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Amblyopia Care Trends Following Widespread Photoscreener Adoption

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Invited Commentary

Supplemental content

IMPORTANCE Amblyopia can result in permanent vision loss if not properly treated before age 7 years. In 2017, the US Preventive Services Task Force recommended that vision screening should occur at least once in all children aged 3 to 5 years to detect amblyopia.

OBJECTIVE To understand trends and factors associated with screening, referral, or diagnosis of amblyopia before and after photoscreening expansion across a relatively large health care system in late 2017.

DESIGN, SETTING, AND PARTICIPANTS This is a retrospective cohort study of electronic health record data from patients with a well child care visit at approximately age 3 years (ages 2.75-3.25 years) in a relatively large, multispecialty group practice in Northern California and linked census data between 2015 and 2022. Data were extracted and analyzed from October 2022 through August 2023.

EXPOSURES Patient sex, race and ethnicity, immunization records, previous well child care visits, and census-level median household income.

MAIN OUTCOMES AND MEASURES Vision screening, pediatric ophthalmology referral, or amblyopia diagnosis, compared using adjusted odds ratios (AORs).

RESULTS The study included 2015-2017 data from 23 246 patients aged 3 years with at least 1 well child care visit (11 206 [48.2%] female) compared with 2018-2022 postexpansion data from 34 281 patients (16 517 [48.2%] female). The screening rate increased from 5.7% (424 of 7505) in 2015 to 72.1% (4578 of 6354) in 2022. The referral rate increased from 17.0% (1279 of 7505) in 2015 to 23.6% (1836 of 7792) in 2018. The diagnosis rate was 2.7% (200 of 7505) in 2015, peaked at 3.4% (263 of 7792) in 2018, and decreased to 1.4% (88 of 6354) in 2022. Compared with White patients, patients who were Asian, Black, or Hispanic were less likely to be screened (Asian: AOR, 0.80; 95% CI, 0.72-0.88; Black: AOR, 0.71; 95% CI, 0.53-0.96; Hispanic: AOR, 0.88; 95% CI, 0.80-0.97). Compared with White patients, patients who were Asian or Hispanic were more likely to be referred (Asian: AOR, 1.49; 95% CI, 1.36-1.62; Hispanic: AOR, 1.32; 95% CI, 1.18-1.48) and were more likely to be diagnosed (Asian: AOR, 1.29; 95% CI, 1.07-1.56; Hispanic: AOR, 1.67; 95% CI, 1.33-2.11).

CONCLUSIONS AND RELEVANCE In this study, increased availability of photoscreeners was associated with an increase in overall rates of vision screening for children aged 3 years in a relatively large health care system. Given that US rates of visual impairment are predicted to increase, additional targeted interventions would be needed to address remaining disparities in amblyopia care along patient- and clinician-level factors.

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Amblyopia is a disease with subnormal visual acuity from an abnormal early visual experience of the brain. Amblyopia can affect 1 or both eyes and can result in permanent vision loss if not properly identified and treated before age 7 years.[1-3] Researchers estimate that between 1% and 6% of children younger than 6 years have amblyopia or associated risk factors.[1] In 2017, the US Preventive Services Task Force (USPSTF) recommended that vision screening occur at least once in all children aged 3 to 5 years to detect amblyopia or its risk factors.[1,4] However, the actual screening rate among children aged 3 years is approximately 40%,[1,5] leaving substantial room for improvement.

One reported reason for lack of screening, particularly at the annual well child care examination, is time constraints to provide accurate and efficient screening.[6,7] To solve this problem, several user-friendly objective vision screening devices give automated estimates of refractive error. Previous research found that vision screening increased from 10% to 80% with the Plusoptix photoscreener (Plusoptix Inc).[6]

Disparities exist for pediatric patients receiving eye care along characteristics of socioeconomic status[8] and race and ethnicity.[9] One photoscreening region increased vision screening rates and suggested that photoscreening could decrease disparity.[10]

Expanding our previous work of a small photoscreening implementation,[6] we examined trends and factors associated with screening, referral, or diagnosis of amblyopia before and after expansion of photoscreening across a relatively large health care system in late 2017 after USPSTF recommendation.

Key Points

Question Is expanding photoscreening across a relatively large health care system associated with screening, referral, or diagnosis of amblyopia?

Findings In this cohort study of 57 527 patients aged 3 years from a multispecialty group practice in Northern California, screening rates increased from 5.7% in 2015 to 72.1% in 2022 after photoscreening expansion; however, compared with White patients, patients who were Asian, Black, and Hispanic were less likely to be screened.

Meaning Overall rates of vision screening increased after photoscreening expansion, but additional targeted interventions would be needed to address remaining disparities in amblyopia care.

Methods

Palo Alto Medical Foundation (PAMF) is a large, multispecialty group practice in Northern California serving approximately 1 million patients annually in the San Francisco Bay area. The Sutter Health Institutional Review Board approved the study and granted a waiver of informed consent given the large number of electronic health records (EHRs). We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Before 2018, only 1 pediatric clinic had a photoscreening device.[6] In 2018, at least 1 photoscreening device was provided to all PAMF primary care sites. Each new site received staff and clinician training about workflows to conduct photoscreenings.

The study cohort of this EHR retrospective analysis and linked census data included patients aged approximately 3 years (defined as 2.75-3.25 years to capture data from patients who had a visit slightly before or after turning 3 years old) and had a well child care visit at PAMF between January 1, 2015, and December 31, 2022.

