Establishing Normative Standards of Binocular Visual Function in Taiwanese Young Adults

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Abstract

Purpose: Traditional normative values of binocular vision, known as Morgan's & Scheiman's and Optometry Extension Program(OEP) expected findings, have been used since long in clinical optometry. However, with technological advances, visual habits and visual demands have changed. Therefore, clinical assessment could examine the applicability of the established criteria in Taiwan.

Methods: Participants aged 15–24 years were recruited from three universities and colleges. After completing the Visual Behavioral Performance questionnaire with four components: near work, visual perception, visual comfort and balance of body, participants were separated into symptomatic or asymptomatic groups based on the results of the questionnaire survey. A 24-step binocular visual examination was undertaken. Data were analyzed with the one-sample *t*-test and an ROC curve to compare and establish normative values for Taiwanese young adults.

Results: Among the 308 healthy Taiwanese young adults, the prevalence of accommodation or vergence anomalies was 15% (46 participants). The commonest dysfunctions in this study were accommodative excess and convergence excess. Most of the binocular visual functions in this study showed significant difference from the traditional normative values: amplitude of accommodation, base-in prism to break and recovery points at distance were better than the traditional normative values, whereas others were worse. In addition, different visual tasks require different binocular visual functions, and the ROC curve was used to analyze the normative values of binocular visual functions required for near work, visual perception, visual comfort, and body balance.

Conclusion and Discussion: The mean values of binocular visual function in Taiwanese young adults were worse than that in the traditional normative values. With changing times, racial differences, and more tasks for visual needs, it is essential to establish binocular visual normative values for Taiwanese young adults.

1. Introduction

Humans, compared with other mammals, derive advantages from binocular vision, under the conditions of perfect eyeball structure, large visual field overlap, and potential action of retinal cells, which when combined with a comprehensive analysis by the brain, not only enables human beings to have better image resolution, but also the ability to perceive three-dimensional visuospatial, stereopsis, and depth perception to further improve fine motor coordination and manipulation abilities [1]. Furthermore, good binocular vision enables visual function-based activities, such as reading, concentration, coordination, balance, and more efficient work [2, 3]. Despite normal visual acuity, many people often have symptoms, such as blurred vision, headache, eye strain or discomfort, intermittent diplopia, inattention, eye rubbing, excessive blinking, photophobia, and so on [4–9]. Binocular visual dysfunction with insufficient accommodation can lead to symptoms when reading, such as reading with finger assistant, skipping or missing, letter reversal, or lack of interest in near vision. Moreover, problems with binocular vision may lead to other related physiological or perceptual problems, including issues in peripheral perception [10], athletic ability [11], visuospatial or sense of direction [12].

Morgan, Shilman standard value and OEP expected value [1, 13–14], which are frequently cited in clinical binocular vision examinations in optometry, have been well-established for a long time. Over time, with the development of science and technology, habits and demands for the use of the eyes have changed. In addition, due to ethnic differences, the suitability of these standard values need evaluation [15–21]. Age is an important factor that affects binocular vision. The effects of aging on the functioning of the visual system, include contrast sensitivity [22], visual acuity[23], accommodation [24], and vergence [27–29]. Furthermore, aging will reduce the amplitude and time of vergence peak velocity [25] and phoria adaptation [26], which is often detected in patients with binocular dysfunction, especially convergence insufficiency [30–33].

Besides age, other variables associated with visual function include brain injury [34], dry eye [35, 36], migraine [37], sleep disturbance [38, 39], dyslexia [40], inattention [41, 42], work in high-tech industry[43], athletic activity [44], and these should also be valued. Moreover, with the emergence of virtual reality technology in recent years, the motion sickness problem, a concern that is valued by the industry and yet unsolved, has been proved to be related to binocular vision problems to some extent [45].

However, the Morgan, Scheiman, and OEP binocular vision standard value [13, 46], which is routinely quoted by optometrists in Taiwan, does not have proven applicability in this ethnic population [15]. Several studies [4–6, 47, 48] found that the prevalence of phoria and accommodation dysfunction ranges from 0.1–33% and 1.2–61.7%, respectively [16, 49], in different countries or among races. Therefore, the application of the traditional standards for clinical diagnosis in Taiwan could be problematic. This study was conducted to comparatively investigate differences in the binocular vision value of young adults in Taiwan and the traditional standard value, and to further analyze items of binocular vision assessment to determine accurate standard requirements for different visual tasks.

