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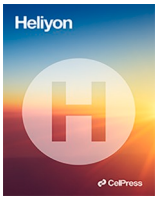

Research article

Demographic and clinical characteristics and risk factors of stereoacuity in convergence insufficiency-type intermittent exotropia

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ABSTRACT

Purpose: To investigate characteristics and risk factors of poor stereoacuity of Convergence insufficiency-type Intermittent Exotropia (CI-type X(T)).
Design: Observational, cross-sectional study.
Methods: The medical records of 615 CI-type X(T) and 222 basic-type intermittent exotropia (X (T)) were enrolled from January 2018 to January 2022. The characteristics were compared between the two types, and the associations between clinical factors and poor stereoacuity were examined using logistic regression.
Results: Compared with basic-type X(T), earlier surgery age, shorter misalignment duration, and the smaller distance exodeviation were observed in CI-type X(T). The CI-type X(T) demonstrated better sensory status and lower incidence of ocular muscle dysfunction than did the basic-type X (T). The surgery age between 6 and 12 years (odds ratio [OR], 0.595; compared with ≤6 years) was inversely associated with poor near stereoacuity, whereas duration more than 4 years (OR, 2.474), amblyopia (OR, 4.057), large distance exodeviation (>60PD: OR, 2.462) and anisometropia (>2.00D: OR, 3.874) were positively associated with poor near stereoacuity. The onset age older than 6 years (6–9 years: OR, 0.397; >9 years: OR, 0.317) was associated with better distance stereoacuity, whereas large distance exodeviation (>60PD: OR, 23.513), and dominant eye best corrected visual acuity (BCVA) worsen than 0.20 (OR, 2.987) were positively associated with poor distance stereoacuity.
Conclusion: CI-type X(T) declined surgery early, with small distance exodeviation, better sensory status, and low incidence of ocular muscle dysfunction. A strong dose-dependent link between early onset age, long misalignment duration, worse dominant eye BCVA, distance exodeviation, amblyopia, anisometropia, and poor stereoacuity was confirmed.

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1. Introduction

Intermittent exotropia (X(T)) is one of the most predominant childhood eye diseases in China, with a prevalence of at least 3.24 % in preschool children [1,2]. X(T) causes the cosmetic problem, reduced stereoacuity, and even mental illness, seriously affecting the quality of life and self-esteem of children and adolescents [3]. X(T) is distinguished into four types according to the exodeviation at near and distance, such as basic type, divergence excess type, convergence insufficiency type, and pseudo-divergence excess type [4].

Convergence insufficiency-type intermittent exotropia (CI-type X(T)) is characterized by a greater exodeviation at near fixation than at distance of 10 prism diopters (PD) or more [5]. In CI-type X(T), the disparity between distance and near might be associated with a weak fusional convergence, low accommodative convergence to accommodation (AC/A) ratio, and excessive distance fusional drive [6,7]. The reported prevalence of CI-type X(T) was 4.5 %–10.0 % in X(T) [8,9]. The main symptoms are eye strain, inability to concentrate, and short attention span [10].

The courses of CI-type X(T) have not been clear. For children who have difficulty cooperating with testing or well control, long-term periodic monitoring was performed until a firm diagnosis and reliable measurements can be obtained before surgery. Sample screening is hard to consider stereoacuity test, but comprehensive eye examination declines adherence due to the high cost and burden for patients' families. The proportion of CI-type X(T) in X(T) has increased in recent years [11]. However, a deeper understanding of CI-type X(T) is currently lacking. To fill these gaps, a study that elucidates the demographic and clinical characteristics of CI-type X(T) will facilitate a more targeted and specific approach to intervention. Understanding the risk factors associated with poor stereoacuity of CI-type X(T) is vital to developing harm reduction strategies, including accurate monitoring of high-risk patients and selection of the appropriate surgical time.

2. Methods

2.1. Study population

This is an observational, cross-sectional study in northwestern China. We obtained informed consent from all participants or guardians (for participating children). This study complies with the ethical principles of the Declaration of Helsinki. The study protocol and study documents were approved by the medical ethics Committee. (reference no. KY20212205–F-1).

The medical records of patients with diagnosed X(T) aged $\geq$3 years who underwent a comprehensive eye examination at the Department of Ophthalmology, Xijing Hospital (Shaanxi Province, China) were included in the analysis, from January 2018 to January 2022. The inclusion criteria are as followings: (1) intermittent exotropia at distance and near; (2) exodeviation of 15 prism diopters (PD) or more at distance in the primary position; (3) no paralytic, restrictive, consecutive and congenital strabismus. Exclusion criteria included the following: previous strabismus surgery, any ocular disease (excluding ptosis, amblyopia, and nystagmus), systemic disease (such as a congenital anomaly or a neurological deficit), and lack of cooperation during the ophthalmologic examination. Patients with orthoptics or stereopsis training for any reason were also excluded from our study.

2.2. Examination

A comprehensive eye examination was performed by optometrists or ophthalmologists, certified using standardized protocols. The prism alternate cover testing (PACT) was conducted to determine ocular alignment at 33 cm and 6 m for all patients, who wore spectacles to correct the refractive error if required. PACT was performed again after more than 1 h of monocular occlusion of the non-dominant eye. The presence of dissociated vertical deviation (DVD), V or A pattern, inferior oblique overaction (IOOA), superior oblique palsy (SOP), and superior oblique overaction (SOOA) were assessed in primary position and the cardinal gaze positions at 33 cm. When patients exhibited a manifest exodeviation, the eye invariably gazing at the target was regarded as the dominant eye.

Sensory status was evaluated by a Titmus Stereo Test (Stereo Optical Co, Chicago, IL, USA) at near through a pair of polarized glasses and a synoptophore (Clement Clarke Ltd., London, U.K.) at distance. Suppression was measured by bagolini bar at 33 cm and 6 m.