Outcome Variables

We focused on patients who (1) underwent vision screening, (2) were referred to pediatric ophthalmology, or (3) were diagnosed with amblyopia. We used billing data to identify vision screening (*Current Procedural Terminology* codes 99174 and 99177 with and without modifier 59 for use of a photoscreener) and amblyopia diagnosis (*International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* codes H53.0+). EHR referral order data identified pediatric ophthalmology referrals, including those for patients who did not receive vision screening during PAMF well child care visits. Screening, referral, or diagnosis rates were computed using the number of patients in our cohort (aged 3 years with a well child care visit during the study period) as the denominator.

Factors Associated With Amblyopia Screening, Referral, or Diagnosis

Despite PAMF's late 2017 systemwide adoption of photoscreeners, we hypothesized that screening, referral, or diagnosis rates may vary across specific patient subgroups. We examined patient demographic characteristics of sex, race and ethnicity (obtained from the EHR, which listed the following options: Asian, Black, Hispanic, White, other [American Indian, multiracial, Native Hawaiian, and other race not further specified], and unknown), immunization records, previous well child care visits, age at vaccination, and census-level median household income not inflation adjusted. Adherence to the recommended schedule for well child care visits and immunizations was viewed as a proxy for a more prevention-oriented guardian. The recommended number of well child care visits, 14, did not change between 2015 and 2022.[11] For immunizations, we followed the minimum recommended number of doses, as there can be varying doses for certain vaccine types. We did not include influenza or COVID-19 vaccinations as it may have been more difficult for guardians to obtain these during the COVID-19 pandemic. The primary vaccines and recommended doses remained the same from 2015 through 2022 (excluding influenza and COVID-19), ranging from 23 to 25.[12,13] We classified previous well child care visits, immunizations, and census-level median household income into 3 levels (low, medium, high) using cutoff values for the tertile distribution of each variable. PAMF is divided into 5 geographic areas, with each area comprising several neighboring cities.

Clinician-level factors included their department location, race and ethnicity (obtained from the EHR with the following options: Asian, Black, Hispanic, White, multiracial, and unknown), sex, and PAMF years of service.

Statistical Analysis

We examined screening, referral, or diagnosis trends over an 8-year period, including a preexpansion phase (2015-2017) and a postexpansion phase (2018-2022). We then focused on factors associated with outcomes during postexpansion, allowing identification of variability and opportunity to improve screening or referral rates. χ^2 Tests examined bivariate associations of patient and clinician characteristics with the outcomes. Multivariate logistic regression was used to estimate adjusted odds ratios (AORs) and 95% CIs, adjusting for covariates and accounting for clustering of patients cared for by the same clinicians. Final models included factors we hypothesized could be associated with these outcomes. All *P* values were 2-sided and were not adjusted for multiple analyses. Analyses were conducted using Stata version 16.1 statistical software (StataCorp LLC).

Results

During the 2015-2017 preimplementation period, 23 246 patients aged 3 years had at least 1 well child care visit. Among them, 11 206 (48.2%) were female; 7658 (32.9%) were Asian, 130 (0.6%) were Black, 2434 (10.5%) were Hispanic, 5800 (25.0%) were White, 2599 (11.2%) were of other race and ethnicity, and 4625 (19.9%) had unknown race and ethnicity. Patients went to a mean (SD) of 7.2 (3.8) previous well child care visits and received a mean (SD) of 16.1 (3.0) vaccinations. Median (IQR) household income was $108 655 ($92 336-$129 668). A total of 16 424 patients (70.6%) were cared for by female primary care clinicians; among primary care clinicians, 7390 (31.8%) were Asian, 289 (1.2%) were Black, 740 (3.2%) were Hispanic, more than 13 966 (>60.1%) were White, fewer than 11 (<0.1%) were multiracial, and 850 (3.7%) had unknown race and ethnicity. The mean (SD) number of PAMF service years for clinicians was 17 (7.0) years. Fewer patients received their 3-year well child care visit in geographic areas C and E (3122 [13.4%] and 2032 [8.7%], respectively) than in areas A, B, and D (5221 [22.5%], 7786 [33.5%], and 5085 [21.9%], respectively) (**Table 1**).

During the 2018-2022 postimplementation period, 34 281 patients aged 3 years had at least 1 well child care visit. Among them, 16 517 (48.2%) were female; 11 506 (33.6%) were Asian, 205 (0.6%) were Black, 3633 (10.6%) were Hispanic, 7813 (22.8%) were White, 4175 (12.2%) were of other race and ethnicity, and 6949 (20.3%) had unknown race and ethnicity. Patients went to a mean (SD) of 8.5 (3.6) previous well child care visits and received a mean of 15.3 (2.7) vaccinations. Median (IQR) household income was $139 716 ($116 269-$161 827). Nearly three-quarters (25 456 [74.3%]) were cared for by female clinicians; among clinicians, 11 740 (34.3%) were Asian, 495 (1.4%) were Black, 1052 (3.1%) were Hispanic, more than 19 928 (>58.2%) were White, fewer than 11 (<0.1%) were multiracial, and 1055 (3.1%) had unknown race and ethnicity. The mean (SD) number of PAMF service years for clinicians was 15 (6.4) years. Fewer patients received their 3-year well child care visit in geographic areas C and E (4311 [12.6%] and 2897 [8.5%], respectively) than in areas A, B, and D (7785 [22.7%], 12 256 [35.8%], and 7032 [20.5%], respectively) (Table 1).