2. Materials And Methods

A research survey was conducted from 18 November 2019 to 30 May 2020. The study protocol was reviewed and approved by the institutional review board of Chung Shan Medical University Hospital (approval no. CS19110), and the study strictly adhered to the principles of research ethics specified in the Declaration of Helsinki and its later amendments. In addition, this manuscript was reported under the STROBE guideline[50]. To ensure accurate measurement results, possible confounding factors, such as laboratory brightness, visual target distance, and subjective differences in measurement tools and equipment operators, were controlled. In addition, to avoid any potential sources of bias, each test was performed by the same optometrist.

2.1 Participants

A total of 327 young individuals, aged 15 to 24 years, were enrolled in this study after excluding patients who had undergone eye or brain surgery or had ophthalmic, metabolic or immune, physiological, or psychological diseases. After receiving information about the research objectives and procedures, 327 individuals consented to participate in the questionnaire survey and undergo binocular visual function examination. Among the participants, 10 had incomplete questionnaire and eye examination, 5 had best corrected visual acuity less than 1.0, 1 had Meniere's disease, 1 had Tourette's disease, 1 had amblyopia, and 1 had strabismus. Therefore, the results were analyzed with 308 subjects.

2.2 Research Materials

The assessment procedures used in this study were noninvasive, non-risk-conferring, and involved no drug administration. Accordingly, the research tools and examination items are divided into two parts: the questionnaire and binocular visual function test. The research questionnaire of visual behavior performance (CSMU-VBP) was organized based on CISS [51], COVD-QoL[52], and the students' visual status questionnaire [53], which have been widely used in optometric clinics, and subsequently compiled in accordance with the relevant research literature. The CSMU-VBP has 48 questions, factor analysis divided the questionnaire into four dimensions(each question may be calculated repeatedly): including 25 questions pertaining to near-vision work (Cronbach's alpha = 0.837), 20 on perception (Cronbach's alpha = 0.780), 14 on comfort (Cronbach's alpha = 0.705), and 12 on postural balance (Cronbach's alpha = 0.775); the reliability of the overall scale was 0.851 [54].

The binocular visual function examination included refraction (ShiNiPon Openfield Refraction, Japan), habitual Rx, distance (Digital Chart System VM-VLC-1900) and near visual acuity (TMVC Near Point Test Card), subjective refraction (Topcon Manual Phoropter VT-10), Von Graefe and Maddox Rod phoria, distance-associated phoria, fused cross cylinder (FCC), vergence range, accommodation amplitude(AA), near-point convergence/accommodation (NPC, NPA, and RAF Binocular Gauge), monocular and binocular accommodation facility(MAF, BAF), convergence facility, near-fixation disparity (The Saladin near point balance card), negative relative accommodation (NRA), and positive relative accommodation (PRA).

2.3 Data Analysis and Statistical Analysis

A one-sample *t*-test and Receiver operating characteristic curve(ROC curve) were performed and data were analyzed using SPSS 26.0 (Chicago, IL, USA); a *p*-value < 0.05 was considered statistically significant.

3. Results

According to the inclusion criteria, a total of 308 (83 male and 225 female) participants (average age 18.7 ± 1.7 years) provided valid samples for analysis in this study. The equivalent spherical degrees of the right and left eye, respectively, were − 3.44 ± 2.76D and − 3.44 ± 2.85D among males and − 3.47 ± 2.51D and − 3.25 ± 2.59D among females. On statistical analysis, there was no significant difference between male and female participants or between the left and right eyes.

3.1 Binocular Visual Function in Taiwanese Young Adults

We enrolled 308 healthy young participants aged 15 to 24 years. According to Scheiman & Wick's[14] criteria, the proportion of normal binocular vision in this study was ascertained as 85% (n = 262), and the frequency of abnormal accommodation and convergence was 15% (n = 46). Among all of the participants, 20 participants only had abnormal accommodation (6.5%), of which excessive accommodation was the commonest (n = 13, 4.2%); 23 participants only had abnormal vergence (7.5%), and the excessive convergence was the commonest (n = 12, 3.9%); 3 participants simultaneously had abnormal accommodation and vergence problems (1%; Table 1 and Fig. 1).

In addition, according to the results of the CSMU-VBP, subjects were divided into the "asymptomatic" (total score < 12) and “symptomatic” (total score ≥ 12) groups by using the lower 25% of the quartile as the cutoff criterion. Among the 308 participants, 43 (14%) were classified as symptomatic, and the remaining 265 (86%) were asymptomatic. Among the 46 participants with abnormal binocular visual function, nearly 78% (36 participants) reported that they had no obvious symptoms (Table 1), 7 had exophoria or esophoria, and 3 had abnormal accommodation and vergence; 50% of the participants with impaired accommodative facility or convergence-insufficient cohesion had symptoms. In particular, among the 262 participants with normal binocular visual function that was classified by the traditional diagnostic criteria, 33 (12.6%) complained of visual problems, and only 10 (21.7%) of the 46 participants with abnormal visual function complained of visual distress, indicating that the patients who reported that they had visual behavior distress may not have binocular visual problems (Fig. 1). Due to the fact that different visual work required different binocular visual functions; the clinical characteristics and diagnostic criteria of Scheiman & Wick's binocular visual dysfunction can be further consideration.

