Visual field plasticity in hearing users of sign language

Chloé Stoll, Richard Palluel-Germain, François-Xavier Gueriot, Christophe Chiquet, Olivier Pascalis, Florent Aptel

Visual field plasticity in hearing users of Sign Language

Chloé Stoll[1, 2, 3], Richard Palluel-Germain[1], François-Xavier Gueriot[4], Christophe Chiquet[4], Olivier Pascalis[1] & Florent Aptel[4]

1. Univ. Grenoble-Alpes, LPNC, F-38040, Grenoble-CNRS, LPNC UMR 5105, F-38040, Grenoble
2. Laboratory for Investigative Neurophysiology, University Hospital Center and University of Lausanne, 1011 Lausanne, Switzerland
3. Department of Ophthalmology, University of Lausanne, Jules Gonin Eye Hospital, 1004 Lausanne, Switzerland
4. Department of Ophthalmology, Centre Hospitalo-Universitaire de Grenoble, BP217

Author Note

Corresponding author:

Dr. Chloé Stoll

Laboratory for Investigative Neurophysiology (LINE), Radiologie Rue Centrale 7, 1003 Lausanne, Suisse

Chloe.stoll@fa2.ch

Abstract

Studies have observed that deaf signers have a larger Visual Field (VF) than hearing non-signers with a particular large extension in the lower part of the VF. This increment could stem from early deafness or from the extensive use of sign language, since the lower VF is critical to perceive and understand linguistics gestures in sign language communication. The aim of the present study was to explore the potential impact of sign language experience without deafness on the VF sensitivity within its lower part. Using standard Humphrey Visual Field Analyzer, we compared luminance sensitivity in the fovea and between 3 and 27 degrees of visual eccentricity for the upper and lower VF, between hearing users of French Sign Language and age-matched hearing non-signers. The sensitivity in the fovea and in the upper VF were similar in both groups. Hearing signers had, howerver, higher luminance sensitivity than non-signers in the lower VF but only between 3 and 15°, the visual location for sign language perception. Sign language experience, no associated with deafness, may then be a modulating factor of VF sensitivity but restricted to the very specific location where signs are perceived.

Keywords: Visual field, Functional plasticity, Sign Language

1. Introduction

It is now well established that early profound deafness leads to enhancements in visual processes in order to compensate the lack of auditory information (Bavelier, Dye, & Hauser, 2006; Pavani & Bottari, 2012). Visual improvements have been mainly reported in the peripheral Visual Field (VF). For example, Proksch and Bavelier (2002) observed that deaf signers were more distracted than hearing non-signers by irrelevant information presented in their peripheral VF whereas hearing non-signers participants were more distracted when it was presented in their central VF. Dye, Hauser, & Bavelier (2009) compared deaf and hearing's visual attention in a more ecological task called the *Useful Field of View*, that required both central and peripheral visual attention. In this task, participants had to identify a central stimulus and to indicate the location of a peripheral target that appeared simultaneously. Deaf participants needed less time presentation than hearing (signers or non-signers) to succesfully complete both central and peripheral task, suggesting that early profound deafness improves selective attention in the visual periphery.

Early deafness affects also more basic aspects of visual processing. For example, using the kinetic and manual Goldman visual field, Buckley, Codina, Bhardwaj, & Pascalis (2010) observed that deaf participants had a larger VF than hearing non-signers. Interestingly, the deaf signers' VF extension was particularly important in the lower part. More precisely, around 30 degrees of visual angle from central fixation, the lower VF area of deaf was 109% larger and the upper one was 69% larger than the hearing ones'. Buckley et al. (2010) suggested that his particular extension could be linked to the use of sign language.

In sign language, the central VF is devoted to lipreading and understand facial expressions, providing linguistic information (Brentari & Crossley, 2002; Liddell, 2003; Reilly, Mcintire, & Seago, 1992) . While looking at the speaker's face, observers have to perceive manual gestures and signs that are mainly produced between the chest and the neck (or in the lower part of the face). Several studies have indeed reported that most of the time during sign language interaction, signers do not directly look at the hands but rather to the face of their interlocutor (Agrafiotis, Canagarajah, Bull, & Dye, 2003; Emmorey, Thompson, & Colvin, 2009; Muir & Richardson, 2005). When signers are facing each other, signs' perception essentially happens in the lower part of the peripheral VF. A trigonometric calculation allows estimating the visual eccentricities where signs are usually perceived. It is based on the location where signs are produced (between the lower part of the face and the breast) and the usual distance between signers (around 120 cm, the limit between personal and social distance according to the proxemics theory; Hall, 1963). The calculation estimates that signs perceived by the lower visual field fall approximately between 4° and 15° of visual eccentricity.

