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## Visual field plasticity in hearing users of Sign Language

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**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, however, 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        1. Introduction

2        It is now well established that early profound deafness leads to enhancements in visual  
3 processes in order to compensate the lack of auditory information (Bavelier, Dye, & Hauser,  
4 2006; Pavani & Bottari, 2012). Visual improvements have been mainly reported in the  
5 peripheral Visual Field (VF). For example, Proksch and Bavelier (2002) observed that deaf  
6 signers were more distracted than hearing non-signers by irrelevant information presented in  
7 their peripheral VF whereas hearing non-signers participants were more distracted when it  
8 was presented in their central VF. Dye, Hauser, & Bavelier (2009) compared deaf and  
9 hearing's visual attention in a more ecological task called the *Useful Field of View*, that  
10 required both central and peripheral visual attention. In this task, participants had to identify a  
11 central stimulus and to indicate the location of a peripheral target that appeared  
12 simultaneously. Deaf participants needed less time presentation than hearing (signers or  
13 non-signers) to successfully complete both central and peripheral task, suggesting that early  
14 profound deafness improves selective attention in the visual periphery.

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

22        In sign language, the central VF is devoted to lipreading and understand facial  
23 expressions, providing linguistic information (Brentari & Crossley, 2002; Liddell, 2003; Reilly,  
24 McIntire, & Seago, 1992) . While looking at the speaker's face, observers have to perceive  
25 manual gestures and signs that are mainly produced between the chest and the neck (or in  
26 the lower part of the face). Several studies have indeed reported that most of the time during  
27 sign language interaction, signers do not directly look at the hands but rather to the face of  
28 their interlocutor (Agrafiotis, Canagarajah, Bull, & Dye, 2003; Emmorey, Thompson, & Colvin,

1 2009; Muir & Richardson, 2005). When signers are facing each other, signs' perception  
2 essentially happens in the lower part of the peripheral VF. A trigonometric calculation allows  
3 estimating the visual eccentricities where signs are usually perceived. It is based on the  
4 location where signs are produced (between the lower part of the face and the breast) and  
5 the usual distance between signers (around 120 cm, the limit between personal and social  
6 distance according to the proxemics theory; Hall, 1963). The calculation estimates that signs  
7 perceived by the lower visual field fall approximately between 4° and 15° of visual  
8 eccentricity.

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

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

24       There are two ways to measure VF sensitivity: the kinetic or the static perimetry. The  
25 kinetic perimetry is a monocular measure in which participants have to detect a dot, with a  
26 given luminance, moving at a constant speed from the periphery to the center while fixating a  
27 central fixation point. Once the dot is detectable in the visual field, its location defines the  
28 limitation to perceive the given luminance. By testing across the visual field, it is possible to

1 measure the visual field area for a given luminance. The static perimetry is also a monocular  
2 measure but instead of trying to find the VF limit for a given luminance, it measures the  
3 luminance sensitivity for a given visual eccentricity. This static perimetry provides more  
4 accurate and reproducible information about the visual field sensitivity than the kinetic one.

5 In the present study, we investigated if regular sign language experience, that induces  
6 atypical motor and linguistic experience, influences visual field sensitivity in hearing  
7 population. More precisely, using static perimetry we compared hearing signers and hearing  
8 non-signers luminance sensitivity in the fovea and in the upper and lower VF. Luminance  
9 sensitivity was established with the Humphrey automated visual field analyzer between 3 and  
10 27 degrees of visual eccentricity. If sign language experience contributes to the VF plasticity  
11 previously observed in deaf signers, hearing signers should present a selective difference  
12 across VF. They should exhibit higher luminance sensitivity than hearing non-signers but  
13 limited to the visual space where signs are mainly produced and perceived, that is in the  
14 lower VF between 3 and 15 degrees of visual eccentricity.

15

## 16 **2. Material and methods**

### 17 **2.1. Participants**

18 Eighteen hearing signers (17 women,  $M_{age} = 39.11$  years,  $SD_{age} = 10.84$  years) took part  
19 in this experiment. They worked with deaf population and were either French-LSF  
20 interpreters, social workers or from the medical staff of the Unit for the Deaf of Grenoble  
21 University Hospital (France). Detailed information about participants' signing experience is  
22 reported in Table 1. In addition, 17 hearing non-signers (14 women,  $M_{age} = 37.18$  years,  
23  $SD_{age} = 9.95$  years) took part in this experiment and had no knowledge in LSF or any other  
24 sign language. They were age-matched with the hearing signers group ( $\pm 1$  year) and were  
25 recruited via an electronic platform for research in cognitive sciences and among colleagues.  
26 The participants were adults without neurological or ophthalmological history, none of them  
27 had pathologic visual impairment (i.e., no strong ametropia) and none of them reported

1 playing action video game. The study lasted about two hours and was approved by the  
 2 Grenoble ethic board for non-interventional research and respected Code of Ethics of the  
 3 World Medical Association (Declaration of Helsinki). The entire study took place in Grenoble  
 4 University Hospital and participants gave their written consent.