Table 1
Frequency of accommodation and vergence anomalies in Taiwanese young adults

	Frequency	Percentage	Asymptomatic		Symptomatic	
Normal	262	85%	15	75%	5	25%
Accommodative dysfunction (AD)	20	6.5%	11	84.6%	2	15.4%
Accommodative excess (AE)	13	4.2%	3	75%	1	25%
Accommodative insufficiency (AI)	4	1.3%	0	0%	2	100%
Accommodative infacility	2	0.6%	1	100%	0	0%
Accommodative excess (AE) and accommodative infacility	1	0.3%	18	78%	5	22%
Vergence dysfunction(VD)	23	7.5%	9	75%	3	25%
Convergence excess(CE)	12	3.9%	2	50%	2	50%
Convergence insufficiency(CI)	4	1.3%	3	100%	0	0%
Basic exophoria	3	1.0%	4	100%	0	0%
Basic esophoria	4	1.3%	3	100%	0	0%
AD + VD	3	1.0%	1	100%	0	0%
Accommodative insufficiency and convergence insufficiency (AI + CI)	1	0.3%	1	100%	0	0%
Accommodative insufficiency (AI) and basic esophoria	1	0.3%	1	100%	0	0%
Accommodative excess (AE) and accommodative infacility and basic esophoria	1	0.3%	229	87.4%	33	12.6%
Total			265	86%	43	14%

3.2 Comparison of Binocular Visual Function Values of Morgan, Scheiman, OEP and those Derived in This Study

Using the standard value of binocular visual function, data were compared to ascertain the difference between the binocular visual function of all participants against the traditional standard value. The results showed that distance phoria; near phoria; gradient AC/A plus and minus; DBI break and recovery; DBO blur, break, and recovery; NBI blur, break, and recovery; NPC, MAF, BAF, NRA, PRA, and accommodative amplitude(AA), all showed statistically significant differences. In particular, DBI break, recovery, and accommodative amplitude performed better than the Morgan and Scheiman standard in this study, and the remainder of the assessed criteria were worse than the standard values. In addition, compared with the expected value of OEP, except for DBO blur, there were statistically significant differences in distance phoria, near phoria, DBI break and recovery, DBO break and recovery, NBI blur, break, and recovery as well as NRA and PRA. Among the inspected items with significant differences, except DBI break, which showed better performance than the expected value of OEP, the value of the rest of the items were worse than the expected value (Table 2).

3.3 Interaction Among Visual Function, Visual Perception and Cognitive Function

In this study, the four dimensions of the Visual Behavior Performance, including (1) near work, (2) perception, (3) comfort, and (4) physical balance, were scored by quartiles; the first quartile, also known as the lower quartile, is equal to the 25th percentile of the data and these were analyzed to identify the presence or absence of symptoms. According to the different dimensions, participants were divided into two groups: "asymptomatic " and "symptomatic". Next, the results of the binocular visual function test were analyzed by using the ROC curve to identify the binocular vision appraisal items and standards for different visual tasks.

In the ROC curve analysis of the total scale, the base-out recovery (AUC = 0.619, p = 0.018) and binocular accommodative facilities (AUC = 0.588, p = 0. 605) could significantly identify visual behavior performance of the participants. The cutoff value of the base-out recovery was 5.5 prism diopter (PD; sensitivity = 0.605, specificity = 0.606; Morgen & Sheiman and OEP standard are both 10 PD; the cutoff point value of binocular accommodative facility is 10.25 cpm (sensitivity = 0.588, specificity = 0.605; Scheiman standard = 10 cpm).

3.3.1 Near work

In the ROC curve analysis of the near-work dimension, the cutoff point of DBO blur (AUC = 0.598, p = 0.028) was 7 degrees (sensitivity = 0.74, specificity = 0.471; Morgen & Sheiman standard = 9). The cutoff point of the DBO recovery (AUC = 0.591, p = 0.052) was 5.5 degrees (sensitivity = 0.543, specific = 0.601; Morgen & Sheiman standard = 10 PD). Poor ability to revert to fusion is more likely to cause complaints about near work. This is very similar to the criterion of pure exophoria (5 degrees) in the clinical features of Sheiman binocular visual dysfunction diagnostic criteria. Therefore, these two functions should have considerable discriminative power when used to predict the conscious performance of the near-work dimension (Table 3).