When studying the perceptual and cognitive processing in early deafness it is then essential to consider the use of sign language. For example, signers (deaf or hearing) are better to match non-familiar faces (Arnold & Murray, 1998; Bettger, Emmorey, Mccullough, & Bellugi, 1997; McCullough & Emmorey, 1997). Sign language also affects behavioral face recognition strategy, deaf being more cautious in their decision strategy than hearing non-signers (Stoll et al., 2018). Concerning peripheral visual processing, the effect of sign language experience is not clear and the specificity for the lower VF remains not well understood (for reviews, Bavelier et al., 2006; Pavani & Bottari, 2012).

Visual field sensitivity is experience dependent. Action video game players have, like deaf, a larger VF than non-players hearing population (Buckley et al., 2010). However, unlike deaf, video game players' extension of VF was not asymmetrical but regularly distributed around the VF. In fact, playing video games does not require paying attention to a particular spatial location but rather across the whole VF. It is therefore important to determine if other type perceptual and motor experience - like the use of sign language - can induce VF plasticity.

There are two ways to measure VF sensitivity: the kinetic or the static perimetry. The kinetic perimetry is a monocular measure in which participants have to detect a dot, with a given luminance, moving at a constant speed from the periphery to the center while fixating a central fixation point. Once the dot is detectable in the visual field, its location defines the limitation to perceive the given luminance. By testing across the visual field, it is possible to measure the visual field area for a given luminance. The static perimetry is also a monocular measure but instead of trying to find the VF limit for a given luminance, it measures the luminance sensitivity for a given visual eccentricity. This static perimetry provides more accurate and reproducible information about the visual field sensitivity than the kinetic one.

In the present study, we investigated if regular sign language experience, that induces atypical motor and linguistic experience, influences visual field sensitivity in hearing population. More precisely, using static perimetry we compared hearing signers and hearing non-signers luminance sensitivity in the fovea and in the upper and lower VF. Luminance sensitivity was established with the Humphrey automated visual field analyzer between 3 and 27 degrees of visual eccentricity. If sign language experience contributes to the VF plasticity previously observed in deaf signers, hearing signers should present a selective difference across VF. They should exhibit higher luminance sensitivity than hearing non-signers but limited to the visual space where signs are mainly produced and perceived, that is in the lower VF between 3 and 15 degrees of visual eccentricity.

2. Material and methods

2.1. Participants

Eighteen hearing signers (17 women, M_{age} = 39.11 years, SD_{age} = 10.84 years) took part in this experiment. They worked with deaf population and were either French-LSF interpreters, social workers or from the medical staff of the Unit for the Deaf of Grenoble University Hospital (France). Detailed information about participants' signing experience is reported in Table 1. In addition, 17 hearing non-signers (14 women, M_{age} = 37.18 years, SD_{age} = 9.95 years) took part in this experiment and had no knowledge in LSF or any other sign language. They were age-matched with the hearing signers group (+/- 1 year) and were recruited via an electronic platform for research in cognitive sciences and among colleagues. The participants were adults without neurological or ophthalmological history, none of them had pathologic visual impairment (i.e., no strong ametropia) and none of them reported playing action video game. The study lasted about two hours and was approved by the Grenoble ethic board for non-interventional research and respected Code of Ethics of the World Medical Association (Declaration of Helsinki). The entire study took place in Grenoble University Hospital and participants gave their written consent.

Table 1
Demographic information about hearing signer participants

##	*Age*	*Age of SL acquisition*	*Signing frequency (estimated hours/week)*	*signing context*
1	41	19	20	work
2	40	37	7	work
3	40	20	20	work
4	46	35	20	work
5	63	50	50	work
6	44	26	15	work + family
7	53	35	8	work
8	31	16	35	work
9	33	18	20	work
10	28	19	30	work
11	60	42	15	work
12	37	22	35	work
13	39	20	30	work + friends
14	31	26	20	work + friends
15	39	16	30	work
16	25	birth	20	family
17	22	birth	2	family
18	32	birth	28	family

2.2. Materials and Procedure

Participants first received a comprehensive ophthalmic examination that included visual acuity assessment (far and near best corrected visual acuity), intra-ocular pressure measurement, slit-lamp anterior segment examination, fundus examination without pupil dilation, and assessment of retinal and optic nerve head microstructure (macular and papillary analysis) by Optical Coherence Tomography (Cirrus HD-OCT model 4000, Zeiss Meditec, Inc, Dublin, CA, USA).

Visual field luminance sensitivity was established via the standard of static perimetry, the Humphrey Automatic VF Analyzer (Zeiss II-i Version 5.1, model 745i, figure 1A), using the 30-2 SITA-Standard program. This monocular technic establishes luminance threshold between an isoluminant curved background (31.5 Apostilbs – asb - or 10.02 candela per m² - cd/m^2) and a dot that varies in luminance intensity in various visual eccentricities.