Screening, Referral, or Diagnosis Rates, 2015-2022

Screening rates ranged from 5.7% (424 of 7505) to 18.7% (1483 of 7927) in 2015-2017 and increased substantially to rates of 61.6% (4800 of 7792) to 72.1% (4578 of 6354) in 2018-2022 (**Figure 1**). We observed increasing rates of referral from 17.0% (1279 of 7505) in 2015 to 23.6% (1836 of 7792) in 2018, then a downward trend to 15.7% (997 of 6354) in 2022. Diagnosis rates ranged between 2.7% (200 of 7505) and 3.1% (243 of 7927) in 2015-2017, peaked at 3.4% (263 of 7792) in 2018, and decreased to 1.4% (88 of 6354) in 2022.

Increasing screening rates were consistent across racial and ethnic groups (**Figure 2**). Black patients had the lowest screening rate in 2020. By 2022, Black and Hispanic patients had lower screening rates compared with Asian and White patients (Asian, 73.1% [1705 of 2332]; Black, 58.5% [24 of 41]; Hispanic, 63.5% [431 of 679]; White, 74.3% [971 of 1306]; *P* < .001).

Factors Associated With Screening, Referral, or Diagnosis, 2018-2022

Screening

Before 2018, vision screening rates slightly increased over time from 5.7% (424 of 7505) in 2015 to 9.6% (752 of 7814) in 2016 to 18.7% (1483 of 7927) in 2017 (Figure 1). Adding more photoscreeners throughout the system led to a dramatic increase in screening to 61.6% (4800 of 7792) in 2018; the screening rate then steadily increased until peaking at 75.1% (4935 of 6574) in 2021 (Figure 1). Given the expanded adoption of screening in 2018, we focused on the postexpansion period to examine factors associated with screening. In the bivariate analyses examining the percentage distribution for screening across racial and ethnic groups, Black and Hispanic patients had relatively lower screening rates compared with Asian and White patients (Asian, 70.9% [8157 of 11 506]; Black, 65.9% [135 of 205]; Hispanic, 67.7% [2458 of 3633]; White, 70.8% [5531 of 7813]; *P* < .001) (**Table 2**). Patients were more likely to be screened if they were female than if they were male (70.3% [11 616 of 16 517] vs 69.3% [12 316 of 17 764]; *P* = .045), had more well child care visits (high, 78.1% [3294 of 4219]; medium, 70.5% [11 691 of 16 592]; low, 66.4% [8947 of 13 470]; *P* < .001), had more vaccinations (high, 71.7% [4538 of 6330]; medium, 70.5% [6989 of 9911]; low, 68.8% [12 405 of 18 040]; *P* < .001), resided in an area with higher median household income (high, 74.0% [8414 of 11 369]; medium, 70.2% [7895 of 11 248]; low, 65.3% [7503 of 11 483]; *P* < .001), or were cared for by Black clinicians (Asian, 70.6% [8283 of 11 740]; Black, 75.8% [375 of 495]; Hispanic, 68.4% [719 of 1052]; White, 69.4% [13 828 of 19 935]; *P* < .001). Patients cared for by PAMF clinicians with a shorter tenure (≤10 years) had a higher screening rate than longer-tenured PAMF clinicians (≤10 years, 78.0% [7172 patients]; 11-20 years, 69.8%

Table 1. Characteristics of Patients and Their Clinicians Before and After Photoscreener Implementation

Characteristic	No. (%) Preimplementation, 2015-2017 (n = 23 246)	No. (%) Postimplementation, 2018-2022 (n = 34 281)
Patients		
Sex		
Female	11 206 (48.2)	16 517 (48.2)
Male	12 040 (51.8)	17 764 (51.8)
Race and ethnicity[a]		
Asian	7658 (32.9)	11 506 (33.6)
Black	130 (0.6)	205 (0.6)
Hispanic	2434 (10.5)	3633 (10.6)
White	5800 (25.0)	7813 (22.8)
Other race or ethnicity[b]	2599 (11.2)	4175 (12.2)
Unknown	4625 (19.9)	6949 (20.3)
Well child care visits before 3-y visit, No.		
Mean (SD)	7.2 (3.8)	8.5 (3.6)
Median (IQR)	9 (4-10)	10 (8-11)
Vaccinations before 3-y visit, No.		
Mean (SD)	16.1 (3.0)	15.3 (2.7)
Median (IQR)	16 (15-17)	15 (14-16)
Household income, $		
Mean (SD)	111 306 (29 385)	140 129 (36 222)
Median (IQR)	108 655 (92 336-129 668)	139 716 (116 269-161 827)
Visit clinicians		
Sex		
Female	16 424 (70.6)	25 456 (74.3)
Male	6822 (29.4)	8805 (25.7)
Race and ethnicity[a]		
Asian	7390 (31.8)	11 740 (34.3)
Black	289 (1.2)	495 (1.4)
Hispanic	740 (3.2)	1052 (3.1)
White	>13 966 (>60.1)[c]	>19 928 (>58.2)[c]
Multiracial	<11 (<0.1)[c]	<11 (<0.1)[c]
Unknown	850 (3.7)	1055 (3.1)
PAMF service time, y		
Mean (SD)	17 (7.0)	15 (6.4)
Median (IQR)	16 (11-20)	15 (10-19)
Patient-clinician race and ethnicity concordance		
Same	7829 (33.7)	10 928 (31.9)
Different	10 096 (43.4)	15 535 (45.3)
Unknown	5321 (22.9)	7818 (22.8)
Geographic area[d]		
A	5221 (22.5)	7785 (22.7)
B	7786 (33.5)	12 256 (35.8)
C	3122 (13.4)	4311 (12.6)
D	5085 (21.9)	7032 (20.5)
E	2032 (8.7)	2897 (8.5)
Year		
2015	7505 (33.3)	NA
2016	7814 (33.6)	NA
2017	7927 (34.1)	NA
2018	NA	7792 (22.7)
2019	NA	8049 (23.5)
2020	NA	5512 (16.1)
2021	NA	6574 (19.2)
2022	NA	6354 (18.5)

Abbreviations: NA, not applicable; PAMF, Palo Alto Medical Foundation.