3.3.2 Perceptual

In the ROC curve analysis of the perceptual dimension(Table 4), the cutoff point of MAF (AUC = 0.583, p = 0.088) was 10.5 cpm (sensitivity = 0.756, specificity = 0.419; Sheiman criterion = 11 cpm); for BAF (AUC = 0.621, p = 0.012), with a cutoff point of 10.25 cpm (sensitivity = 0.70, specificity = 0.481; Scheiman standard = 10 cpm), individuals with good performance of monocular and binocular accommodation facilities can switch between binocular distance and near vision, the smoothness and comfort are better and, the vision is more stable and not too strained, such that those affected can focus more on cognition and learning [79, 80]. In contrast, individuals with poor binocular accommodation facilities found it very difficult and experienced unstable vision when look objects at various distance, and the mental effort needed to adjust the vision was excessive; thus, they found it difficult to focus attention on main working; moreover, they experienced much difficulty not only in three-dimensional perception [81], but also in visual recognition and comprehension [82]. The cutoff point (10.25 cpm) analyzed in this study is close to the traditional standard value (10 cpm); therefore, MAF and BAF functions were used to predict the perception dimension, and the conscious performance should have facilitated considerable discrimination.

3.3.3 Comfort

In the ROC curve analysis of comfort(Table 4), the cutoff point of DLP (AUC = 0.567, p = 0.050) was 2.25 PD of exophoria (sensitivity = 0.459, specificity = 0.673; Morgen & Sheiman criterion = 1 PD of exophoria; OEP standard = 0.5 PD of exophoria); the cutoff point for DBI break (AUC = 0.574, p = 0.031) was 11.5 PD (sensitivity = 0.593, specificity = 0.563; Morgen & Sheiman standard = 7 PD; OEP standard = 9 PD); for NBI blur (AUC = 0.561, p = 0.039), the cutoff point was 15 PD (sensitivity degree = 0.229, specificity = 0.884; Morgen & Sheiman standard = 13 PD; OEP standard = 14 PD); the cutoff point for NBI break (AUC = 0.585, p = 0.014) was 17.5 PD (sensitivity = 0.697, specificity = 0.449; Morgen & Sheiman standard = 21 PD; OEP standard = 22 PD); the cutoff value of NBI recovery (AUC = 0.581, p = 0.019) was 13 PD (sensitivity = 0.422, specificity = 0.717; Morgen & Sheiman standard = 13 PD; OEP criteria = 18 PD); and the NPC cut off point was 5.75 cm (AUC = 0.570, p = 0.042, sensitivity = 0.679, specificity = 0.452; Sheiman standard = 5 cm). The abovementioned six binocular vision criteria can significantly identify the comfort dimension with regard to an easy starting point and appropriate ability of convergence and divergence, both in the far and in the near vision, which can make eyes relax and retract easily [83, 84, 86]. Therefore, the six binocular visual function items should be used to predict the conscious performance of the comfort dimension with considerable discriminating power.

3.3.4 Balance

In the ROC curve analysis of balance dimension, the cutoff point of NFD (AUC = 0.629, p = 0.005) was 0.5 PD of exotropic shift (sensitivity = 0.809, specificity = 0.368; the standard value of the optometry practical textbook is ortho); the cutoff point of the negative gradient AC/A is 2.25△/D (AUC = 0.590, p = 0.050; sensitivity = 0.652, specificity = 0.558; Morgen & Scheiman criterion = 4Δ/D; OEP criterion = 4Δ/D); and the cutoff point of NPC (AUC = 0.584, p = 0.033) was 4.75 cm (sensitivity = 0.596, specificity = 0.591; Sheiman standard = 5 cm). NFD represents the accuracy and stability of the near gaze. The standard (0.5 PD exotropic shift) analyzed in this study is similar to the standard value (ortho) specified in the optometry clinical practice textbook. The results indicated that the deviation of the NFD was higher than 0.5 exotropic PD when the direction of the esotropic NDF increased, and the complaints of balance increased simultaneously [85]. Gradient AC/A (negative) indicates that convergence will be generated under the stimulation of 1D accommodation. The cutoff node (2.25△/D) analyzed by the study is 1.75△/D less than the traditional standard value (4△/D), which means that as long as the gradient AC/A (negative) ratio of the subject exceeds 2.25△/D, there will be significant complaint about balance-related symptoms [88]; the converging near point represents the maximum amplitude that can be converged [87], and the cutoff point (4.75 cm) analyzed by the study is close to the standard value of Sheiman (5 cm), which means that the convergence point is related to postural balance[88]. The postural balance ability was correlated with NFD, negative gradient AC/A, and NPC.