During the VF assessment, participants had to keep their gaze on a central point (at a given distance of 30 cm) and to press a remote button once they detect the 4mm² target that randomly appeared for 200 ms at different visual eccentricities and locations (figure 1A, B and C). The *30-2 visual field* estimates luminance threshold in 76 points (19 per visual quadrant) across 5 visual eccentricities (i.e., 3°, 9°, 15°, 21°, 27°) and in the fovea. The luminance intensity of the target varies (from 0.1 to 10 000 asb) according to a 2dB bracketing step adaptation and the luminance threshold corresponds to the light intensity perceived 50% of the time in a given location and is defined in decibel (figure 1D). Decibel is a logarithmic unit used to express the power ratio between a measured intensity and a reference one (here luminance intensity). A zero-decibel threshold corresponds to no measurable difference between the reference intensity (here the maximal luminance of the target, i,e, 10 000 asb) and the target luminance intensity measured. Humphrey Visual Field Analyzer can establish threshold from 0 dB to 51 dB. Thus, the higher the threshold is, the more the participant is sensitive to luminance.

Participants always performed the test with their dominant eye first. The experimenter was present during the entire test to monitor eye gaze and stop the test if a break was needed. Eye fixation was controlled by the device and if participant made too many visual saccades or random responses (i.e., when test liability was low according to the device's standard) the test was stopped and a new one was started. Visual field quality criteria were: fixation loss < 20%, false positive < 33% and false negative < 33% and each test lasted between 5:30 min and 7 min.

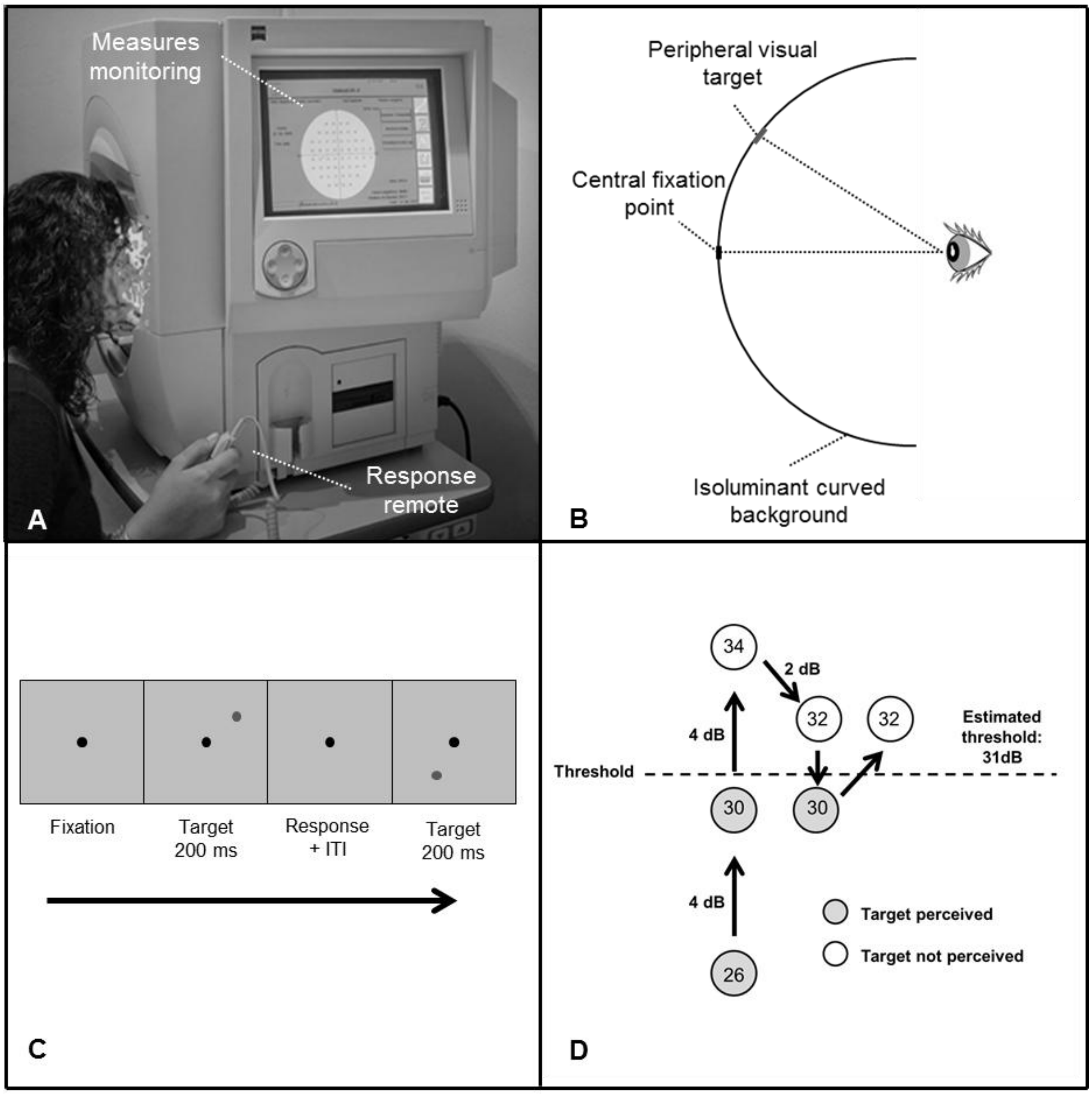
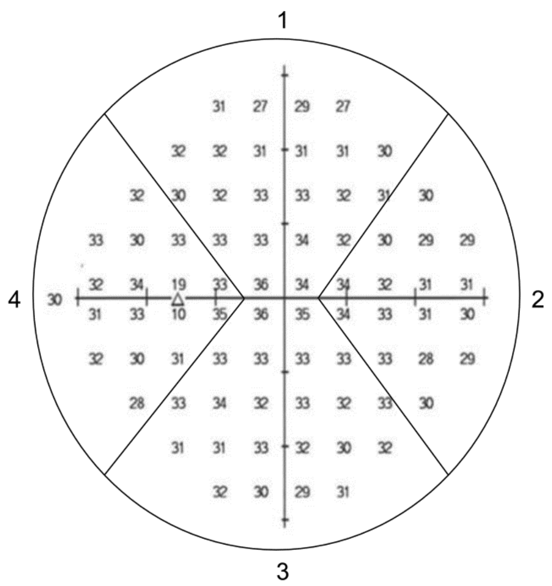