5 **Table 1**  
 6 ***Demographic information about hearing signer participants***  
 7

##	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

8

## 9 **2.2. Materials and Procedure**

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

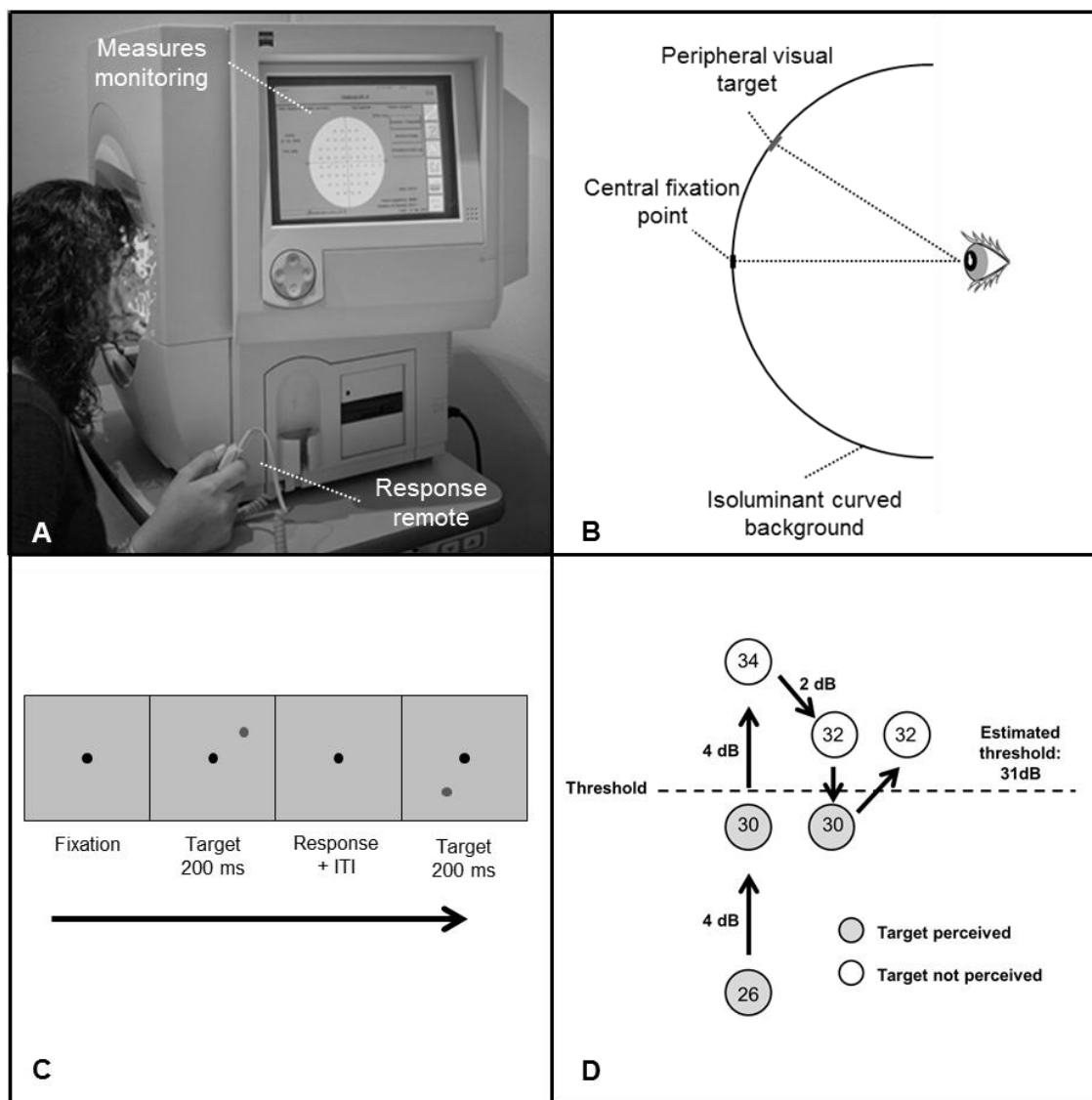
16 Visual field luminance sensitivity was established via the standard of static perimetry, the  
 17 Humphrey Automatic VF Analyzer (Zeiss II-i Version 5.1, model 745i, figure 1A), using the  
 18 30-2 SITA-Standard program. This monocular technic establishes luminance threshold

1 between an isoluminant curved background (31.5 Apostilbs – asb - or 10.02 candela per m<sup>2</sup> -  
2 cd/m<sup>2</sup>) and a dot that varies in luminance intensity in various visual eccentricities.