Table 2
Comparison between binocular visual function and traditional standard values

Examination	Total (n = 308) Mean ± SD	Scheiman's normative value	*p*-value	comparison	OEP Expected finding	*p*-value	Comparison
DLP	1.79 exophoria ± 3.26	1 exophoria ± 2	< 0.001	↓	0.5	< 0.001	↓
NLP	5.85 exophoria ± 6.73	3 exophoria ± 3	< 0.001	↓	6	0.697	↓
NFD_H	0.83 exophoria ± 2.14	-	-	-	-	-	-
Gradient AC/A(plus)	2.57 ± 4.93	4 ± 2	< 0.001	↓	-	-	-
Gradient AC/A(minus)	2.59 ± 4.67	4 ± 2	< 0.001	↓	-	-	-
DBI_break	11.21 ± 3.67	7 ± 3	< 0.001	↑	9	< 0.001	↑
DBI_recovery	4.39 ± 2.55	4 ± 2	0.0387	↑	5	< 0.001	↓
DBO_blur	6.46 ± 7.11	9 ± 4	< 0.001	↓	7	0.186	≈
DBO_break	17.22 ± 7.81	19 ± 8	0.0143	↓	19	< 0.001	↓
DBO_recovery	6.2 ± 4.04	10 ± 4	< 0.001	↓	10	< 0.001	↓
NBI_blur	6.81 ± 7.24	13 ± 4	< 0.001	↓	14	< 0.001	↓
NBI_break	18.36 ± 6.37	21 ± 4	< 0.001	↓	22	< 0.001	↓
NBI_recovery	11.16 ± 5.49	13 ± 5	< 0.001	↓	18	< 0.001	↓
NBO_blur	4.23 ± 7.21	17 ± 5	< 0.001	↓	15	< 0.001	↓
NBO_break	15.78 ± 6.85	21 ± 6	< 0.001	↓	21	< 0.001	↓
NBO_recovery	7.16 ± 5.47	11 ± 7	< 0.001	↓	15	< 0.001	↓
NPC_break	6.16 ± 2.68	5 ± 2.5	< 0.001	↓	-	-	-
MAF	9.45 ± 5.03	11 ± 5	< 0.001	↓	-	-	-
BAF	9.93 ± 4.41	10 ± 5	0.9193	≈	-	-	-
NRA	1.71 ± 0.61	2.00 ± 0.50	< 0.001	↓	2.00	< 0.001	↓
PRA	-1.97 ± 1.29	-2.37 ± 1.00	< 0.001	↓	-2.25	< 0.001	↓

AC/A: Accommodative Convergence/ accommodation; NFD_H: Near Horizontal Fixation Disparity

Examination	Total (n = 308) Mean ± SD	Scheiman's normative value	*p*-value	comparison	OEP Expected finding	*p*-value	Comparison
AA	15.09 ± 4.68	18 – 1/3age*(= 11.8)	< 0.001	↑	-	-	-
AC/A: Accommodative Convergence/ accommodation; NFD_H: Near Horizontal Fixation Disparity							

Table 3
The standard binocular visual function values of near work and perceptual dimension