Figure 1. Experimental paradigm. A: Humphrey VF analyzer device B: Principle of VF assessment: participant has to detect a peripheral target while keeping the eye on the central fixation point. C: Trials sequence. D: target luminance bracketing step adaptation (adapted from Nordmann, 2001).

2.3. Data analysis

Decibel is a relative and logarithmic unit mainly used for clinical purposes but is not ideal for statistical analysis. The thresholds were therefore transformed in cd/m², the linear International System unit of luminance before performing statistical analysis (in order to facilitate the reading of the figures and tables, the data were however kept in decibels). Visual fields were divided in 4 quadrants (i.e., upper, lower, temporal and nasal) but only the upper and lower one were analyzed (figure 2). Data from the left and the right eye were compared and averaged before running the analysis.

The visual field sensitivity being highly age-dependent, we conducted an ANCOVA on foveal threshold between hearing signers and hearing non-signers with the age of participants as a covariate. In order to increase our statistical power and to test the “signing space” hypothesis[1] (i.e., hearing signers would have a higher threshold than non-signers in the lower VF between 3° and 15°) we grouped visual eccentricities (3°, 9° and, 15° together vs 21° and 27° together). The “signing space” hypothesis was directly tested with a mixed-designed ANCOVA in the lower VF with group as inter-subject variable, visual eccentricities as a within-subject variable and age as a covariable. Then, a similar mixed-designed ANCOVA was conducted in the upper VF to assess the symmetrical visual space. Finally, and before testing these two questions, a confirmatory analysis was ran to check the reliability of our data by replicating the standard physiologic differences within the VF with a mixed-designed ANCOVA between hearing signers and hearing non-signers with VF location (i.e., upper VF and lower VF), visual eccentricities (i.e., [3; 15] and [21; 27]) as within-subject variables and age as a covariate.



[1] The signing space is not restricted to the lower visual field since some signs are produced at face level and therefore do not fall within the lower VF. The expression here is therefore a generalization to label the research hypothesis.

Figure 2. Data provided by the 30-2 program, Humphrey VF analyzer. Visual field was divided in 4 quadrants (i.e., upper (1), lower (3), temporal (2) and nasal (4)).

3. Results

Data from one hearing non-signer participant were removed from analysis because she had ophthalmic retinal abnormality that could have biased her results. Data from left and right eye were averaged because they were not significantly different (all p_s> 0.05). The two groups were not significantly different regarding the age, $t(32) = 0.59$, $p = 0.56$, and finally, all VF measures were considered as reliable regarding to standard quality criteria (i.e., fixation loss < 20%, false positive < 33% and false negative < 33%).

3.1. Foveal threshold

There was no significant difference in foveal threshold between signers and non-signers, $F(1; 31) = 0.07$, $p = 0.79$, $\eta^2_p = 0.002$. As expected, the age of participants was significantly related to the foveal threshold, $F(1, 31) = 7.57$, $p = 0.001$, $\eta^2_p = 0.20$. The older the participant was, the lower the threshold was, r = -0.44, $p = 0.009$. Mean foveal thresholds are reported in Table 2.

Table 2
Luminance threshold in the fovea (in decibel).