Best corrected visual acuity (BCVA) was measured with spectacles, if necessary, at a distance of 6 m, and calculated in logMAR. Slit lamp biomicroscopy and fundus photographs were performed to identify ocular abnormalities. Cycloplegic refraction was performed to determine refractive error after using tropicamide (Santen Pharmaceutical, Co, Japan) or 1 % atropine sulfate (Akorn, Inc., Lake Forest, IL, USA). Amblyopia for children was diagnosed according to BCVA worse than age-referenced normal values and interocular difference of two or more lines.

Sociodemographic data were collected by ophthalmologists to ask participants or legal guardians, including age at onset, history of birth, family strabismus history, and medical history.

2.3. Definition

Near stereoacuity was defined as normal ($\leq$100 arcsec), subnormal (100–400 arcsec), and abnormal stereoacuity (>400 arcsec) [12]. The better near stereoacuity included normal and subnormal participants and poor near stereoacuity was defined as abnormal stereoacuity. Synoptophore defined no stereoscopic as poor distance stereoacuity.

The onset age of apparent exodeviation was defined as the age at which the parents or ophthalmologists first detected ocular misalignment or recognized it by photos. The duration of misalignment age was the disparity between surgery age and onset age.

Spherical equivalent (SE) refractive error was calculated as the sphere power plus one-half of the cylinder power. Emmetropia was defined as SE refractive error between −0.50 D and +2.00D in both eyes; myopia was defined as SE refractive error less than −0.50 D, and hyperopia was defined as SE refractive error more than +2.00D [13]. The type of refractive status was defined as the eye with the greater absolute value of SE refractive error. Anisometropia was defined as an interocular difference ≥1.50 D in SE.

2.4. Statistical analysis

All analyses were performed with SPSS software for Windows (version 26.0.0; SPSS Inc, Chicago, USA). The Mann-Whitney U was used to compare the median of two independent samples, and the chi-square test or Fisher Exact test was used to compare the sample

Table 1
Comparison of demographic and refractive characteristics between CI-type and basic-type (X)T.

	CI-type(n = 615)	basic-type(n = 222)	*P* Value
Demographic characteristics			
Gender, female, no.(%)	279(45.4)	110(49.5)	0.193
Age of surgery, median(range)	10(5–53)	17(3–49)	<0.001
Age of onset, median(IQR)	6(3–10)	7(3–12)	0.457
Duration of misalignment, median(IQR)	3(1–8)	6(4–16)	<0.001
History of oxygen at birth, no.(%)	9(1.5)	4(1.8)	0.976[a]
Preterm birth, no.(%)	16(2.6)	6(2.7)	0.938
Family strabismus history, no.(%)	23(3.7)	6(2.7)	0.460
Amblyopia, no.(%)	50(8.1)	13(5.9)	0.271
Ptosis, no.(%)	32(5.2)	9(4.1)	0.496
Nystagmus, no.(%)	5(0.8)	2(0.9)	1.000[a]
Horizontal exodeviation angle at near (PD), median(IQR)	65(50–85)	85(40–90)	0.626
Horizontal exodeviation angle at distance (PD), median(IQR)	40(30–60)	80(40–90)	<0.001
Disparity of near and distance deviation(PD), median(IQR)	20(10–30)	5(0–5)	<0.001
Vertical deviation angle(PD), median(IQR)	5(0–5)	5(0–5)	0.301
Dissociated vertical deviation, no.(%)	17(2.8)	17(7.7)	0.002
Dissociated horizontal deviation, no.(%)	0(0)	1(0.5)	0.265[a]
V pattern, no.(%)	71(11.5)	32(14.4)	0.265
A pattern, no.(%)	8(1.3)	6(1.8)	0.835[a]
IOOA, no.(%)	291(47.3)	133(59.9)	0.001
SOP, no.(%)	15(2.4)	12(5.4)	0.032
SOOA, no.(%)	10(1.6)	5(2.3)	0.758[a]
Near stereoacuity (arcsec), no.(%)			<0.001
normal(40–100)	283(46.0)	65(29.3)	
subnormal(100–400)	55(8.9)	10(4.5)	
abnormal(400–2000)	277(45.0)	147(66.2)	
Distance stereoacuity, no.(%)			
Simultaneous perception	156(25.4)	16(7.2)	<0.001
Fusion	93(15.1)	12(5.4)	<0.001
Stereopsis	92(15.0)	12(5.4)	<0.001
Suppression at near, no.(%)	193(31.4)	98(44.1)	0.001
Suppression at distance, no.(%)	245(39.8)	111(50.0)	0.008
	CI-type(n = 615)	basic-type(n = 222)	*P* Value
Refractive characteristics			
Dominant eye, no.(%)			0.262
OD	319(51.9)	115(51.8)	
OS	296(48.1)	107(48.2)	
BCVA, logMAR, median(IQR)			
Dominant eye	0.00(0.00–0.10)	0.00(0.00–0.00)	0.007
Non-dominant eye	0.00(0.00–0.10)	0.00(0.00–0.10)	0.082
Sphere of the dominant eye(D), median(IQR)	0.00(-1.75–0.00)	0.00(-1.00–0.06)	0.139
Sphere of the non-dominant eye(D), median(IQR)	−0.50(-2.50–0.25)	0.00(-2.31–0.06)	0.344
Astigmatism of the dominant eye(D), median(IQR)	−0.50(-1.00–0.00)	0.00(-0.75–0.00)	0.216
Astigmatism of the non-dominant eye(D), median(IQR)	−0.50(-1.00–0.00)	0.00(-0.75–0.00)	0.195
SE of the dominant eye, median(IQR)	−0.50(-2.25–0.25)	−0.25(-1.50–0.25)	0.137
SE of the non-dominant eye, median(IQR)	−0.88(-2.88–0.25)	−0.25(-2.53–0.25)	0.274
Interocular difference in SE (D), median(IQR)	0.50(0.13–1.25)	0.50(0.00–1.50)	0.961
Refractive status, no.(%)			0.168
Hyperopia	29(4.7)	9(4.1)	
Emmetropia	198(32.2)	87(39.2)	
Myopia	388(63.1)	126(56.8)	
Anisometropia (1.5D), no.(%)	113(18.4 %)	53(23.9 %)	0.078

