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Visual problems and falls

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Definitions

Visual functions are complex, but are remarkably well worked out in terms of their psychophysics and neurophysiology [1, 2]. The main functions from the point of view of assessing risk of falls are visual acuity, contrast sensitivity and depth perception.

- Visual acuity is a measure of spatial resolution, usually at high contrast, and is best described in terms of Minimum Angle Resolvable. More familiar are various letter charts, such as the Snellen or Bailey-Lovie charts [3, 4]. This sort of vision is used for perceiving fine detail.
- Contrast sensitivity is ability to detect stimuli of varying brightness against a background of a given brightness. It is measured as the difference in luminescence divided by the mean luminescence. It is useful for detecting large objects in a cluttered environment, including under sub-optimal illumination [2, 5].
- Depth perception comprises (binocular) stereopsis and monocular cues. Stereopsis is the ability to perceive objects in three dimensions, as a result of disparities in the retinal images of an object caused by the spatial separation of the eyes in the head. It operates within 'Panum's area'—for near vision, within a metre or so of the plane of fixation. It is measured as the angle (seconds of arc) of disparity that can be perceived as a single object. Monocular vision can be interpreted as indicating depth, including many techniques used by artists (perspective, interposition, scattering of light with distance, relative size) and motion cues (relative speed, motion parallax) [6].

These three functions are generally quite closely correlated ($r \sim 0.6$): poor performance on one implies poor performance on the others [5, 7]. For this reason it is difficult to disentangle exactly which function is most important. Some specific conditions lead to disparities between functions, for example amblyopia, or causes of unilateral blindness, early unilateral cataract, or unilateral cataract extraction in patients with bilateral cataract.

Other functions have also been considered, including visual field defects, glare, and visual sensitivity to light [8–10]. Some aspects which are likely to be important, including visual inattention and visual memory, have been studied little. Studies have also considered self-reported poor vision, use of topical eye medication [9] and different visual diagnoses. In general terms, it appears that overall visual function is more important than any particular diagnosis.

Studies of a possible association between vision and falls have used a number of different outcomes. These include balance, all falls, and second (recurrent) falls, usually within a 12-month period. Other studies have considered injurious falls or fractures. Some evidence suggests that poor vision is a risk factor for fracturing in a given fall [11], so it could primarily be a risk factor for fracturing rather than falling *per se*. The advantage of a restrictive outcome measure is that it reduces misclassification (of, for example, people who have fallen during hazardous activities), which would otherwise reduce the apparent strength of any real association between vision and a true propensity to fall [12]. Despite this practical constraint, it is important to realise that falls risk is a continuum. What varies, is the probability that an individual will fall during a given activity or external insult.

The balance system

There are two main influences on balance: the intrinsic mechanisms of postural control, and the extrinsic environmental and activity factors which challenge it. Vision is one of four sensory mechanisms which detect perturbations of balance (along with the vestibular apparatus, neck and lower limb proprioception and tactile sensation in the feet). This is demonstrated in swaymeter experiments—sway increases 50% or more with eyes closed compared with eyes open, both whilst standing on firm surfaces, and whilst standing on foam, where lower limb sensation is diminished [13, 14]. There are moderate correlations between measured visual function (acuity and contrast sensitivity) and sway [5, 14, 15]. Sway is strongly associated with future risk of falls [13].

The postural control system is most challenged during activity, or due to environmental or pathological conditions (for example, walking on thick carpet, peripheral neuropathy), and with age. Elderly people are more dependent on vision than the young—'Romberg's quotient' (sway eyes open/sway eyes closed), which describes the effect of visual stabilization on posture is 0.48 in patients over 85, compared with 0.78 at age

50–60 [16]. Visual mechanisms for correcting sway are relatively slow compared with muscle and tendon stretch receptors, with latencies of up to 200 Ms. Moreover, reaction times are generally increased in elderly people [13]. This explains, in part, why elderly people are less able to correct loss of balance sufficiently to stay upright.