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

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





2

3 **Figure 1.** Experimental paradigm. A: Humphrey VF analyzer device B: Principle of VF assessment:

4 participant has to detect a peripheral target while keeping the eye on the central fixation point. C:

5 Trials sequence. D: target luminance bracketing step adaptation (adapted from Nordmann, 2001).

6

7 **2.3. Data analysis**

8 Decibel is a relative and logarithmic unit mainly used for clinical purposes but is not ideal

9 for statistical analysis. The thresholds were therefore transformed in  $\text{cd}/\text{m}^2$ , the linear

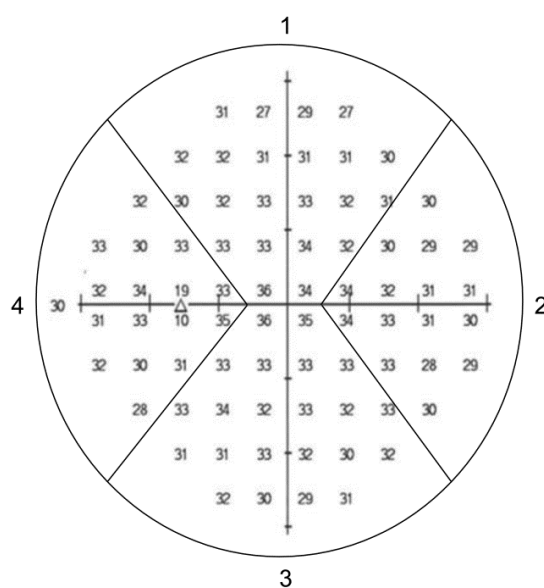
10 International System unit of luminance before performing statistical analysis (in order to

11 facilitate the reading of the figures and tables, the data were however kept in decibels).

12 Visual fields were divided in 4 quadrants (i.e., upper, lower, temporal and nasal) but only the

1 upper and lower one were analyzed (figure 2). Data from the left and the right eye were  
 2 compared and averaged before running the analysis.

3 The visual field sensitivity being highly age-dependent, we conducted an ANCOVA on foveal  
 4 threshold between hearing signers and hearing non-signers with the age of participants as a  
 5 covariate. In order to increase our statistical power and to test the “signing space”  
 6 hypothesis<sup>1</sup> (i.e., hearing signers would have a higher threshold than non-signers in the lower  
 7 VF between 3° and 15°) we grouped visual eccentricities (3°, 9° and, 15° together vs 21° and  
 8 27° together). The “signing space” hypothesis was directly tested with a mixed-designed  
 9 ANCOVA in the lower VF with group as inter-subject variable, visual eccentricities as a  
 10 within-subject variable and age as a covariable. Then, a similar mixed-designed ANCOVA  
 11 was conducted in the upper VF to assess the symmetrical visual space. Finally, and before  
 12 testing these two questions, a confirmatory analysis was ran to check the reliability of our  
 13 data by replicating the standard physiologic differences within the VF with a mixed-designed  
 14 ANCOVA between hearing signers and hearing non-signers with VF location (i.e., upper VF  
 15 and lower VF), visual eccentricities (i.e., [3; 15] and [21; 27]) as within-subject variables and  
 16 age as a covariate.



17

<sup>1</sup> 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.

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

### 3 4 **3. Results**

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

#### 11 12 **3.1. Foveal threshold**

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

18 **Table 2**  
19 *Luminance threshold in the fovea (in decibel).*

	<i>Foveal Threshold</i>	
	<b>M</b>	<b>Stand. Error</b>
Signers	37.61	0.27
Non-signers	37.42	0.47

20

21

#### 22 **3.2. 30-2 Visual Field**

23 The mixed-design ANCOVA revealed a significant main effect of visual eccentricity,  $F(1, 31)$   
24  $= 87.45$ ,  $p < 0.0001$ ,  $\eta^2_p = 0.74$ , with higher thresholds between 3° and 15° than between 21°  
25 and 27° and a significant main effect of VF location,  $F(1, 31) = 7.82$ ,  $p = 0.009$ ,  $\eta^2_p = 0.20$ ,  
26 with higher thresholds in the lower VF. As for the fovea, the ANCOVA revealed that the age

1 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  
 2 = 0.12. This age effect was stronger for larger visual eccentricity as suggested by significant  
 3 interaction between age and visual eccentricity,  $F(1, 31) = 9.96, p = 0.003, \eta^2_p = 0.24$ .