No: number; IQR: interquartile range; PD: prism diopters; IOOA: inferior oblique overaction; SOP: superior oblique palsy; SOOA: superior oblique overaction; OD: right eyes; OS: left eyes; D: diopters; SE: spherical equivalent.
[a] Fisher's Exact Test.

rate between CI-type X(T) and basic-type X(T). The Kruskal-Wallis H was used to compare the median between three independent samples, such as different levels of stereoacuity in CI-type X(T). Covariance model was used to adjust baseline age, duration of misalignment, and near exodeviation angle. Logistic regression was used to assess whether poor stereoacuity was associated with the following parameters: surgery age, gender, duration of misalignment, and other risk factors in participants with CI-type X(T). To identify independent factors associated with poor stereoacuity, multivariate logistic regression analyses with forward stepwise selection were performed to calculate the odds ratios (ORs) and 95 % confidence intervals (CIs) with a $P < 0.05$ criterion for entry into the model and $P < 0.10$ for retention in the model. We set a significant level at $P < 0.05$. All reported P values are 2-sided.

3. Results

The study collected 1122 patients in the Department of Xijing Hospital between 2018 and 2022. A total of 285 patients were excluded from the subsequent analysis. Of them, 23 patients with divergence excess-type X(T), 232 patients with incomplete clinical data, 15 patients with previous strabismus intervention or orthoptics, and 15 patients with other ocular diseases. Among the remaining 837 participants, 615 participants were CI-type X(T) and 222 participants were basic-type X(T). The characteristics of the participants are shown in Table 1.

3.1. Difference between CI-type X(T) and basic-type X(T) by demographic and clinical characteristics

The gender difference was not observed between CI-type X(T) and basic-type X(T) ($P = 0.193$). There was a significant surgery age difference between the two types, with older in basic-type X(T) (median [range], 17 [3–49] years) and younger in CI-type X(T) ((median [range], 10 [5–53] years), $P < 0.001$). Similar to surgery age, there was a significant duration of misalignment difference between CI-type X(T) (median [interquartile range, IQR], 3 [1–8] years) with basic-type X(T) (median [IQR], 6 [4–16] years, $P < 0.001$) and remained after adjusting for surgery age ($P = 0.003$). We also examined the age at onset, and there was no significant difference between the two types ($P = 0.457$). We analysed the prevalence of the participants about history of birth, family strabismus history as well as diseases always complicated by strabismus, which did not differ between the two types.

One remarkable difference was that the near angle of exodeviation in CI-type X(T) (median [IQR], 65 [50–85] PD) was similar to basic-type X(T) (median [IQR], 85 [40–90] PD, $P = 0.626$), but the distance angle in CI-type X(T) (median [IQR], 40 [30–60] PD) was smaller than that in basic-type X(T) (median [IQR], 80 [40–90] PD, $P < 0.001$). The presence of DVD (basic-type and CI-type: 7.7 % vs. 2.8 %, $P = 0.002$), IOOA (basic-type and CI-type: 59.9 % vs. 47.3 %, $P = 0.001$), and SOP (basic-type and CI-type: 5.4 % vs. 2.4 %, $P = 0.032$) were noted more in basic-type X(T) than CI-type X(T). Near and distance stereoacuity differences were observed between the two types, with basic-type X(T) worsening than CI-type X(T). The ratio of remaining near normal stereoacuity in CI-type X(T) and basic-type X(T) were 46.0 % and 29.3 %; the ratio of remaining distance normal stereoacuity was 15.0 % and 5.4 %. The ratio of suppression both at near and distance was significantly higher for basic-type X(T). These differences remained even after adjustment for age, duration of misalignment, and near exodeviation angle (DVD: $P = 0.001$; IOOA: $P = 0.016$; near and distance stereoacuity: $P < 0.001$, respectively).

Table 2
Comparison of clinical characteristics between different levels of near stereoacuity in CI-type (X)T.

	Normal(n = 283)	Subnormal(n = 55)	Abnormal(n = 277)	*P* Value
Gender, female, no.(%)	135(47.7)	29(52.7)	115(41.5)	0.176
Age of surgery, median(range)	9(4–42)	9(3–52)	15(3–53)	<0.001
Age of onset, median(IQR)	6(3–9)	7(3–9)	6(3–12)	0.311
Duration of misalignment, median(IQR)	2(1–5)	2(1–5)	6(2–10)	<0.001
Amblyopia, no.(%)	11(3.9)	4(7.3)	35(12.6)	0.001[a]
BCVA, LogMAR, median(IQR)				
Dominant	0.00(0.00–0.00)	0.00(0.00–0.10)	0.00(0.00–0.10)	0.204
Non-dominant	0.00(0.00–0.10)	0.00(0.00–0.10)	0.00(0.00–0.10)	0.036
SE(D), median(IQR)				
Dominant	−0.37(-2.13–0.25)	−0.25(-1.00–0.50)	−0.75(-2.50–0.00)	0.005
Non-dominant	−0.50(-2.38–0.25)	−0.63(-2.50–0.75)	−1.50(-3.63–0.00)	0.001
Anisometropia, no. (%)	24(8.5)	10(18.2)	79(28.5)	<0.001
HD(PD), median(IQR)				
Near	60(48–83)	60(50–85)	80(60–95)	<0.001
Distance	38(30–50)	40(28–50)	50(35–80)	<0.001
Vertical deviation angle(PD), median(IQR)	5(0–5)	5(0–5)	5(0–5)	0.048
Dissociated vertical deviation, no.(%)	5(1.8)	1(1.8)	11(4.0)	0.253
V pattern	32(11.3)	6(10.9)	33(11.0)	0.982
A pattern	2(0.7)	0(0.0)	6(2.2)	0.282[a]
IOOA, no.(%)	112(39.6)	31(56.4)	148(53.4)	0.002
SOP, no.(%)	2(0.7)	3(5.5)	10(3.6)	0.013[a]
SOOA, no.(%)	4(1.4)	1(1.8)	5(1.8)	0.806[a]

no: number; IQR: interquartile range; SE: spherical equivalent; BCVA: best corrected visual acuity; D: diopters; HD: horizontal deviation; PD: prism diopters; IOOA: inferior oblique overaction; SOP: superior oblique palsy; SOOA: superior oblique overaction.