Head movement has the potential to degrade visual images. The vestibulo-ocular reflex helps stabilize retinal images when movement occurs. Instability in vestibular disease may have a visual component because of this. Vision may also contribute to poor stability in dementia, because of loss of visual fixation. This is common in dementia, as demonstrated by EEG evidence [17].

Visual acuity

Poor visual acuity, variously defined, approximately doubles the risk of falls. The association is demonstrated in studies of different designs, in community, institutional and previous-faller populations, and with various different outcomes (Table 1) [5, 13, 18–26]. Adjustment for other falls risk factors generally has only a small effect suggesting that the relationship between vision and falls is not explained (or 'confounded') by any third factor. Caution is required, however. In a study of lateral stability, those who could perform a tandem stance with eyes open but not with eyes closed, had worse acuity than those with good balance. In this case, acuity (with eyes open) could have had nothing to do with the instability (which occurred when the eyes were closed)—other sensory mechanisms must have been involved as well [15].

The studies of Kelsey *et al.* [23] and Cummings *et al.* [24] demonstrate graded (or 'dose-response') relationships—falls risk decreases linearly with number of chart letters read (there are 70 letters on the type of chart used, the odds ratios quoted in Table 1 being approximately per standard deviation). This is demonstrated further in the French EPIDOS study [27]. The 7% with the worst vision (⩽2/10 using the decimal Snellen fraction) had 4.3 times greater risk than the 36% with normal vision (>7/10). Intermediate acuities were associated with progressively greater risks in between. Not all the evidence is this neat however. The Blue Mountains study showed increased risk, but in this relatively young population with good vision, risk did not decrease linearly with acuity [21]. The Framingham study showed a progressive decrease in hip fracture risk with better acuity in the *worse* eye [28]. Since binocular acuity approximates to acuity in the *better* eye, this led to the suggestion that it was not acuity itself, but something related to it, such as depth perception, which was important.

Depth perception

Studies have concentrated on stereopsis, since measurement of monocular depth perception is difficult. Various (monocular) illusions are potentially important, however, including moving repeating patterns (escalators, striped walls), and patterns on floor coverings [29, 30]. These illusions can cause misjudgement of depth. The temporary loss of focus on stairs when wearing bifocal spectacle lenses is another example.

Stereopsis is measured by considering the illusion of depth that arises when slightly disparate images are perceived by each retina (for example, the Wirt fly or Frisby tests). The greater the separation of images that can be seen as three dimensional, the better the depth perception. One hundred to 120 seconds of arc is approximately the standard deviation of the measures used (therefore, most of the population has stereopsis within about four times this range). Studies show relative risks of about two for poor depth perception, with graded relationships in some cases, although the evidence is thinner than for acuity (Table 2) [22–24, 28]. Some reports have indicated that an

Table 1. Association between falls risk and visual acuity

Study	Type	*N*	Outcome	Visual acuity	OR	Adjusted OR
Beaver Dam [18]	X sec	3722	2+ falls	6/7.5	2.6	–
Koski *et al.* [19]	Cohort	942	Injury	6/18	1.8	2.3
Grisso *et al.* [20]	Ca-co	348	Hip #	Self report	5.1	4.8
Blue Mountains [21]	X sec	3299	2+ falls	6/9	2.1	1.9
Nevitt *et al.* [22]	Cohort	325	2+ falls	6/15	1.5	NA
Tinetti *et al.* [25]	Cohort	336	1+ fall	>20% near vision loss	1.7	NA
Kelsey *et al.* [23]	Cohort	9704	Colles #	Per 10 letters	1.2	1.2 (2.1)
Cummings *et al.* [24]	Cohort	9516	Hip #	Per 7.4 letters	1.1	NA (1.5)
Lord *et al.* [13]	Cohort	341	0 *vs* 2+ falls	MAR 1.45 *vs* 1.68		

X sec = cross sectional; Ca-co = case-control; OR = odds ratio; NA = no significant association; MAR = minimum angle resolvable (minutes).
Number in parentheses represent estimates of OR for top versus bottom quarter.

association exists between falls risk and stereopsis, but did not quantify it or report it further where another (related) measure of visual function was more strongly associated [27].