	Foveal Threshold	
	M	**Stand. Error**
Signers	37.61	0.27
Non-signers	37.42	0.47

3.2. 30-2 Visual Field

The mixed-design ANCOVA revealed a significant main effect of visual eccentricity, $F(1, 31) = 87.45$, $p < 0.0001$, $\eta^2_p = 0.74$, with higher thresholds between 3° and 15° than between 21° and 27° and a significant main effect of VF location, $F(1, 31) = 7.82$, $p = 0.009$, $\eta^2_p = 0.20$, with higher thresholds in the lower VF. As for the fovea, the ANCOVA revealed that the age of participants was significantly related to luminance sensitivity, $F(1, 31) = 4.25$, $p = 0.04$, $\eta^2_p = 0.12$. This age effect was stronger for larger visual eccentricity as suggested by significant interaction between age and visual eccentricity, $F(1, 31) = 9.96$, $p = 0.003$, $\eta^2_p = 0.24$.

Finally, the analysis did not reveal a significant main effect of group, $F(1, 31) = 1.42$, $p = 0.24$, but a significant interaction between groups and visual eccentricity, $F(1, 31) = 6.04$, $p = 0.019$, $\eta^2_p = 0.19$. Note however that the three ways interaction is not significant: $F(1, 31) = 1.26$, $p = 0.27$, $\eta^2_p = 0.039$.

Signing space hypothesis: lower VF ANCOVA

The ANCOVA for the lower visual field revealed that the group by eccentricity effect observed in the general ANCOVA was driven by a significant group by eccentricity interaction in the lower VF, $F(1, 31) = 6.32$, $p = 0.017$, $\eta^2_p = 0.17$. More precisely, hearing signers had higher thresholds than non-signers between 3° and 15°, $F(1, 31) = 4.44$, $p = 0.04$, $\eta^2_p = 0.13$, but not between 21° and 27°, $F(1, 31) = 0.003$, $p = 0.95$, $\eta^2_p < 0.001$, as predicted by our “signing space” hypothesis (figure 3, right pattern).

Effect of age of acquisition and frequency of signing

Because both of these factors could impact participants’ luminance sensitivity, partial correlations controlling the effect of age were tested between (1) age SL of acquisition and luminance threshold and (2) frequency of signing and luminance threshold but both were non-significant ($r = -0.125$, $p = 0.633$ and, $r = 0.059$, $p = 0.822$ respectively).

The symmetrical visual space: Upper VF ANCOVA

The ANCOVA for the upper visual field did not reveal significant interaction between group and visual eccentricity, $F(1, 31) = 2.60$, $p = 0.12$, suggesting no impact of sign language experience for luminance sensitivity in the upper visual field regardless of visual eccentricity (figure 3, left pattern).

Overall these results suggest that hearing signers had higher luminance sensitivity than hearing non-signers specifically in the lower VF between 3° and 15°, supporting the “Signing space” hypothesis. Mean threshold for each visual eccentricity and each VF location tested by the 30-2 are reported table 2 for the upper VF and table 3 for the lower one.

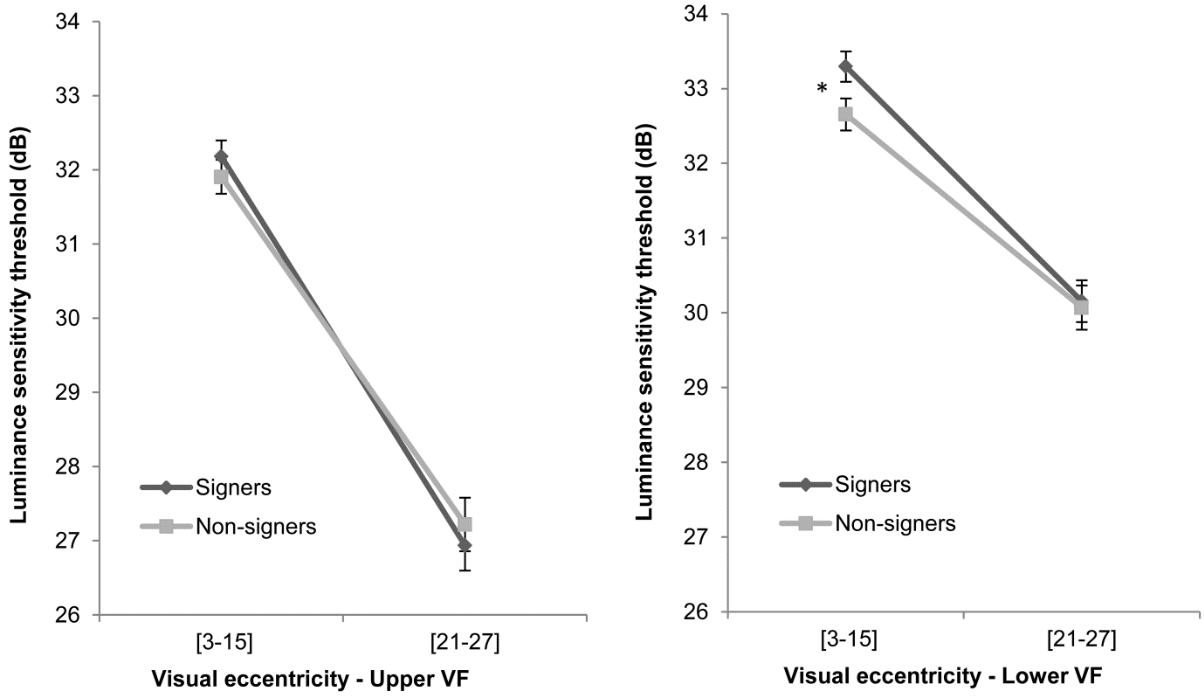


Figure 3. Mean luminance sensitivity (threshold in dB) in the upper and lower VF at different visual eccentricities for both hearing signers and non-signers. Error bar represent standard errors of the mean and the * indicates a significant difference ($p < 0.05$).