[a] : Fisher's Exact Test.

Table 3
Univariable and multivariable logistic regression analyses for near stereoacuity CI-type (X)T.

Variables	Without stereoacuity (n = 277)	With stereoacuity (n = 338)	Univariable analysis		Multivariable analysis	
			OR(95%CI)	*P* value	OR(95%CI)	*P* value
Gender						
Male	162(58.5 %)	174(51.5 %)	Reference			
Female	115(41.5 %)	164(48.5 %)	0.753(0547–1.038)	0.083		
Age of surgery(years)						
≤6	41(14.8 %)	78(23.1 %)	Reference		Reference	
6~12	78(28.2 %)	190(56.2 %)	0.781(0.493–1.238)	0.293	0.595(0.357–0.993)	**0.047**
12~18	56(20.2 %)	32(9.5 %)	3.329(1.872–5.921)	**<0.001**	1.678(0.860–3.271)	0.129
18~24	49(17.7 %)	15(4.4 %)	6.215(3.114–12.402)	**<0.001**	2.112(0.929–4.799)	0.074
24~30	30(10.8 %)	14(4.1 %)	4.077(1.948–8.532)	**<0.001**	1.371(0.73–3.279)	0.479
>30	23(8.3 %)	9(2.7 %)	4.862(2.061–11.470)	**<0.001**	1.439(0.533–3.886)	0.473
Age of onset(years)						
≤3	93(33.6 %)	96(28.4 %)	Reference			
3~6	50(18.1 %)	85(25.1 %)	0.607(0.387–0.953)	**0.030**		
6~9	42(15.2 %)	86(25.4 %)	0.504(0.316–0.804)	**0.004**		
>9	92(33.2 %)	71(21.0 %)	1.338(0.878–2.038)	0.176		
Duration of misalignment(years)						
≤2	71(25.6 %)	175(51.8 %)	Reference		Reference	
2~4	40(14.4 %)	73(21.6 %)	1.351(0.841–2.170)	0.214	1.410(0.840–2.369)	0.194
>4	166(59.9 %)	90(26.6 %)	4.546(3.119–6.626)	**<0.001**	2.474(1.548–3.954)	**<0.001**
Amblyopia						
No	242(87.4 %)	323(95.6 %)	Reference		Reference	
Yes	35(12.6 %)	15(4.4 %)	3.114(1.663–5.832)	**<0.001**	4.057(2.013–8.176)	**<0.001**
Horizontal exodeviation angle at near(PD)						
≤30	2(0.7 %)	11(3.3 %)	Reference			
30~60	101(36.5 %)	176(52.1 %)	3.156(0.686–14.523)	0.140		
>60	174(62.8 %)	151(44.7 %)	6.338(1.383–29.045)	**0.017**		
Horizontal exodeviation angle at distance(PD)						
≤30	66(23.8 %)	155(45.9 %)	Reference		Reference	
30~60	124(44.8 %)	141(41.7 %)	2.065(1.418–3.007)	**<0.001**	1.810(1.189–2.755)	**0.006**
>60	87(31.4 %)	42(12.4 %)	4.865(3.048–7.764)	**<0.001**	2.462(1.405–4.313)	**0.002**
NDD(PD)						
10	76(27.4 %)	82(24.3 %)	Reference			
11~20	106(38.3 %)	113(33.4 %)	1.012(0.672–1.524)	0.954		
21~30	49(17.7 %)	60(17.8 %)	0.881(0.540–1.438)	0.613		
31~40	27(9.75)	51(15.1 %)	0.571(0.326–1.001)	0.051		
>40	19(6.9 %)	32(9.5 %)	0.641(0.335–1.224)	0.178		
Vertical deviation angle(PD)						
≤5	224(80.9 %)	301(89.0 %)	Reference			
6~10	44(15.9 %)	34(10.1 %)	1.739(1.076–2.810)	**0.024**		
>10	9(3.2 %)	3(0.9 %)	4.031(1.079–15.061)	**0.038**		
IOOA						
No	129(46.6 %)	195(57.7 %)	Reference			
Yes	148(53.4 %)	143(42.3 %)	1.564(1.136–2.154)	**0.006**		
BCVA, logMAR, Dominant eye						
≤0.10	239(38 %)	312(92.3 %)	Reference			
≥0.20	38(13.7 %)	26(7.7 %)	1.908(1.127–3.230)	**0.016**		
BCVA, logMAR, Non-dominant eye						
≤0.10	226(81.6 %)	308(91.1 %)	Reference			
≥0.20	51(18.4 %)	30(8.9 %)	2.317(1.430–3.754)	**0.001**		
Sphere (D), Dominant eye						
0.49~+1.99	137(49.5 %)	198(58.6 %)	Reference			
2.99~-0.50	91(32.9 %)	96(28.4 %)	1.370(0.956–1.964)	0.087		
5.99~-3.00	31(11.2 %)	29(8.6 %)	1.545(0.890–2.681)	0.122		
≤-6.00	12(4.3 %)	6(1.8 %)	2.891(1.059–7.888)	**0.038**		
≥+2.00	6(2.2 %)	9(2.7 %)	0.964(0.335–2.769)	0.945		
Sphere (D), Non-dominant eye						
0.49~+1.99	101(36.5 %)	169(50.0 %)	Reference			
2.99~-0.50	83(30.0 %)	110(32.5 %)	1.263(0.866–1.840)	0.225		
5.99~-3.00	58(20.9 %)	45(13.3 %)	2.157(1.360–3.419)	**0.001**		
≤-6.00	21(7.6 %)	5(1.5 %)	7.028(2.570–19.218)	**<0.001**		
≥+2.00	14(5.1 %)	9(2.7 %)	2.603(1.087–6.231)	**0.032**		
Astigmatism (D), Dominant eye						
≤0.50	141(50.9 %)	204(60.4 %)	Reference			
0.51–1.00	72(26.0 %)	78(23.1 %)	1.336(0.908–1.964)	0.141		
1.01–1.50	29(10.5 %)	35(10.4 %)	1.199(0.701–2.051)	0.508		
1.51–2.00	20(7.2 %)	16(4.7 %)	1.809(0.906–3.611)	0.093		
>2.00	15(5.4 %)	5(1.5 %)	4.340(1.542–12.214)	**0.005**		