[a] Race and ethnicity for both patients and clinicians were obtained from the electronic health record.

[b] Other race or ethnicity includes American Indian, multiracial, Native Hawaiian, and other race not further specified in the health system electronic health record.

[c] Counts of 0 to 10 (multiracial) have been suppressed and the category with the highest frequency (White) has been coarsened to maintain anonymity.

[d] Each area comprises several neighboring cities, grouped together by PAMF.

Figure 1. Trends in Screening, Referral, and Diagnosis of Amblyopia From 2015 to 2022

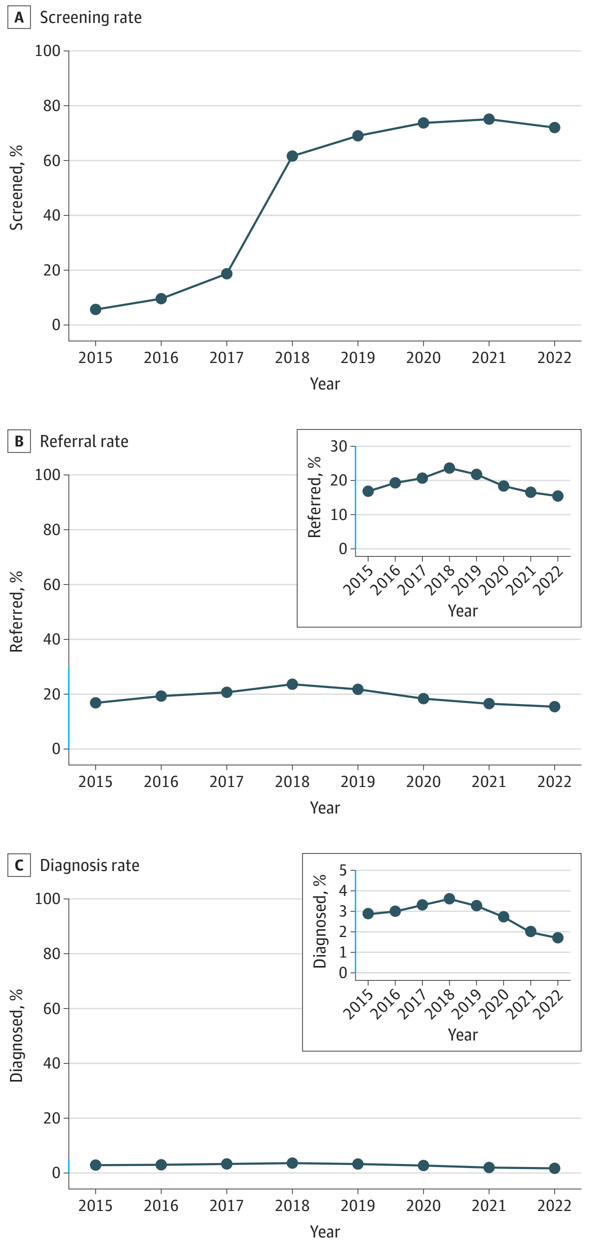
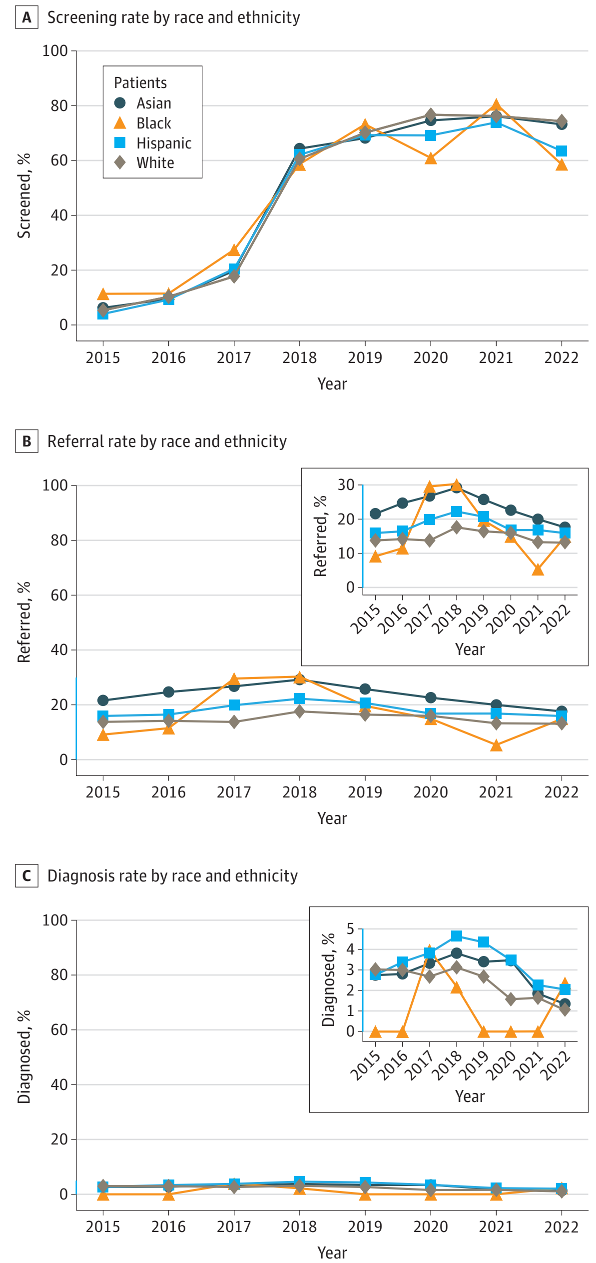


