by game-taking strategy. For example, a user may have sacrificed proportion correct or matching accuracy to achieve a faster response time/rate. Researchers attempted to prevent this by clearly instructing patients to place priority in accurately popping balloons or matching pictures, not necessarily completing the tasks as fast as possible. The absence of a reward for better game performance aimed to further mitigate this phenomenon.

With over half of the world's population digitally connected through social media, gaming, and other aspects of the metaverse, there is an opportunity to improve access to health care for billions of individuals. There is potential in the idea of using everyday interactions with computer, mobile, and other digital applications to evaluate the sensory systems, such as vision, in those with ocular disease. The VPI may provide an opportunity for more holistic and contextual screening evaluations of one's overall health and wellness in the metaverse. Future, larger-scale studies evaluating the validity and reliability of VPI metrics across different disease states are necessary to determine the true utility of this tool. Studies confirming the validity and reliability of the VPI will allow us to evaluate its potential role as a performance biomarker for health span, including augmentation and rehabilitation, which will be useful across the spectrum of high-performance athletes, patients undergoing treatment, or individuals focused on healthy aging. Tracking the effect of therapeutic interventions and performance enhancing exercises on VPI metrics are of future interest.

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Disclosures:

All authors have completed and submitted the ICMJE disclosures form.

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I.K.A.: Consultant − Aequus, Aerie Pharmaceuticals, Akorn, Alcon, Allergan, Aquea Health, Inc, ArcScan, Avisi, Bausch Health, Beaver Visitec, Beyeonics, Bionode, Carl Zeiss Meditec, Centricity Vision, Inc, CorNeat Vision, Custom Surgical, Elios Vision, ElutiMed, Equinox, eyeFlow, Inc, Genentech, Glaukos, Gore, Heine, Heru, Iantrek, InjectSense, Iridex, Care, iStar, Ivantis, Johnson & Johnson Vision, Labtician Thea, LayerBio, Leica Microsystems, Life Long Vision, Long Bridge Medical, Inc, MicroOptx, MST Surgical, Myra Vision, New World Medical, Ocular Instruments, Ocular Therapeutix, Oculo, Omega Ophthalmics, PolyActiva, PulseMedica, Radiance Therapeutics, Inc, Ripple Therapeutics, Sanoculis, Santen, R; Shifamed, LLC, Sight Sciences, Smartlens, Inc, Stroma, Thea Pharma, ViaLase, Vizzario, Visus Therapeutics, VSY Biotechnology; Speaker honoraria − Alcon, Allergan, Meditec, Heine, Johnson & Johnson Vision, MST Surgical; Grants − Allergan, Glaukos, Care, Ivantis, Johnson & Johnson Vision, New World Medical

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Abbreviations and acronyms:
AR = augmented reality; **DR** = diabetic retinopathy; **EBB** = eye−brain−body; **HMI** = human-machine interface; **IQ** = intelligence quotient; **SDK** = software development kit; **VR** = virtual reality; **VPI** = Vision Performance Index.

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