(*continued on next page*)

Table 3 (*continued*)

Variables	Without stereoacuity (n = 277)	With stereoacuity (n = 338)	Univariable analysis		Multivariable analysis	
			OR(95%CI)	*P* value	OR(95%CI)	*P* value
Astigmatism (D), Non-dominant eye						
≤0.50	136(49.1 %)	185(54.7 %)	Reference			
0.51–1.00	76(27.4 %)	79(23.4 %)	1.309(0.891–1.923)	0.171		
1.01–1.50	23(8.3 %)	41(12.1 %)	0.763(0.437–1.331)	0.341		
1.51–2.00	20(7.2 %)	23(6.8 %)	1.183(0.624–2.241)	0.606		
>2.00	22(7.9 %)	10(3.0 %)	2.993(1.372–6.526)	**0.006**		
Spherical equivalent (D), Dominant eye						
0.49~+1.99	109(39.4 %)	166(49.1 %)	Reference			
2.99~-0.50	107(38.6 %)	117(34.6 %)	1.393(0.975–1.989)	0.069		
5.99~-3.00	37(13.4 %)	36(10.7 %)	1.565(0.932–2.629)	0.090		
≤-6.00	17(6.1 %)	8(2.4 %)	3.236(1.350–7.758)	**0.008**		
≥+2.00	7(2.5 %)	11(3.3 %)	0.969(0.364–2.577)	0.950		
Spherical equivalent (D), Non-dominant eye						
0.49~+1.99	94(33.9 %)	142(42.0 %)	Reference			
2.99~-0.50	77(27.8 %)	121(35.8 %)	0.961(0.653–1.415)	0.842		
5.99~-3.00	68(24.5 %)	50(14.8 %)	2.054(1.312–3.218)	**0.002**		
≤-6.00	27(9.7 %)	8(2.4 %)	5.098(2.221–11.703)	**<0.001**		
≥+2.00	11(4.0 %)	17(5.0 %)	0.977(0.438–2.180)	0.956		
Anisometropia(D)						
≤1.00	167(60.3 %)	279(82.5 %)	Reference		Reference	
1.01–2.00	56(20.2 %)	43(12.7 %)	2.176(1.400–3.383)	**0.001**	1.769(1.060–2.950)	**0.029**
>2.00	54(19.5 %)	16(4.7 %)	5.638(3.126–10.171)	**<0.001**	3.874(2.003–7.496)	**<0.001**

PD: prism diopters; NDD: near-distance disparity; IOOA: inferior oblique overaction; BCVA: best corrected visual acuity; D: diopters.

In addition, we compared sphere, cylinder power, SE, anisometropia, and the rate of refractive error, there was no difference between the two types ($P > 0.05$). Although dominant eye BCVA was better in basic-type X(T) than CI-type X(T) (0.00[0.00–0.00] vs. 0.00[0.00–0.10]; $P = 0.007$), the differences disappeared after adjustment for age ($P = 0.668$). Briefly, there was no difference in BCVA between the two groups at similar ages.

3.2. Clinical features of different near stereoacuity levels in CI-type X(T)

Comparing the characteristics of different levels of near stereoacuity, 283 patients (46.0 %) showed normal stereoacuity, 55 patients (8.9 %) had subnormal stereoacuity and 277 patients (45.0 %) had abnormal stereoacuity (Table 2). The median of surgery age 15 years in the abnormal stereoacuity group was older than the other two groups with median surgery age of 9 years ($P < 0.001$). The duration of misalignment was similar in normal and subnormal groups and was shorter than in the abnormal group ($P < 0.001$). The deviation angle was larger in the abnormal group both horizontal and vertical than in those classified as normal or subnormal (near and distance HD: $P < 0.001$; vertical deviation [VD]: $P = 0.048$). Moreover, non-dominant eye BCVA and SE were different among the three groups (non-dominant eye BCVA: $P = 0.036$; dominant eye SE: $P = 0.005$; non-dominant eye SE: $P = 0.001$). We also observed that the ratio of amblyopia and anisometropia, and the incidence of IOOA or SOP were different among the three groups (amblyopia: $P = 0.001$; anisometropia: $P < 0.001$; IOOA: $P = 0.002$; SOP: $P = 0.013$). Overall, the abnormal group showed relatively poorer visual acuity and more comorbidities. Patients in all three groups were not significantly different in any of the parameters.

3.3. Risk factors associated with near stereoacuity in CI-type X(T)

To determine the risks associated with the impairment of stereoacuity, we examined age, duration of misalignment, exodeviation angle at near and distance, VD, the presence of amblyopia, DVD and IOOA, and the refractive status between participants with better (≤400 arcsec) and poor near stereoacuity (>400 arcsec) by adjusting the confounding factors though logistic regression (Table 3).

In multivariable analysis (Table 3), the age of surgery between 6 and 12 years (odds ratio [OR],0.595; 95 % CI, 0.357–0.993; $P = 0.047$; compared with ≤6 years) was inversely associated with poor near stereoacuity, whereas the duration of misalignment more than 4 years (>4 years: OR, 2.474; 95%CI, 1.548–3.954; $P < 0.001$; compared with ≤2 years), amblyopia (OR, 4.057; 95%CI, 2.013–8.176; $P < 0.001$), large exodeviation at distance (30~60PD: OR, 1.810; 95%CI, 1.189–2.755; $P = 0.006$; >60PD: OR, 2.462; 95%CI, 1.405–4.313; $P = 0.002$; compared with ≤30PD) and anisometropia >1.00D (1.00–2.00D: OR, 1.769; 95 % CI, 1.060–2.950; $P = 0.029$; >2.00D: OR, 3.874; 95%CI, 2.003–7.496; $P < 0.001$, compared with ≤1.00D) were positively associated with poor near stereoacuity.