Figure 2. Trends in Screening, Referral, and Diagnosis of Amblyopia According to Race and Ethnicity From 2015 to 2022



Race and ethnicity were obtained from the electronic health record.

[9093 patients]; ≥21 years, 63.8% [3059 patients]; *P* < .001). Patients were less likely to be screened if they had their 3-year well child care visit in geographic areas C and E (57.3% [2470 of 4311] and 61.1% [1769 of 2897], respectively) than areas A and B (74.5% [5799 of 7785] and 74.8% [9162 of 12 256], respectively) (*P* < .001) (eFigure in Supplement 1).

For the multivariate regressions, compared with White patients, patients who were Asian, Black, or Hispanic were less likely to be screened (Asian: AOR, 0.80; 95% CI, 0.72-0.88; Black: AOR, 0.71; 95% CI, 0.53-0.96; Hispanic: AOR, 0.88, 95% CI, 0.80-0.97) (**Table 3**). Patients were more likely to be screened if they had more well child care visits compared with low well child care visits (high: AOR, 1.49; 95% CI, 1.29-1.71; medium: AOR, 1.21; 95% CI, 1.12-1.30), were more up-to-date with vaccinations compared with low vaccinations (high: AOR, 1.14; 95% CI, 1.05-1.23), resided in an area with a higher census-level household income compared with low household income (high: AOR, 1.20; 95% CI, 1.08-1.33), or were cared for by shorter-tenured PAMF clinicians compared with the longest tenure (≤10 years: AOR, 1.72; 95% CI, 1.12-2.65). Patients were less likely to be screened if they had their 3-year well child care visit in geographic area C (AOR, 0.57; 95% CI, 0.38-0.86) or E (AOR, 0.56; 95% CI, 0.40-0.78) compared with area A.

Table 2. Characteristics of 34 281 Patients and Their Clinicians by Screening, Referral, or Diagnosis of Amblyopia Following Photoscreener Implementation

Characteristic	Screening (n = 23 932 [69.8%])		Referral (n = 6718 [19.6%])		Diagnosis (n = 867 [2.5%])	
	No. (%)	*P* value	No. (%)	*P* value	No. (%)	*P* value
Patients						
Sex						
Female	11 616 (70.3)	.045	3187 (19.3)	.18	442 (2.7)	.10
Male	12 316 (69.3)		3531 (19.9)		425 (2.4)	
Race and ethnicity[a]						
Asian	8157 (70.9)	<.001	2675 (23.3)	<.001	318 (2.8)	<.001
Black	135 (65.9)		36 (17.6)		<11[b]	
Hispanic	2458 (67.7)		677 (18.6)		123 (3.4)	
White	5531 (70.8)		1218 (15.6)		166 (2.1)	
Other race or ethnicity[c]	2868 (68.7)		777 (18.6)		91 (2.2)	
Unknown	4783 (68.8)		1335 (19.2)		167 (2.4)	
Well child care visits[d]						
Low	8947 (66.4)	<.001	2453 (18.2)	<.001	318 (2.4)	.27
Medium	11 691 (70.5)		3421 (20.6)		440 (2.7)	
High	3294 (78.1)		844 (20.0)		109 (2.6)	
Vaccinations[d]						
Low	12 405 (68.8)	<.001	3228 (17.9)	<.001	366 (2.0)	<.001
Medium	6989 (70.5)		2116 (21.4)		294 (3.0)	
High	4538 (71.7)		1374 (21.7)		207 (3.3)	
Household income[d]						
Low	7503 (65.3)	<.001	2234 (19.5)	.07	336 (2.9)	.001
Medium	7895 (70.2)		2282 (20.3)		280 (2.5)	
High	8414 (74.0)		2172 (19.1)		246 (2.2)	
Visit clinician						
Sex						
Female	18 122 (71.2)	<.001	5095 (20.1)	.001	653 (2.6)	.49
Male	5798 (65.9)		1619 (18.4)		214 (2.4)	
Race and ethnicity[a]						
Asian	8283 (70.6)	.002	2402 (20.5)	<.001	314 (2.7)	.37
Black	375 (75.8)		136 (27.5)		18 (3.6)	
Hispanic	719 (68.4)		218 (20.7)		27 (2.6)	
White	13 828 (69.4)		3759 (18.9)		487 (2.4)	
Multiracial	<11[b]		<11[b]		<11[b]	
Unknown	726 (68.2)		203 (19.2)		21 (2.0)	
PAMF service time, y						
1-10	7172 (78.0)	<.001	1860 (20.2)	<.001	249 (2.7)	<.001
11-20	9093 (69.8)		2574 (19.8)		355 (2.7)	
≥21	3059 (63.8)		1039 (21.7)		137 (2.9)	
Geographic area[e]						
A	5799 (74.5)	<.001	1655 (21.3)	<.001	235 (3.0)	<.001
B	9162 (74.8)		2629 (21.5)		306 (2.5)	
C	2470 (57.3)		659 (15.3)		69 (1.6)	
D	4732 (67.3)		1506 (21.4)		180 (2.6)	
E	1769 (61.1)		269 (9.3)		77 (2.7)	
Year						
2018	4800 (61.6)	<.001	1836 (23.6)	<.001	263 (3.4)	<.001
2019	5556 (69.0)		1742 (21.6)		254 (3.2)	
2020	4063 (73.7)		1042 (18.9)		139 (2.5)	
2021	4935 (75.1)		1101 (16.8)		123 (1.9)	
2022	4578 (72.1)		997 (15.7)		88 (1.4)	