4 Finally, the analysis did not reveal a significant main effect of group,  $F(1, 31) = 1.42, p =$   
 5 0.24, but a significant interaction between groups and visual eccentricity,  $F(1, 31) = 6.04, p =$   
 6 0.019,  $\eta^2_p = 0.19$ . Note however that the three ways interaction is not significant:  $F(1, 31) =$   
 7 1.26,  $p = 0.27, \eta^2_p = 0.039$ .

### 8 **Signing space hypothesis: lower VF ANCOVA**

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

### 15 **Effect of age of acquisition and frequency of signing**

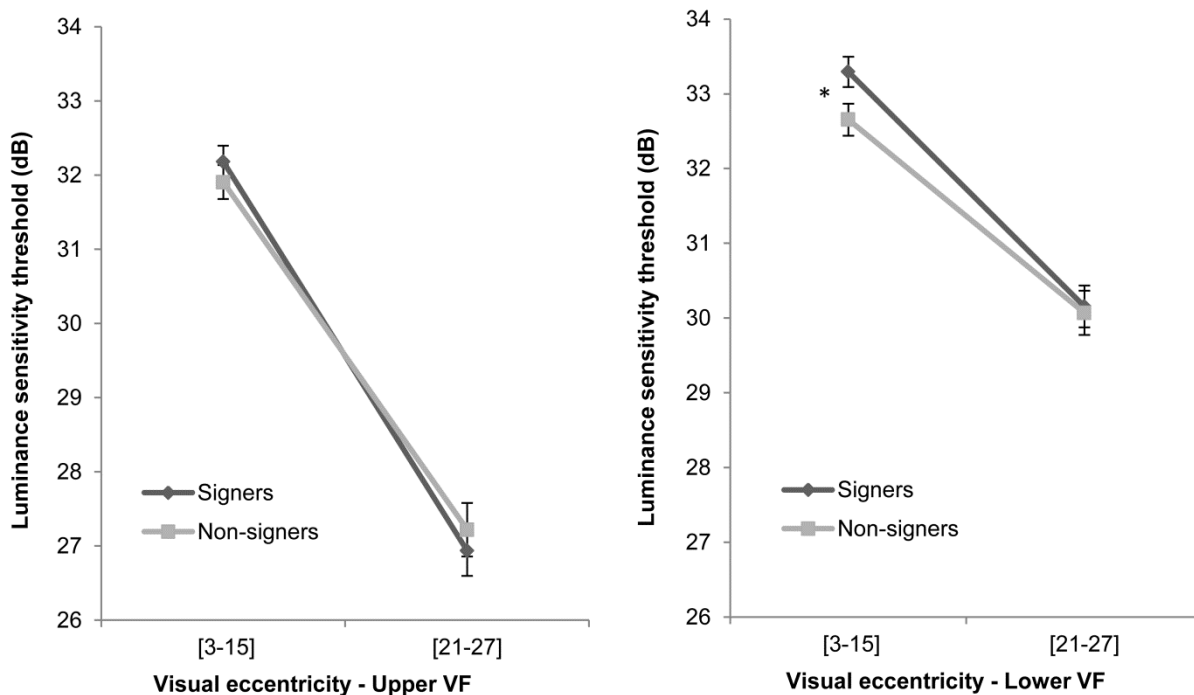
16 Because both of these factors could impact participants’ luminance sensitivity, partial  
 17 correlations controlling the effect of age were tested between (1) age SL of acquisition and  
 18 luminance threshold and (2) frequency of signing and luminance threshold but both were  
 19 non-significant ( $r = -0.125, p = 0.633$  and,  $r = 0.059, p = 0.822$  respectively).  
 20

### 21 **The symmetrical visual space: Upper VF ANCOVA**

22 The ANCOVA for the upper visual field did not reveal significant interaction between group  
 23 and visual eccentricity,  $F(1, 31) = 2.60, p = 0.12$ , suggesting no impact of sign language  
 24 experience for luminance sensitivity in the upper visual field regardless of visual eccentricity  
 25 (figure 3, left pattern).  
 26

1  
2  
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6  
7

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.