Contrast sensitivity

Classically contrast sensitivity is measured using gratings (repeating patterns) of varying contrasts. For practical purposes there are letter charts of differing contrasts (Pelli-Robson) [31], and various ordinal scales [5]. Several studies have shown associations between contrast sensitivity and falls risk (Table 3) [13, 18, 21, 27]. Cummings *et al.* [24] and Lord *et al.* [26] demonstrated graded relationships with falls risk, and in these studies contrast sensitivity was more important than acuity in predicting falls.

Prevalence of visual problems

In the absence of ocular pathology, visual acuity and dark adaptation worsen after about age 50. The main influence on visual function with age, however, is the rapid increase in pathology with age. For example, the prevalence of visually impairing cataract in either eye increases from 17% at age 65 to 70% in the patients over 80 (Table 4) [32, 33]. This results in a sharp increase in the prevalence of both poor acuity and contrast sensitivity with age (Table 5) [13], and means that population prevalence figures are difficult to interpret without age-standardization. A population survey in London found 30% of people over 65 to have less than good vision; 6% were essentially blind [32]. Almost identical figures were reported by the French EPIDOS study, despite the older age range (75+) (Table 6) [27]—we might speculate on the extent to which this is due to better access to cataract surgery and optometry in France compared with the UK.

Institutional care residents have especially high prevalences of visual impairment, mostly caused by cataract or refractive errors [17, 34, 35]. Over half the patients in one study of elderly hospital in-patients had acuity of 6/18 or worse, rising to three-quarters if the admission was for falls [36].

Does poor vision cause falls?

The issue of causality is crucial if we want to intervene to prevent falls. Most of the standard criteria for assessing causality are met [37]. The strength of the association is only moderate, but is about the same as the increased risk of heart disease in smokers. There is a 'dose-response' relationship—falls risk increases with worse vision. Prospective studies demonstrate that poor vision precedes falls. There is good consistency between different types of studies in different populations. And poor vision provides a biologically plausible mechanism for predisposition to falls. The final criterion, that of experimental manipulation (a randomized controlled trial

Table 2. Association between falls risk and depth perception

Study	Type	*N*	Outcome	Stereopsis	OR	Adjusted OR
Nevitt *et al.* [22]	X sec	325	2+ falls	<200 sec arc	1.6	NA
			3+ falls	Per 120 sec arc	–	2.1 (9.3)
Kelsey *et al.* [23]	Cohort	9704	Colles #	Per 100 sec arc	1.2 (2.1)	–
EPIDOS [27]	Cohort	7575	Hip #	'Associated'		
Cummings *et al.* [24]	Cohort	9516	Hip #	Lowest quartile	2.1	1.9
Framingham [28]	Cohort	2633	Hip #	Acuity disparity	1.5	NA

X sec = cross sectional; OR = odds ratio; NA = no significant association.
Number in parentheses represent estimates of OR for top versus bottom quarter.

Table 3. Association between falls risk and contrast sensitivity

Study	Type	*N*	Outcome	Contrast sensitivity	OR	Adjusted OR
Beaver Dam [18]	X sec	2140	2+ falls	Log CS < 1.5	1.4	–
			Hip #		1.8	–
Blue Mountains [21]	X sec	2121	2+ falls	1–8 scale	1.2 (3.6)	–
EPIDOS [27]	Cohort	7575	Hip #	'Associated'		
Cummings *et al.* [24]	Cohort	9516	Hip #	Per SD	'Associated'	1.2 (1.7)
Lord *et al.* [5]	X sec	95	0 *vs* 1 *vs* 2+ falls	log CS 17.5 *vs* 16.5 *vs* 14.5		
Lord *et al.* [13]	Cohort	341	0 *vs* 2+ falls	log CS 21.6 *vs* 18.8		

X sec = cross sectional; OR = odds ratio; NA = no significant association; MAR = minimum angle resolvable (minutes).
Number in parentheses represent estimates of OR for top versus bottom category.