Abbreviation: PAMF, Palo Alto Medical Foundation.

[a] Race and ethnicity for both patients and clinicians were obtained from the electronic health record.

[b] Counts of 0 to 10 have been suppressed to maintain anonymity.

[c] Other race or ethnicity includes American Indian, multiracial, Native Hawaiian, and other race not further specified in the health system electronic health record.

[d] Previous well child care visits, immunizations, and census-level median household income were categorized into 3 levels (low, medium, high) using cutoff values for the tertile distribution of each variable.

[e] Each area comprises several neighboring cities, grouped together by PAMF.

Table 3. Multivariate Regression Results for Screening, Referral, or Diagnosis of Amblyopia Following Photoscreener Implementation

	Screening		Referral		Diagnosis	
Characteristic	AOR (95% CI)	*P* value	AOR (95% CI)	*P* value	AOR (95% CI)	*P* value
Patients						
Sex						
Female	1.03 (0.98-1.08)	.26	0.96 (0.91-1.01)	.14	1.12 (0.98-1.28)	.10
Male	1 [Reference]		1 [Reference]		1 [Reference]	
Race and ethnicity[a]						
Asian	0.80 (0.72-0.88)	<.001	1.49 (1.36-1.62)	<.001	1.29 (1.07-1.56)	.008
Black	0.71 (0.53-0.96)	.02	1.06 (0.74-1.53)	.75	0.45 (0.11-1.79)	.26
Hispanic	0.88 (0.80-0.97)	.01	1.32 (1.18-1.48)	<.001	1.67 (1.33-2.11)	<.001
White	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Other race or ethnicity[b]	0.81 (0.74-0.88)	<.001	1.14 (1.03-1.25)	.01	1.06 (0.82-1.37)	.68
Unknown	0.78 (0.70-0.88)	<.001	1.14 (1.02-1.27)	.02	1.07 (0.86-1.33)	.57
Well child care visit[c]						
High	1.49 (1.29-1.71)	<.001	1.33 (1.19-1.49)	<.001	1.61 (1.26-2.06)	<.001
Medium	1.21 (1.12-1.30)	<.001	1.19 (1.13-1.26)	<.001	1.17 (0.99-1.37)	.06
Low	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Vaccinations[c]						
High	1.14 (1.05-1.23)	.002	1.04 (0.94-1.15)	.44	1.29 (1.07-1.56)	.009
Medium	1.05 (0.96-1.16)	.27	1.01 (0.94-1.09)	.82	1.09 (0.95-1.26)	.22
Low	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Household income[c]						
High	1.20 (1.08-1.33)	.001	0.89 (0.81-0.97)	.01	0.89 (0.74-1.06)	.19
Medium	1.08 (0.97-1.19)	.16	0.88 (0.81-0.95)	.001	0.86 (0.72-1.03)	.10
Low	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Visit clinician						
Sex						
Female	1.21 (0.88-1.66)	.24	1.14 (0.96-1.34)	.13	1.04 (0.87-1.25)	.67
Male	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
PAMF service time, y						
1-10	1.72 (1.12-2.65)	.01	0.95 (0.78-1.15)	.59	0.95 (0.73-1.23)	.68
11-20	1.16 (0.76-1.76)	.49	0.87 (0.72-1.05)	.14	0.92 (0.71-1.21)	.56
≥21	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
Geographic area[d]						
A	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
B	1.04 (0.79-1.37)	.76	1.04 (0.89-1.21)	.62	0.85 (0.71-1.02)	.08
C	0.57 (0.38-0.86)	.007	0.72 (0.53-0.96)	.03	0.61 (0.39-0.96)	.03
D	0.76 (0.53-1.09)	.13	1.09 (0.93-1.27)	.28	0.89 (0.70-1.13)	.34
E	0.56 (0.40-0.78)	.001	0.41 (0.32-0.52)	<.001	0.84 (0.57-1.24)	.39
Year						
2018	1 [Reference]	NA	1 [Reference]	NA	1 [Reference]	NA
2019	1.34 (1.11-1.62)	.002	0.89 (0.82-0.98)	.01	0.92 (0.76-1.11)	.37
2020	1.65 (1.37-1.98)	<.001	0.74 (0.68-0.81)	<.001	0.71 (0.58-0.88)	.002
2021	1.69 (1.39-2.06)	<.001	0.63 (0.56-0.71)	<.001	0.52 (0.41-0.67)	<.001
2022	1.42 (1.16-1.74)	.001	0.57 (0.50-0.66)	<.001	0.39 (0.29-0.51)	<.001

Abbreviations: AOR, adjusted odds ratio; NA, not applicable; PAMF, Palo Alto Medical Foundation.