Table 2

Luminance sensitivity in the upper visual field (threshold in decibel). Standard errors of the mean are in brackets.

	Upper Visual Field				
	3°	*9°*	*15°*	*21°*	*27°*
Signers	33.83 (0.23)	32.38 (0.25)	30.33 (0.27)	27.71 (0.30)	26.16 (0.42)
Non-signers	33.43 (0.25)	32.05 (0.27)	30.24 (0.29)	27.99 (0.31)	26.45 (0.45)

Table 3

Luminance sensitivity in the lower visual field (threshold in decibel). Standard errors of the mean are in brackets.

	Lower Visual Field				
	3°	*9°*	*15°*	*21°*	*27°*
Signers	34.06 (0.23)	33.62 (0.22)	32.20 (0.25)	30.80 (0.33)	29.51 (0.31)
Non-signers	33.51 (0.24)	32.91 (0.24)	31.54 (0.26)	30.88 (0.35)	29.25 (0.33)

4. Discussion

The present study aimed to compare luminance sensitivity in hearing signers and hearing non-signers in their upper and lower visual fields. More particularly we investigated whether sign language experience without deafness influenced luminance sensitivity in the portion of VF involved in sign language perception.

We observed an increase of the sensitivity in hearing signers compared to hearing non-signers limited to the signing space. There was no difference beyond 15° in the lower VF, in the fovea or in the upper part of the VF regardless visual eccentricity (figure 3). It appears that active and regular sign language practice, which involves specific perceptual and motor experience, increases luminance sensitivity in a very specific part of the VF. We also observed that the threshold values were not correlated with the age of acquisition or the frequency of signing and that there was no significant interaction between these variables. Thus, sign language fluency seems a key criterion to observe an enhancement in luminance sensitivity but we don't know how and when during the learning process it happens. A longitudinal study with hearing students enrolled in a sign language interpreting program, from the beginning of their learning to their graduation would provide interesting data on this issue. The non-significant correlation between age of acquisition and the luminance sensitivity in the signing space is not a strong evidence to conclude on the impact of the age of sign language acquisition since the participant's sample is relatively small and since frequency of signing can be a cofound variable. One relevant way to determine the impact of the age acquisition would be to compare VF sensitivity between a substantial number of hearing early signers and hearing late signers.

In our study we assessed VF luminance sensitivity with the Humphrey VF Analyzer which is frequently used to diagnose glaucoma and to monitor the progress of the affection. Even if this method is one of the gold standard to assess VF sensibility, thresholds can be overestimated with a high ratio of false positive (i.e., more than 20%; Newkirk, Gardiner, Demirel, & Johnson, 2006) or be less precise than other VF analyzer methods and especially for low level of thresholds (i.e., vision loss like in glaucoma, Fredette, Giguère, Anderson, Budenz, & McSoley, 2015; Spry, Johnson, & McKendrick, 2003). In our study, false positive ratios do not exceed 7% and since participants had no visual impairment we did not observe low threshold). We are then confident about the reliability of our data and the significant interaction between group and visual eccentricity clearly supported our hypothesis with a difference only in the lower visual field in the specific location sign language perception. Sign language experience can therefore be considered as a modulating factor of VF sensitivity.

It is important to note that in the Humphrey VF analyzer variation of contrast and luminance are confounded. It is thus impossible from our data to establish if the higher visual sensitivity observed is linked to greater luminance or to greater contrast sensitivity. However, the Finney and Dobkins (2001) study can bring some elements to address this question. They measured absolute contrast sensitivity with moving gratings in both deaf and hearing signers and observed no sensitivity difference both in term of visual field asymmetry (i.e., left/right and upper/lower) and visual eccentricity (i.e., central/periphery, 15°). They concluded that neither early deafness nor long-time sign language exposure affect contrast sensitivity. We can then assume that our results are more likely to reflect higher sensitivity for luminance than for contrast.