CSMU-VBP questionnaire	Near work					Perceptual dimension				
	AUC	*p*-value	Sensitivity	Specificity	Cutoff point	AUC	*p*-value	Sensitivity	Specificity	Cutoff point
DLP	.534	.441	0.471	0.646	<−2.25	.464	.463	0.146	0.94	<−6.75
NLP	.524	.587	0.294	0.805	<−10.5	.478	.646	0.268	0.798	<−10.5
NFD_H	.473	.553	0.12	0.902	<−2.5	.500	.995	0.098	0.966	<−5.0
Gradient AC/A(plus)	.519	.672	0.412	0.66	> 3.75	.548	.324	0.366	0.771	> 4.75
Gradient AC/A(minus)	.540	.366	0.451	0.663	> 3.75	.517	.726	0.463	0.66	> 3.75
DBI_break	.505	.916	0.3	0.763	< 8.5	.548	.330	0.325	0.764	< 8.5
DBI_recovery	.468	.479	0.12	0.969	< 1.5	.504	.932	0.35	0.707	< 2.5
DBO_blur	**.598**	**.028**	**0.74**	**0.471**	**< 7**	.504	.931	0.7	0.348	< 9.0
DBO_break	.565	.154	0.583	0.586	< 15	.513	.796	0.579	0.579	< 15.0
DBO_recovery	**.591**	**.050**	**0.543**	**0.601**	**< 5.5**	.569	.180	0.917	0.23	< 8.5
NBI_blur	.472	.528	0.765	0.234	< 13	.459	.394	0.756	0.233	< 13.0
NBI_break	.549	.270	0.471	0.625	< 16.5	.539	.426	0.61	0.5	< 18.5
NBI_recovery	.542	.340	0.353	0.77	< 7.5	.546	.342	0.585	0.534	< 10.5
NBO_blur	.511	.812	0.824	0.258	< 9	.479	.667	0.829	0.184	< 11.0
NBO_break	.555	.228	0.277	0.833	< 9.5	.560	.234	0.595	0.523	< 14.5
NBO_recovery	.532	.484	0.936	0.147	< 13	.496	.941	0.162	0.916	< 1.5
NPC_break	.466	.437	0.059	0.976	> 12.5	.576	.119	0.78	0.336	< 6.25
MAF	.532	.467	0.804	0.275	< 12.5	**.583**	**.088**	**0.756**	**0.419**	**< 10.5**
BAF	.550	.258	0.941	0.217	< 13.5	**.621**	**.012**	**0.707**	**0.481**	**< 10.25**
NRA	.535	.428	0.529	0.584	< 1.63	.497	.954	0.805	0.273	< 2.13
PRA	.529	.515	0.373	0.716	>−1.13	.493	.893	0.854	0.184	>−3.13
AA	.536	.422	0.824	0.29	> 12.43	.520	.679	0.805	0.283	< 12.43

Table 4
The standard binocular visual function values of comfort and balance dimensions

CSMU-VBP questionnaire	Comfort					Balance				
	AUC	*p*-value	Sensitivity	Specificity	Cutoff point	AUC	*p*-value	Sensitivity	Specificity	Cutoff point
DLP	**.567**	**.050**	**0.459**	**0.673**	**<−2.25**	.447	.245	0.064	0.977	<−8.5
NLP	.548	.163	0.468	0.643	<−6.25	.434	.149	0.128	0.927	<−16.5
NFD_H	.581	.581	0.343	0.69	<−1.5	**.629**	**.005**	**0.809**	**0.368**	**>−0.5**
Gradient AC/A(plus)	.503	.934	0.672	0.376	< 1.75	.528	.544	0.34	0.769	> 4.75
Gradient AC/A(minus)	.536	.296	0.321	0.766	> 4.25	**.590**	**.051**	**0.652**	**0.558**	**> 2.25**
DBI_break	**.574**	**.031**	**0.593**	**0.563**	**> 11.5**	.544	.332	0.362	0.769	< 9.5
DBI_recovery	.471	.402	0.065	0.965	< 1.5	.491	.853	0.348	0.708	< 2.5
DBO_blur	.494	.858	0.75	0.291	< 11.0	.571	.123	0.723	0.465	< 7.0
DBO_break	.486	.682	0.107	0.907	< 7.5	.530	.529	0.512	0.571	< 15.0
DBO_recovery	.529	.414	0.263	0.795	< 2.5	.560	.214	0.548	0.599	< 5.5
NBI_blur	**.561**	**.077**	**0.229**	**0.884**	**> 15.0**	.447	.248	0.745	0.231	< 13.0
NBI_break	**.585**	**.014**	**0.697**	**0.449**	**> 17.5**	.548	.297	0.596	0.5	< 18.5
NBI_recovery	**.581**	**.019**	**0.422**	**0.717**	**> 13.0**	.523	.612	0.234	0.896	< 4.5
NBO_blur	.504	.909	0.771	0.253	< 9.0	.506	.889	0.979	0.081	< 17.0
NBO_break	.528	.428	0.272	0.791	< 11.0	.470	.532	0.233	0.77	< 11.0
NBO_recovery	.510	.767	0.806	0.241	< 11.0	.426	.120	0.116	0.91	< 1.5
NPC_break	**.570**	**.042**	**0.679**	**0.452**	**< 5.75**	**.584**	**.066**	**0.596**	**0.591**	**< 4.75**
MAF	.529	.401	0.376	0.695	< 7.5	.502	.970	0.652	0.404	< 10.5
BAF	.522	.518	0.333	0.756	< 7.5	.523	.614	0.957	0.054	< 16.5
NRA	.489	.749	0.33	0.719	< 1.375	.485	.741	0.34	0.709	< 1.375
PRA	.539	.260	0.56	0.523	<−1.63	.504	.923	0.872	0.188	>−3.125
AA	.548	.169	0.407	0.687	> 16.56	.534	.464	0.809	0.286	> 12.43