[a] Race and ethnicity were obtained from the electronic health record.

[b] Other race or ethnicity includes American Indian, multiracial, Native Hawaiian, and other race not further specified in the health system electronic health record.

[c] Previous well child care visits, immunizations, and census-level median household income were categorized into 3 levels (low, medium, high) using cutoff values for the tertile distribution of each variable.

[d] Each area comprises several neighboring cities, grouped together by PAMF.

Referral

Referrals slightly increased in the preexpansion period from 17.0% (1279 of 7505) in 2015 to 20.6% (1633 of 7927) in 2017. They then increased more than in the overall postexpansion phase, during which 19.6% of patients (6718 of 34 281) were referred to pediatric eye care professionals between 2018 and

2022 (Figure 1 and Table 2). In the bivariate analyses examining the percentage distribution for referral across racial and ethnic groups, Asian patients had the highest referral rate, followed by patients who were Hispanic, Black, and White (Asian, 23.3% [2675 of 11 506]; Hispanic, 18.6% [677 of 3633]; Black, 17.6% [36 of 205]; White, 15.6% [1218 of 7813]; *P* < .001). Patients were more likely to be referred if they had more well child care visits (high, 20.0% [844 of 4219]; medium, 20.6% [3421 of 16 592]; low, 18.2% [844 of 4219]; *P* < .001), had received more vaccinations (high, 21.7% [1374 of 6330]; medium, 21.4% [2116 of 9911]; low, 17.9% [3228 of 18 040]; *P* < .001), were cared for by female clinicians (female clinician, 20.1% [5095 of 25 456]; male clinician, 18.4% [1619 of 8805]; *P* = .001), or were cared for by Black clinicians (Asian, 20.5% [2402 of 11 740]; Black, 27.5% [136 of 495]; Hispanic, 20.7% [218 of 1052]; White, 18.9% [3759 of 19 935]; *P* < .001). Patients who were cared for by PAMF clinicians with at least 21 years of service had a higher referral rate than shorter-tenured PAMF clinicians (≥21 years, 21.7% [1039 of 4798]; 11-20 years, 19.8% [2574 of 13 026]; ≤10 years, 20.2% [1860 of 9195]; *P* < .001). Patients were less likely to be referred if they had their 3-year well child care visit in geographic area C or E (15.3% [659 of 4311] and 9.3% [269 of 2897], respectively) than areas A, B, and D (21.3% [1655 of 7785], 21.5% [2629 of 12 256], and 21.4% [1506 of 7032], respectively) (*P* < .001).

Compared with White patients, Black patients had a comparable likelihood of referral, while Asian and Hispanic patients were more likely to be referred (Asian: AOR, 1.49; 95% CI, 1.36-1.62; Black: AOR, 1.06; 95% CI, 0.74-1.53; Hispanic: AOR, 1.32; 95% CI, 1.18-1.48) (Table 3). Patients were more likely to be referred if they had more well child care visits (high: AOR, 1.33; 95% CI, 1.19-1.49; medium: AOR, 1.19; 95% CI, 1.13-1.26). Patients who resided in areas with high or medium census-level household income were less likely to be referred than those who resided in the area with low household income (high: AOR, 0.89; 95% CI, 0.81-0.97; medium: AOR, 0.88; 95% CI, 0.81-0.95). Patients were less likely to be referred if they had their 3-year well child care visit in geographic area C (AOR, 0.72; 95% CI, 0.53-0.96) or E (AOR, 0.41; 95% CI, 0.32-0.52) compared with area A.

Diagnosis

Amblyopia diagnosis rates ranged from 2.7% (200 of 7505) in 2015 to 3.1% (243 of 7927) in 2017 and then decreased in the postexpansion phase, with 2.5% (867 of 34 281) of overall patients being diagnosed with amblyopia between 2018 and 2022 (Figure 1). In bivariate analyses examining the percentage distribution for diagnosis across racial and ethnic groups, Hispanic patients had the highest diagnosis rate, followed by patients who were Asian, White, or Black (Asian, 2.8% [318 of 11 506]; Black, 1.0% [<11 of 205]; Hispanic, 3.4% [123 of 3633]; White, 2.1% [166 of 7813]; *P* < .001). Patients were more likely to have an amblyopia diagnosis if they had more vaccinations (high, 3.3% [207 of 6330]; medium, 3.0% [294 of 9911]; low, 2.0% [366 of 18 040]; *P* < .001) or resided in areas with low census-level household income (low, 2.9% [336 of 11 483]; medium, 2.5% [280 of 11 248]; high, 2.2% [246 of 11 369]; *P* = .001). Patients cared for by PAMF clinicians with at least 21 years of service had a higher diagnosis rate than those cared for by shorter-tenured PAMF clinicians (≥21 years, 2.9% [137 of 4798]; 11-20 years, 2.7% [355 of 13 026]; ≤10 years, 2.7% [249 of 9195]; *P* < .001). Patients who had their 3-year well child care visit in geographic area C had the lowest rate of amblyopia diagnosis (1.6% [69 of 4311]), while those with visits in area A had the highest rate (3.0% [235 of 7785]) (*P* < .001).