Bosworth and Dobkins (2002) have compared VF field asymmetry for peripheral visual motion processing in deaf, hearing signers and non-signers. Contrary to our study, they didn't observe a difference between signers and non-signers in the lower visual field. Only deaf signers exhibited an advantage for motion processing in the lower VF. This discrepancy could be explained by the category of stimuli used: dynamic in their study *vs* static in our study. Motion processing recruits specific areas in the posterior part of the brain (MT and MST) that are more activated in deaf signers than in hearing (signers and non-signers) when they have to attend moving stimuli in the peripheral VF (Bavelier et al., 2001). To our knowledge only one other study has observed that sign language experience modifies visual perception on the lower part of VF (Dye, Seymour, & Hauser, 2015). In this study, signers (deaf or hearing) exhibited an attention bias toward the lower peripheral VF in a Useful Field of View task (described in the introduction) by comparing error distribution across VF locations. These results, combined with ours, highlight the importance to explore vertical VF asymmetries when studying the perceptual outcomes of deafness and sign language experience.

Our results support the idea that perceptual and/or motor expertise enhances perceptual processing. Indeed, several studies investigated sensory and cognitive processing in experts like athletes, musicians and video game players. Beyond the physical performances, elite athletes outperformed typical population for sports-related skills like visuo-spatial attention, anticipation or even decision making (e.g., Memmert, 2009; Mori, Ohtani, & Imanaka, 2002; Muiños & Ballesteros, 2013; Williams & Ford, 2008; Zwierko, 2008). Musicians also develop skills linked to their practice, like auditory discrimination, rhythms and fine motors skills (e.g., Chartrand & Belin, 2006; Lotze, Scheler, Tan, Braun, & Birbaumer, 2003; Pallesen et al., 2010; Pau, Jahn, Sakreida, Domin, & Lotze, 2013; Zatorre, Chen, & Penhune, 2007). Interestingly, video game players who regularly play music and rhythm games like Guitar Hero or Rock Band are better than controls for melody, tuning and tempo perceptual abilities and with relatively similar abilities than musicians (Pasinski, Hannon, & Snyder, 2016). Action video games experts also develop visual and attention skills similar to the enhancements observed in the deaf population (e.g., Buckley, Codina, Bhardwaj, & Pascalis, 2010; Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2003, 2006, 2007; Spence & Feng, 2010). Therefore, being fluent in sign language is more than “speaking” another language; it is also mastering complex visuo-motor constraints that could induce bottom-up plasticity.

References

Arnold, P., & Murray, C. (1998). Memory for faces and objects by deaf and hearing signers and hearing nonsigners. *Journal of Psycholinguistic Research*, *27*(4), 481–497. https://doi.org/10.1023/A:1023277220438

Bavelier, D., Brozinsky, C., Tomann, A., Mitchell, T., Neville, H., & Liu, G. (2001). Impact of early deafness and early exposure to sign language on the cerebral organization for motion processing. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *21*(22), 8931–42. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11698604

Bavelier, D., Dye, M., & Hauser, P. C. (2006). Do deaf individuals see better? *Trends in Cognitive Sciences*, *10*(11), 512–8. https://doi.org/10.1016/j.tics.2006.09.006

Bettger, J., Emmorey, K., Mccullough, S., & Bellugi, U. (1997). Enhanced Facial Discrimination : Effects of Experience With American Sign Language. *The Journal of Deaf Studies and Deaf Education*, *2*(4), 223–233.

Bosworth, R. G., & Dobkins, K. R. (2002). Visual field asymmetries for motion processing in deaf and hearing signers. *Brain and Cognition*, *49*(1), 170–81. https://doi.org/10.1006/brcg.2001.1498

Brentari, D., & Crossley, L. (2002). Prosody on the hands and face: Evidence from American Sign Language. *Sign Language & Linguistics*, *5*, 105–130. https://doi.org/10.1075/sll.5.2.03bre

Buckley, D., Codina, C., Bhardwaj, P., & Pascalis, O. (2010). Action video game players and deaf observers have larger Goldmann visual fields. *Vision Research*, *50*(5), 548–56. https://doi.org/10.1016/j.visres.2009.11.018

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica*, *119*(2), 217–230. https://doi.org/10.1016/j.actpsy.2005.02.004

Chartrand, J. P., & Belin, P. (2006). Superior voice timbre processing in musicians. *Neuroscience Letters*, *405*(3), 164–167. https://doi.org/10.1016/j.neulet.2006.06.053

Dye, M., Hauser, P. C., & Bavelier, D. (2009). Is visual selective attention in deaf individuals enhanced or deficient? The case of the useful field of view. *PloS One*, *4*(5), e5640. https://doi.org/10.1371/journal.pone.0005640

Dye, M., Seymour, J. L., & Hauser, P. C. (2015). Response bias reveals enhanced attention to inferior visual field in signers of American Sign Language. *Experimental Brain Research*, *234*(4), 1–10. https://doi.org/10.1007/s00221-015-4530-3

Finney, E. M., & Dobkins, K. R. (2001). Visual contrast sensitivity in deaf versus hearing populations: exploring the perceptual consequences of auditory deprivation and experience with a visual language. *Brain Research. Cognitive Brain Research*, *11*(1), 171–83. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11240120