3.4. Risk factors associated with distance stereoacuity in CI-type X(T)

The influencing factors for poor distance stereoacuity determined by the logistic regression model are presented in Table 4.

The age of onset older than 6 years (6–9 years: OR, 0.397; 95%CI, 0.193–0.818; $P = 0.012$; >9 years: OR, 0.317; 95%CI, 0.155–0.652; $P = 0.002$; compared with ≤3 years) was associated with better distance stereoacuity (Table 4). Exodeviation at distance

Table 4
Univariable and multivariable logistic regression analyses for distance stereoacuity CI-type (X)T.

Variables	Without stereoacuity (n = 523)	With stereoacuity (n = 92)	Univariable analysis		Multivariable analysis	
			OR(95%CI)	*P* value	OR(95%CI)	*P* value
Gender						
Male	296(56.6 %)	40(43.5 %)	Reference			
Female	227(43.4 %)	52(56.5 %)	0.590 (0.377–0.922)	**0.021**		
Age of surgery(years)						
≤6	107(20.5 %)	12(13.0 %)	Reference			
6~12	211(40.3 %)	57(62.0 %)	0.415 (0.214–0.807)	**0.010**		
12~18	75(14.3 %)	13(14.1 %)	0.647 (0.280–1.496)	0.309		
18~24	59(11.3 %)	5(5.4 %)	1.323 (0.445–3.938)	0.615		
24~30	40(7.6 %)	4(4.3 %)	1.121 (0.342–3.681)	0.850		
>30	31(5.9 %)	1(1.1 %)	3.477 (0.435–27.795)	0.240		
Age of onset(years)						
≤3	174(33.3 %)	15(16.3 %)	Reference		Reference	
3~6	114(21.8 %)	21(22.8 %)	0.468 (0.232–0.946)	**0.034**	0.606 (0.290–1.266)	0.183
6~9	101(19.3 %)	27(29.3 %)	0.322 (0.164–0.635)	**0.001**	0.397 (0.193–0.818)	**0.012**
>9	134(25.6 %)	29(31.5 %)	0.398 (0.205–0.773)	**0.006**	0.317 (0.155–0.652)	**0.002**
Duration of misalignment(years)						
≤2	190(36.3 %)	56(60.9 %)	Reference			
2~4	102(19.5 %)	11(12.0 %)	2.733 (1.371–5.447)	**0.004**		
>4	231(44.2 %)	25(27.2 %)	2.723 (1.637–4.531)	**<0.001**		
Amblyopia						
No	478(91.4 %)	87(94.6 %)	Reference			
Yes	45(8.6 %)	5(5.4 %)	1.638 (0.632–4.243)	0.309		
Horizontal exodeviation angle at near(PD)						
≤30	6(1.1 %)	7(7.6 %)	Reference			
30~60	216(41.3 %)	61(66.3 %)	4.131 (1.339–12.748)	**0.014**		
>60	301(57.6 %)	24(26.1 %)	14.632 (4.555–47.002)	**<0.001**		
Horizontal exodeviation angle at distance(PD)						
≤30	157(30.0 %)	64(69.6 %)	Reference		Reference	
30~60	240(45.9 %)	25(27.2 %)	3.913 (2.364–6.479)	**<0.001**	4.283 (2.547–7.203)	**<0.001**
>60	126(24.1 %)	3(3.3 %)	17.121 (5.254–55.791)	**<0.001**	23.513 (7.051–78.406)	**<0.001**
NDD(PD)						
10	133(25.4 %)		25(27.2 %)		Reference	
11~20	189(36.1 %)		30(32.6 %)		1.184 (0.666–2.105)	0.565
21~30	91(17.4 %)		18(19.6 %)		0.950 (0.490–1.842)	0.880
31~40	65(12.4 %)		13(14.1 %)		0.940 (0.452–1.956)	0.868
>40	45(8.6 %)		6(6.5 %)		1.410 (0.544–3.656)	0.480
Vertical deviation angle(PD)						
≤5	440(84.1 %)		85(92.4 %)		Reference	
6~10	72(13.8 %)		6(6.5 %)		2.318 (0.976–5.503)	0.057
>10	11(2.1 %)		1(1.1 %)		2.125 (0.271–16.677)	0.473
IOOA						
No	268(51.2 %)		56(60.9 %)		Reference	
Yes	255(48.8 %)		36(39.1 %)		1.480 (0.941–2.327)	0.089

(*continued on next page*)

Table 4 (*continued*)