Compared with White patients, Black patients had a comparable likelihood of amblyopia diagnosis, while Asian and Hispanic patients were more likely to be diagnosed with amblyopia (Asian: AOR, 1.29; 95% CI, 1.07-1.56; Black: AOR, 0.45; 95% CI, 0.11-1.79; Hispanic: AOR, 1.67; 95% CI, 1.33-2.11) (Table 3). Patients were more likely to be diagnosed if they had more well child care visits compared with low well child care visits (high: AOR, 1.61; 95% CI, 1.26-2.06) or if they had more vaccinations compared with low vaccinations (high: AOR, 1.29; 95% CI, 1.07-1.56). Patients were less likely to be diagnosed if they had their 3-year well child care visit in geographic area C (AOR, 0.61; 95% CI, 0.39-0.96) compared with area A.

Discussion

Rates of screening substantially increased to roughly 70% at our organization in 2017 and 2018 after implementing photoscreeners on a large scale throughout PAMF in response to USPSTF recommendations. While others have suggested that photoscreeners could decrease disparities,[10] we found that disparities persisted in our population despite photoscreening. In particular, Black children and Hispanic children received disparately less screening. It may be that some screening differences are due to factors regarding all photoscreening devices, which could potentially harbor bias. As Horwood et al stated, "Commercially sensitive software algorithms derived from largely Caucasian populations may not apply globally and although referral criteria can often be adjusted, background calculation of refractive error cannot."[3] Sravani et al called for "an ethnicity- or individual-specific defocus calibration factor for accurate estimation of refraction using photorefraction."[14]

With screening rates generally increasing since 2018, it was surprising that both referral and diagnosis rates have been decreasing during the same period. One potential explanation is that if there are access problems due to a lack of ophthalmologists, clinicians might "not want multiple false or borderline referrals"[3] when services are "stretched and scarce,"[3] possibly leading them to not refer as often. Diagnosis rates during this period ranged from 1.4% to 3.4%, which are still within reported estimates,[1] specifically for Hispanic patients[15] and Asian patients.[16] This may be due to some regional differences, as areas C and E were less likely to screen, refer, or diagnose amblyopia. This may have been due to a lack of pediatric ophthalmologists in these areas, as these regions are smaller and area C has lower median household income. Clinicians might be hesitant to perform a screening or make a referral if they are unable to connect patients with a specialist. This is consistent with research showing that the prevalence of pediatric ophthalmologists in a state is highly correlated with amblyopia diagnosis rates.[17]

We are unsure why the screening rate for Black patients increased in 2021 and then decreased in 2022, and this warrants future investigation. Interestingly, we found that Black clinicians were more likely to screen and refer patients. In an exploratory analysis, we examined patient-clinician race and ethnicity concordance, which we did not report because of the relatively small sample size for both Black clinicians and Black patients. The American Academy of Ophthalmology advocates for increasing diversity in ophthalmologists to improve vision health care for all individuals in the US,[18] and our findings suggest that this should also extend to increasing diversity for referring primary care clinicians as well since they are the ones largely conducting these initial screenings and referrals.

Given that a gap in screening rates remains despite increased access to photoscreeners at PAMF, another strategy could be to use the data from this analysis to create a predictive model for amblyopia risk factor diagnosis in 3-year-olds at well child care visits. This would incorporate what we have seen with race or ethnicity, socioeconomic status, region, and clinician characteristics, similar to what has been done for older children (aged 4-6 years).[19]

Limitations

This study has limitations. This was a retrospective cohort study using observational data. We adjusted for confounders in our analyses, but our study is subject to potential biases. Our results are associations and not cause-and-effect relationships. The timing of the large-scale photoscreener implementation in 2018 was around the same time the new USPSTF guidelines were released, so it is possible that the increase in screening rates could also be due to those guidelines or other unknown factors. A small pilot study implementing photoscreeners found an increase in screening rates of 80% after photoscreener introduction in 2010,[6] which suggests that photoscreeners could have had a similar impact in 2018, although this cannot be definitively determined. Our findings have limited generalizability as our study population has relatively high levels of income, driven by the socioeconomic status of people in the geographic area served by PAMF. It is possible we missed some previous diagnoses, referrals, well child care visits, and vaccinations that occurred outside our system. However, given Epic EHR's Care Everywhere health information exchange platform and our inclusion criteria stipulating a 3-year well child care visit, these previous encounters would likely have been pulled into our EHR. We may also have missed some visits due to our inclusion criteria being too narrow for the 3-year well child care visit (ages 2.75-3.25 years), particularly as the Centers for Disease Control and Prevention recommended very early in the COVID-19 pandemic to delay nonemergency care, such as preventive visits, to minimize the risk of contracting and spreading COVID-19.[20] However, we did not see a significant decrease when adjusting for the proportion of visits compared with other years. The USPSTF recommends increased screening for children aged 3 to 5 years, so it is possible that some clinicians waited until later visits to conduct screenings. Additionally, our data only show what was documented in the EHR in discrete fields; free-text notes may have indicated that clinicians had requested child screening but guardians declined.

Conclusions

Increasing the availability of photoscreeners was associated with increased overall vision screening rates in 3-year-olds in a relatively large health care system, yet disparities in amblyopia care persisted along patient- and clinician-level factors. Disparately untreated and undertreated children with amblyopia are at risk of reaching visual maturity with disease burdens that will accentuate the disproportionate impact of avoidable visual impairment. Given that rates of visual impairment in the US have been predicted to significantly increase by 2050,[21] our study highlights that more needs to be done beyond mass photoscreening to decrease existing disparities.

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