Fredette, M. J., Giguère, A., Anderson, D. R., Budenz, D. L., & McSoley, J. (2015). Comparison of Matrix with Humphrey Field Analyzer II with SITA. *Optometry and Vision Science : Official Publication of the American Academy of Optometry*, *92*(5), 527–536. https://doi.org/10.1097/OPX.0000000000000583 [doi]

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*(6939), 534–7. https://doi.org/10.1038/nature01647

Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology. Human Perception and Performance*, *32*(6), 1465–78. https://doi.org/10.1037/0096-1523.32.6.1465

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science*, *18*(1), 88–94. https://doi.org/10.1111/j.1467-9280.2007.01853.x

Liddell, S. K. (2003). *Grammar, gesture, and meaning in American Sign Language* (Cambridge). New-York.

Lotze, M., Scheler, G., Tan, H. R. M., Braun, C., & Birbaumer, N. (2003). The musician's brain: Functional imaging of amateurs and professionals during performance and imagery. *NeuroImage*, *20*(3), 1817–1829. https://doi.org/10.1016/j.neuroimage.2003.07.018

McCullough, S., & Emmorey, K. (1997). Face processing by deaf ASL signers: evidence for expertise in distinguished local features. *Journal of Deaf Studies and Deaf Education*, *2*(4), 212–22. https://doi.org/10.1093/oxfordjournals.deafed.a014327

Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. *International Review of Sport and Exercise Psychology*, *2*(2), 119–138. https://doi.org/10.1080/17509840802641372

Mori, S., Ohtani, Y., & Imanaka, K. (2002). Reaction times and anticipatory skills of karate athletes. *Human Movement Science*, *21*(2), 213–30. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12167300

Muiños, M., & Ballesteros, S. (2013). Visuospatial attention and motor skills in kung fu athletes. *Perception*, *42*(10), 1043–1050. https://doi.org/10.1068/p7567

Newkirk, M. R., Gardiner, S. K., Demirel, S., & Johnson, C. A. (2006). Assessment of false positives with the Humphrey Field Analyzer II perimeter with the SITA algorithm. *Investigative Ophthalmology and Visual Science*, *47*(10), 4632–4637. https://doi.org/10.1167/iovs.05-1598

Nordmann, J.-P. (2001). *Périmétrie automatique* (Laboratoire Bausch-Lomb Edition). Montpellier, France.

Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PLoS ONE*, *5*(6). https://doi.org/10.1371/journal.pone.0011120

Pasinski, A. C., Hannon, E. E., & Snyder, J. S. (2016). How musical are music video game players? *Psychonomic Bulletin and Review*, *23*(5), 1553–1558. https://doi.org/10.3758/s13423-015-0998-x

Pau, S., Jahn, G., Sakreida, K., Domin, M., & Lotze, M. (2013). Encoding and recall of finger sequences in experienced pianists compared with musically naïve controls: A combined behavioral and functional imaging study. *NeuroImage*, *64*(1), 379–387. https://doi.org/10.1016/j.neuroimage.2012.09.012

Pavani, F., & Bottari, D. (2012). Visual Abilities in Individuals with Profound Deafness A Critical Review. In M. Murray & M. Wallas (Eds.), *The Neural Bases of Multisensory Processes* (CRC Press). Boca Raton, FL.

Proksch, J., & Bavelier, D. (2002). Changes in the spatial distribution of visual attention after early deafness. *Journal of Cognitive Neuroscience*, *14*(5), 687–701. https://doi.org/10.1162/08989290260138591

Reilly, J., Mcintire, M. L., & Seago, H. (1992). Affective prosody in American Sign Language. *Sign Language Studies*, *75*, 113–128.

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology*, *14*(2), 92–104. https://doi.org/10.1037/a0019491

Spry, P. G. D., Johnson, C. A., & McKendrick, A. M. (2003). Measurement error of visual field tests in glaucoma. *British Journal of Ophthalmology*, *87*(1), 107–112. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed9&NEWS=N&AN=36071789

Stoll, C., Palluel-Germain, R., Caldara, R., Lao, J., Dye, M. W. G., Aptel, F., & Pascalis, O. (2018). Face recognition is shaped by the use of sign language. *Journal of Deaf Studies and Deaf*

Education, *23*(1), 62–70. https://doi.org/10.1093/deafed/enx034

Williams, a M., & Ford, P. R. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology*, *1*(1), 4–18. https://doi.org/10.1080/17509840701836867

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: auditory-motor interactions in music perception and production. *Nature Reviews. Neuroscience*, *8*(7), 547–558. https://doi.org/10.1038/nrn2152

Zwierko, T. (2008). Differences in Peripheral Perception between Athletes and Nonathletes. *Journal of Human Kinetics*, *19*(1), 53–62. https://doi.org/10.2478/v10078-008-0004-z