4. Discussion

According to the analysis of the results of the binocular visual function examination in this study, the proportion of accommodation excess and convergence excess among young adults in Taiwan is highest, which is similar to the results reported in some foreign studies [48, 50, 55, 56]. However, the findings of this study are very different from that of most previous studies with regard to accommodation insufficiency and convergence insufficiency[9, 57–58]. The researchers preliminarily estimated the use of 3C productions at close visual range for a long time since childhood [59–62] resulted in an inability to relax accommodation and convergence, that might be reasonable to explain the diagnosis of accommodation and convergence excesses in Taiwanese youths [56, 63]. However, the above mentioned diagnostic criteria of clinical assessment for the classification of abnormal binocular visual function have a history of nearly 20 years, and many reports has confirmed differences in race and age [16, 17, 19, 21, 65–68]; therefore, the different diagnostic criteria for binocular vision dysfunction should be updated [17–20].

In total, 308 Taiwanese young individuals aged 15 to 24 years were enrolled in this study. According to the clinical characteristics and diagnostic criteria of binocular visual dysfunction classification specified by Scheiman & Wick and the CSMU-VBP used in this study, the results were as follows: 262 participants (85%) were classified as having normal binocular visual function, whereas 46 (15%) had abnormal function. In addition, according to the analysis of the questionnaire results, 265 (86%) participants were classified as asymptomatic and 43 (14%) as symptomatic. The proportions in clinical diagnosis, classification, and symptom analysis seem very similar. In fact, this is far from the truth; among the 46 participants with binocular visual dysfunction, nearly 80% (36, 78%) had no obvious symptoms, and only 22% (n = 10) had symptoms; moreover, among the 43 participants classified as symptomatic, nearly 80% (n = 33, 77%) were diagnosed with normal binocular visual function, and only about 23% (n = 10) had abnormal visual function.

The binocular visual function of young Taiwanese subjects is different from the standard values that are often referred to in clinical practice, and the inspection values are mostly lower than the standard values. Except for the proven ethnic differences and age differences [16, 17, 19, 21, 65–68], most of the speculations that are related to the standard value did not take refractive errors, visual demand, and technological developments into consideration [69–71]. Although it might not be conferring reading difficulty [72–74] when the accommodation range and the DBI break are both relatively high, overuse of near vision as well as the excessive use of accommodation and cohesion that results in functional fatigue or rigidity may lead to poor overall binocular visual performance. Regardless of the results of the study’s analysis, it can be confirmed that the construction of a new Taiwanese native binocular vision standard value should constitute a direction for future research.

In this study, ROC curve analysis was used to find identify the standard values of binocular vision criteria for different visual behavior performance dimensions. When patients have visual disturbances, the visual behavior scale questionnaire can be used to distinguish one type or more types of patients. After identification of the type of visual disturbance in each dimension, the binocular vision inspection items can be used to discriminate each dimension to determine whether the inspection value meets the diagnostic criteria (cutoff point). Next, the values thus obtained can be used to adjust prescription or vision training [75–78] to help patients solve their visual problems. For example, the patient fills in the questionnaire of the Visual Behavior Performance Scale, and the score in the perception dimension is 7 points (≥ 5 is symptomatic), which is the category of perceptual visual disturbance. The results of monocular and binocular accommodation facility are 8 and 7 cpm respectively (lower than the criteria of MAF < 10.5 cpm and BAF < 10.25 cpm). The examiner can preliminarily determine that the patient has abnormal function in monocular and binocular accommodation. By improving binocular visual function, the perceptual ability can also be improved simultaneously.

5. Conclusions

The results of this study show that binocular accommodation ability can predict most visual behaviors. It is suggested that the binocular accommodation sensitivity should be included in routine optometry examination, which is very beneficial for ascertaining the patients' visual behavior performance and distress. The average binocular vision performance of young people in Taiwan is worse than the traditionally expected value, and when using the traditional binocular visual function abnormal classification criteria, nearly 80% of the patients diagnosed with binocular vision abnormality have no obvious symptoms. With the changes of the times and racial differences, the habits and needs of eye use have greatly increased; thus, it is imperative to establish the standard value of binocular vision function specifically for Taiwanese individuals. This study analyzed the binocular visual function of Taiwanese youth based on questionnaires and binocular vision examination; however, there are some limitations due to the large difference in the proportion of male and female participants in this study, that should be mentioned further.