Variables	Without stereoacuity (n = 523)	With stereoacuity (n = 92)	Univariable analysis		Multivariable analysis			
			OR(95%CI)	*P* value	OR(95%CI)	*P* value		
BCVA, logMAR, Dominant eye								
≤0.10	463(88.5 %)	88(95.7 %)	Reference		Reference			
≥0.20	60(11.5 %)	4(4.3 %)	2.851 (1.010–8.046)	**0.048**	2.987 (1.009–8.839)	**0.048**		
BCVA, logMAR, Non-dominant eye								
≤0.10	448(85.7 %)	86(93.5 %)	Reference					
≥0.20	75(14.3 %)	6(6.5 %)	2.400 (1.012–5.687)	**0.047**				
Sphere (D), Dominant eye								
0.49~+1.99	292(55.8 %)	43(46.7 %)	Reference					
2.99~-0.50	154(29.4 %)	33(35.9 %)	0.687 (0.419–1.126)	0.137				
5.99~-3.00	46(8.8 %)	14(15.2 %)	0.484 (0.245–0.954)	**0.036**				
≤-6.00	17(3.3 %)	1(1.1 %)	2.503 (0.325–19.292)	0.378				
≥+2.00	14(2.7 %)	1(1.1 %)	2.062 (0.264–16.077)	0.490				
Sphere (D), Non-dominant eye								
0.49~+1.99	236(45.1 %)	34(37.0 %)	Reference					
2.99~-0.50	157(30.0 %)	36(39.1 %)	0.628 (0.377–1.047)	0.074				
5.99~-3.00	84(16.1 %)	19(20.7 %)	0.637 (0.345–1.177)	0.150				
≤-6.00	25(4.8 %)	1(1.1 %)	3.602 (0.473–27.447)	0.216				
≥+2.00	21(4.0 %)	2(2.2 %)	1.513 (0.339–6.741)	0.587				
Astigmatism (D), Dominant eye								
≤0.50	292(55.8 %)	53(57.6 %)	Reference					
0.51–1.00	126(24.1 %)	24(26.1 %)	0.953 (0.563–1.612)	0.857				
1.01–1.50	54(10.3 %)	10(10.9 %)	0.980 (0.470–2.045)	0.957				
1.51–2.00	32(6.1 %)	4(4.3 %)	1.452 (0.493–4.275)	0.498				
>2.00	19(3.6 %)	1(1.1 %)	3.449 (0.452–26.312)	0.232				
Astigmatism (D), Non-dominant eye								
≤0.50	268(51.2 %)	53(57.6 %)	Reference					
0.51–1.00	136(26.0 %)	19(20.7 %)	1.416 (0.806–2.486)	0.227				
1.01–1.50	50(9.6 %)	14(15.2 %)	0.706 (0.364–1.369)	0.303				
1.51–2.00	39(7.5 %)	4(4.3 %)	1.928 (0.661–5.623)	0.229				
>2.00	30(5.7 %)	2(2.2 %)	2.966 (0.688–12.791)	0.145				
Spherical equivalent (D), Dominant eye								
0.49~+1.99	242(46.3 %)	33(35.9 %)	Reference					
2.99~-0.50	186(35.6 %)	38(41.3 %)	0.667 (0.403–1.105)	0.116				
5.99~-3.00	56(10.7 %)	17(18.5 %)	0.449 (0.234–0.863)	**0.016**				
≤-6.00	22(4.2 %)	3(3.3 %)	1.00 (0.284–3.525)	1.000				
≥+2.00	17(3.3 %)	1(1.1 %)	2.318 (0.299–17.995)	0.421				
Spherical equivalent (D), Non-dominant eye								
0.49~+1.99	207(39.6 %)	29(31.5 %)	Reference					
2.99~-0.50	162(31.0 %)	36(39.1 %)	0.630 (0.371–1.072)	0.088				
5.99~-3.00	95(18.2 %)	23(25.0 %)	0.579 (0.318–1.053)	0.073				
≤-6.00	33(6.3 %)	2(2.2 %)	2.312 (0.527–10.147)	0.267				

(*continued on next page*)

Table 4 (*continued*)

Variables	Without stereoacuity (n = 523)	With stereoacuity (n = 92)	Univariable analysis		Multivariable analysis	
			OR(95%CI)	*P* value	OR(95%CI)	*P* value
≥+2.00	26(5.0 %)	2(2.2 %)	1.821 (0.411–8.079)	0.430		
Anisometropia(D)						
≤1.00	373(71.3 %)	73(79.3 %)	Reference			
1.01–2.00	89(17.0 %)	10(10.9 %)	1.742 (0.865–3.508)	0.120		
>2.00	61(11.7 %)	9(9.8 %)	1.326 (0.631–2.790)	0.456		

PD: prism diopters; NDD: near-distance disparity; IOOA: inferior oblique overaction; BCVA: best corrected visual acuity; D: diopters.

larger than 30 PD (30~60PD: OR, 4.283; 95%CI, 2.547–7.203; $P < 0.001$; >60PD: OR, 23.513; 95%CI, 7.051–78.406; $P < 0.001$; compared with ≤30PD), and dominant eye BCVA worsen than 0.20 (≥0.20: OR, 2.987; 95%CI, 1.000–8.839; $P = 0.048$; compared with ≤0.10) were risk factors associated with poor distance stereoacuity.

4. Discussion

Using medical data from 837 participants of CI-type X(T) and basic-type X(T), we presented much-needed information evaluating the characteristics and associated risk factors that damage stereoacuity for CI-type X(T). The disparities in CI-type X(T) and basic-type X(T) included surgery age, duration of misalignment, distance exodeviation, sensory status, and the presence of ocular muscle dysfunction. Onset age, duration of misalignment, amblyopia, distance exodeviation angle, dominant eye BCVA, and large SE gap between the two eyes were associated with poor stereoacuity in CI-type X(T). The understanding of demographic and clinical characteristics of CI-type X(T) helps to develop clinical management strategies and extend precision monitoring to populations at high risk of poor stereoacuity.

In our study, although similar in the age of onset, the age of surgery for CI-type X(T) was younger than basic-type X(T). CI-type X(T) is always compared with eye strain, and diplopia owing to the eyes do not converge adequately, leading to an inability to concentrate when reading or near vision work [10]. They have more opportunities to visit clinics and treatment early than basic-type X(T).

We found that younger age at onset and surgery age under 6 years were significantly associated with a higher risk of poor stereoacuity. This doesn't implicitly mean that procedure time should be postponed for early-onset X(T). Stereoacuity emerges primarily from 3 months of age and gradually reaches adult levels at the youngest age about 4 years [14,15]. Previous studies [16] have mostly suggested that early-onset X(T) affects stereoacuity, mainly by interfering with the normal development of stereopsis and disrupting fusion function [17]. Consequently, most of the early-onset X(T) patients required early surgery to realign the two eyes timely to stimulate the visual cortex producing stereoacuity [18]. Further, Abroms et al. [19] suggested that timely surgical intervention was more likely to achieve a superior sensory outcome for patients who had a misalignment 5 years' duration or less. We observed an increased likelihood of damage to stereoacuity with a duration of misalignment of more than 4 years, which was helpful determine the severity and thus as a criterion for deciding the surgical intervention timing.