1  
 2 **Figure 3.** Mean luminance sensitivity (threshold in dB) in the upper and lower VF at different visual  
 3 eccentricities for both hearing signers and non-signers. Error bar represent standard errors of the  
 4 mean and the \* indicates a significant difference ( $p < 0.05$ ).

5  
 6 **Table 2**  
 7 *Luminance sensitivity in the upper visual field (threshold in decibel). Standard errors of the mean are*  
 8 *in brackets.*  
 9

	<u>Upper Visual Field</u>				
	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)

10  
 11 **Table 3**  
 12 *Luminance sensitivity in the lower visual field (threshold in decibel). Standard errors of the mean are in*  
 13 *brackets.*  
 14

	<u>Lower Visual Field</u>				
	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)

#### 1        **4. Discussion**

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

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

23        In our study we assessed VF luminance sensitivity with the Humphrey VF Analyzer  
24 which is frequently used to diagnose glaucoma and to monitor the progress of the affection.  
25 Even if this method is one of the gold standard to assess VF sensibility, thresholds can be  
26 overestimated with a high ratio of false positive (i.e., more than 20%; Newkirk, Gardiner,  
27 Demirel, & Johnson, 2006) or be less precise than other VF analyzer methods and especially  
28 for low level of thresholds (i.e., vision loss like in glaucoma, Fredette, Giguère, Anderson,

1 Budenz, & McSoley, 2015; Spry, Johnson, & McKendrick, 2003). In our study, false positive  
2 ratios do not exceed 7% and since participants had no visual impairment we did not observe  
3 low threshold). We are then confident about the reliability of our data and the significant  
4 interaction between group and visual eccentricity clearly supported our hypothesis with a  
5 difference only in the lower visual field in the specific location sign language perception. Sign  
6 language experience can therefore be considered as a modulating factor of VF sensitivity.

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

17 Bosworth and Dobkins (2002) have compared VF field asymmetry for peripheral  
18 visual motion processing in deaf, hearing signers and non-signers. Contrary to our study,  
19 they didn't observe a difference between signers and non-signers in the lower visual field.  
20 Only deaf signers exhibited an advantage for motion processing in the lower VF. This  
21 discrepancy could be explained by the category of stimuli used: dynamic in their study vs  
22 static in our study. Motion processing recruits specific areas in the posterior part of the brain  
23 (MT and MST) that are more activated in deaf signers than in hearing (signers and non-  
24 signers) when they have to attend moving stimuli in the peripheral VF (Bavelier et al., 2001).  
25 To our knowledge only one other study has observed that sign language experience modifies  
26 visual perception on the lower part of VF (Dye, Seymour, & Hauser, 2015). In this study,  
27 signers (deaf or hearing) exhibited an attention bias toward the lower peripheral VF in a  
28 Useful Field of View task (described in the introduction) by comparing error distribution



1 across VF locations. These results, combined with ours, highlight the importance to explore  
2 vertical VF asymmetries when studying the perceptual outcomes of deafness and sign  
3 language experience.

4 Our results support the idea that perceptual and/or motor expertise enhances  
5 perceptual processing. Indeed, several studies investigated sensory and cognitive  
6 processing in experts like athletes, musicians and video game players. Beyond the physical  
7 performances, elite athletes outperformed typical population for sports-related skills like  
8 visuo-spatial attention, anticipation or even decision making (e.g., Memmert, 2009; Mori,  
9 Ohtani, & Imanaka, 2002; Muiños & Ballesteros, 2013; Williams & Ford, 2008; Zwierko,  
10 2008). Musicians also develop skills linked to their practice, like auditory discrimination,  
11 rhythms and fine motors skills (e.g., Chartrand & Belin, 2006; Lotze, Scheler, Tan, Braun, &  
12 Birbaumer, 2003; Pallesen et al., 2010; Pau, Jahn, Sakreida, Domin, & Lotze, 2013; Zatorre,  
13 Chen, & Penhune, 2007). Interestingly, video game players who regularly play music and  
14 rhythm games like Guitar Hero or Rock Band are better than controls for melody, tuning and  
15 tempo perceptual abilities and with relatively similar abilities than musicians (Pasinski,  
16 Hannon, & Snyder, 2016). Action video games experts also develop visual and attention  
17 skills similar to the enhancements observed in the deaf population (e.g., Buckley, Codina,  
18 Bhardwaj, & Pascalis, 2010; Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2003,  
19 2006, 2007; Spence & Feng, 2010). Therefore, being fluent in sign language is more than  
20 “speaking” another language; it is also mastering complex visuo-motor constraints that could  
21 induce bottom-up plasticity.

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