Declarations

Author Contributions: Conceptualization, C.-Y.C., P.-H.W. and. S.-T.C.; investigation, data curation, and formal analysis, C.-Y.C., P.-H.W., S.-T.C., and X.-Y.Z.; writing—original draft preparation, C.-Y.C. and P.-H.W.; writing—review and editing, C.-Y.C., and K.-C.S. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Availability of Data and Materials: All data generated or analyzed during this study are included in this published article and its supplementary information files. Correspondence and requests for materials should be addressed to C.-Y.C.

Competing of Interests: The authors declare no competing interest.

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Figures

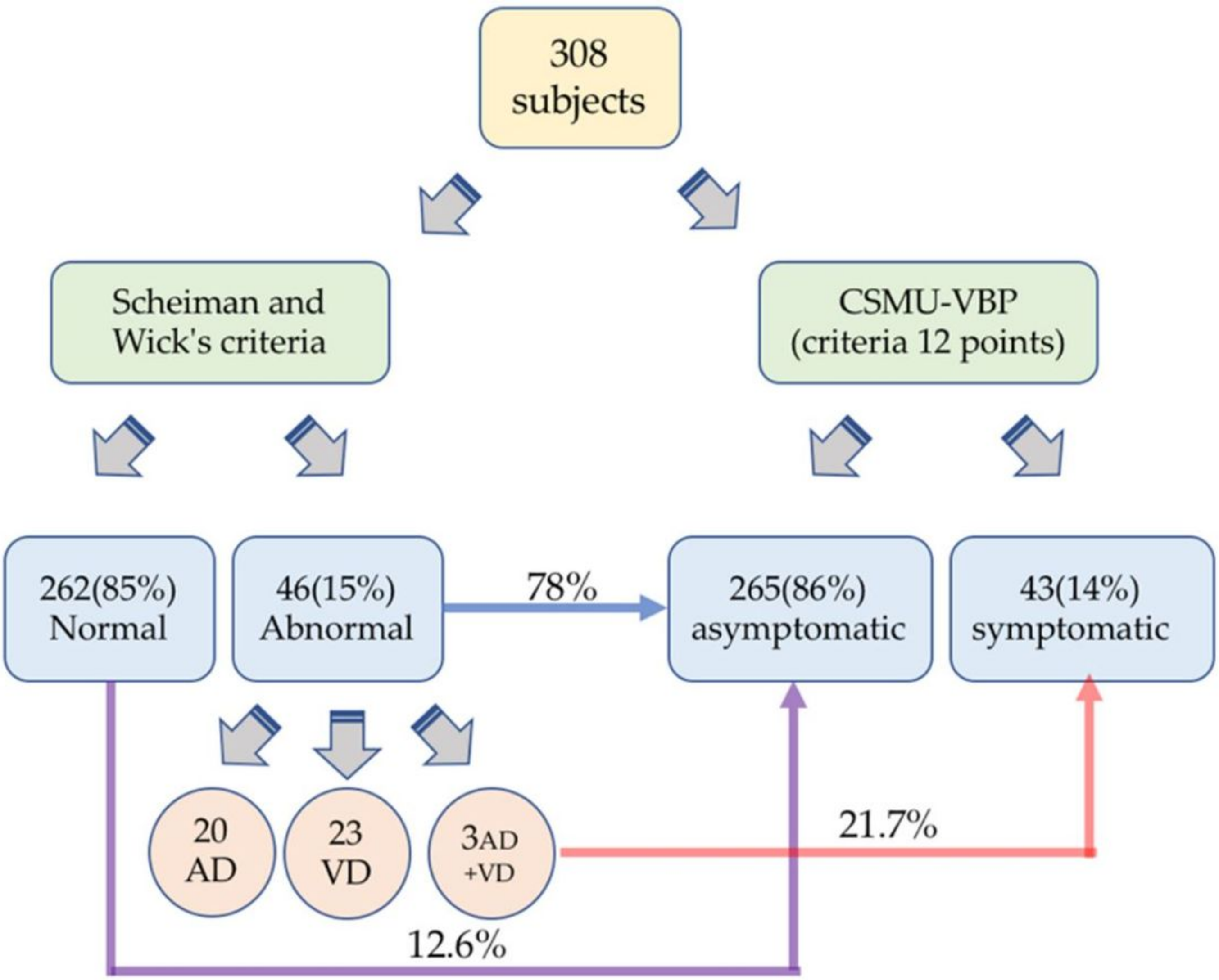

Figure 1

Frequency of Scheiman and Wick’s criteria and CSMU-VBP

Supplementary Files

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- CSMUVBP.pdf