Surprisingly, no statistically significant was found in near exodeviation but remarked difference in distance exodeviation between CI-type X(T) and basic-X(T). Similar to our study, Lee et al. [20] reported that near exodeviation was similar in both types, and distance exodeviation was smaller in CI-type X(T). The reasons behind this observation are likely related to the excessive distance fusional drive in CI-type X(T), and further study may contribute to uncovering the underlying reasons for CI. Besides, the near and distance stereoacuity of CI-type X(T) was better than basic-type X(T). A similar trend was also found in the suppression test. Hong et al. [21] proclaimed the ratio of presence near stereoacuity was higher at 19.3 % in CI-type X(T) than in basic-type X(T), similar to 16.7 % in the present study. The reason may be the small distance angle, which made it easy to keep exophoria and binocular fusion. In addition, lower prevalence of ocular muscle dysfunction is beneficial for preserving stereoacuity in CI-type X(T).

Our result demonstrated that larger distance exodeviation was a more important contributor to poor stereoacuity both at near and distance in CI-type X(T). In different studies, there are conflicting results about the relationship between deviation angle and stereoacuity. It is mainly due to the following two possible hypotheses: firstly, the measurement was instability both in angle magnitude and stereoacuity during the day because of the intermittent fixation; secondly, the fusion function broken by occlusion changed the angle of deviation [22]. Nevertheless, the maximal exodeviation angle was measured by PACT after 1 h of diagnosis of monocular occlusion. Although both exodeviation and type of X(T) changed after occlusion, the success rate of surgery significantly improved [23]. Therefore, the angle measured after occlusion was relatively stable and reliable. Moreover, by performing test-retest stereoacuity measurements, the results were accurate and credible in this study.

Zhong et al. [24] measured dynamic stereopsis (the detection sensitivity was higher than that of static stereopsis) to demonstrate the significant relationship between exodeviation and stereoacuity. They [24] concluded the result that larger exodeviation had poor stereoacuity. The reasons might be as follows. Stereoacuity is the computation of depth that relies on binocular vision and the disparity between the images of a target in the left and right eyes [25,26]. The orthotopic position is the basis of disparity. In CI-type X(T) patients, small distance exodeviation made it easier to control the ocular position as orthotopic which stimulated the cortical visual center and established stereoacuity [22,27]. Further studies with data on control and duration of misalignment per day are needed to

explore determinant reasons for the relationship between exodeviation angle and stereoacuity.

The present study reported a higher risk of stereoacuity in amblyopia and worse dominant eye BCVA. As severe amblyopia tended to progress to constant exotropia, almost all amblyopia was mild in this study. Whereas, blurred retinal imaging due to worse dominant eye BCVA or amblyopia rendered fusion tenuous, which caused poor stereoacuity [17]. This result suggested that intervention of amblyopia is beneficial for stereoacuity in X(T).

Additionally, the result of an association between anisometropia and a higher risk of poor stereoacuity was not surprising. A similar observation was reported in Han et al. [28]' study. They [28] reported that the preservation rate of near stereoacuity was 55.6 % in the anisometropia group, which was significantly lower than other refractive error groups. For patients with anisometropia, the difficulty in the fusion of the binocular retinal images increased with the degree of anisometropia, contributing to poor stereoacuity.

This study has several limitations as well. First, because our research was conducted in a single center and based on the hospital, these results might not reflect the tendency in the general population of individuals with CI-type X(T). Although cross-sectional stereoacuity distributions in different age groups suggest age-related trends, only longitudinal data can provide definitive evidence that the disease duration damage stereoacuity. Second, the onset age was first detected by the self-report from the patient or parents, so we observed their previous photographs to confirm. Third, the Titmus test provides the subject with monocular cues. Although some studies [29] defined poor stereoacuity as 800 arcsec or worse, stereoacuity from 400 to 800 arcsec was considered poor in our study to avoid overestimating the preservation rate of near stereoacuity.

In conclusion, we described the demographic and clinical characteristics of CI-type X(T) by comparing the parameters with basic-type X(T) and established a strong dose-dependent link between early age of onset, long duration of misalignment, worse dominant eye BCVA, distance exodeviation, and poor stereoacuity and confirmed the role of other risk factors, such as amblyopia, anisometropia. These observations helped to deepen our knowledge of CI-type X(T) as well as promote developing effective clinical management strategies. Our study provided important insight into helping ophthalmologists and patients in making decisions regarding the timing of surgical intervention and early management of amblyopia and refractive error. However, a longitudinal prospective study is needed both to better control the interference of confounders and to evaluate the potential impact of early treatment.

Data Availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Consent to participate

We have informed consent from the patient.

Declaration of Helsinki

We confirm that the study and data collection are compliant with the principles of the Declaration of Helsinki.

Table of contents statement

The study aims to investigate characteristics and risk factors of poor stereoacuity of Convergence insufficiency-type Intermittent Exotropia (CI-type X(T)). CI-type X(T) declined surgery early, with small distance exodeviation, better sensory status, and low incidence of ocular muscle dysfunction. A strong dose-dependent link between early onset age, long misalignment duration, worse dominant eye BCVA, distance exodeviation, amblyopia, anisometropia, and poor stereoacuity was confirmed.

CRediT authorship contribution statement

Lu Zhang: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Kaiqiao He:** Writing – review & editing, Supervision, Software, Data curation. **Zijian Wang:** Writing – review & editing, Supervision, Software, Data curation. **Guiou Zhang:** Writing – review & editing, Supervision, Software, Data curation. **Namin Li:** Writing – review & editing, Supervision. **Xiaoni Yu:** Writing – review & editing, Supervision. **Changmei Guo:** Writing – review & editing, Supervision, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Changmei Guo reports article publishing charges was provided by Natural Science Basic Research Program of Shaanxi Province. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have

appeared to influence the work reported in this paper.

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