Table 4. Age-specific prevalence of acuity impairing cataract (6/12 or worse) in North London [33]

Age/years	Prevalence (either eye)	Unoperated prevalence
65–69	17%	11%
70–74	25%	20%
75–79	42%	33%
80–84	55%	49%
85–100	70%	56%

Table 5. Age-specific prevalence of moderate impairment in acuity and contrast sensitivity in Sydney [13]

	Age group		
	65–74 years	75–84 years	85+ years
N	228	157	22
Acuity <6/15	3.5%	14%	36%
Contrast sensitivity <16 dB	2.2%	10%	23%

Table 6. Prevalence of different visual acuities [27, 32]

	Acuity	Prevalence
EPIDOS study, France		
(aged 75+ years)	>7/10	36%
	5–7/10	36%
	3–4/10	20%
	⩽2/10	7%
North London		
(aged 65+ years)	⩾6/12	70%
	6/12–6/60	24%
	⩽6/60	6%

showing that improving vision decreases risk of falls) has not been demonstrated.

High prevalence risk factors with a moderately strong association can be very important at the population level. The population attributable risk fraction (PARF) is the theoretical extent to which abolishing a risk factor should prevent a condition [12]. This can be calculated at 13–74% for acuity, and 11–37% for contrast sensitivity and stereopsis. Since these are closely correlated (poor performance on one generally implies poor performance on the others) these figures cannot simply be added up. Moreover, it is possible that there are alternative explanations (confounding factors), in part at least, which account for the relationship, so these figures are imprecise. The only obvious potential confounder, however, is age, and empirical studies have not demonstrated strong confounding effects (crude and adjusted odds ratios are similar). These estimates should therefore be fairly robust.

Interventions

Provision of adequate glasses, and better access to cataract surgery are the main interventions to consider. In the London survey these were the causes of 67% of visual impairment. Eighty-eight % of people with visually impairing (6/12 or worse) cataract were not in contact with eye services, and the prevalence of unoperated cataract varied from 11% in 65 year olds to 56% in 85 year olds. Seventy % of people with visual impairing refractive errors had not seen an optician in the previous year [32]. A survey of hosptial in-patients showed that 40% had refractive errors, and 60% of these had not seen optician in 3 years [36]. Overall, 70% of visual impairment in London and 79% in the Liverpool hospital were reckoned to be remediable.

Cataract surgery is certainly effective at improving acuity. The UK national cataract outcomes study reported pre- and post-operative acuity in 18 454 patients. Preoperatively, 72% had acuity of 6/18 or worse, with 21% being blind. Overall, 86% achieved acuity of 6/12 or better (the standard required for driving). For patients without ocular comorbidy (about half the sample), this figure was 92% [38]. Subjective and objective benefit is gained from both first and second eye surgery [39, 40]. Surgery is performed as a day case, under local anaesthetic. If the operation is done by phakoemulsification, half have good vision within a few days, 99% by four weeks.

Age-related macular degeneration, diabetic retinopathy and glaucoma account for the majority of the remaining causes of visual impairment [32, 36]. For these conditions, the main ophthalmological objective is to prevent deterioration rather than restoring normal vision. However, measures can be taken to optimise the visual environment, remove physical hazards, and reduce other falls risk factors. Risk of falling increases progressively with number of risk factors [22, 24, 25]. If visual impairment is irremediable, attention to other risk factors becomes even more important.

Summary

Visual impairment is a risk factor for falls, on average approximately doubling falls risk in a wide variety of studies. Falls risk increases as visual impairment worsens. The relationship is almost certainly causal. Vision accounts for perhaps a quarter to a half of all falls, although this estimate is imprecise. Visual impairment in 70% or more of elderly people is remediable with relatively simple interventions (correcting refractive errors and cataract surgery), making it an important potential target for intervention at the population level. However, no intervention has yet been proven to reduce falls risk in a randomized controlled trial.

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