Supplemental Information: Typical exogenous covert orienting of attention without the ability to plan eye movements

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Other Supplementary Materials for this manuscript include the following:

Data available online on the Open Science Framework platform (link: https://osf.io/cwne6/).

Lead Contact:

Further information and requests for resources should be directed to and will be fulfilled by the Lead Contact, Nicolas Masson (Nicolas.masson@uclouvain.be).

Supplemental information on the participants

We tested three women born with congenital gaze paralysis in the context of a Moebius syndrome (all right-handed; various education levels) and 15 typically-developed control participants (14 females; 1 left-handed; all college students or graduates with normal or corrected-to-normal vision and no history of psychiatric or neurological disorder; Mean age ± SD: 20 ± 2 years). Moebius Syndrome is a rare condition characterized by nonprogressive congenital facial palsy and a variable spectrum of oculomotor impairment [S1].

Participant HGP1 (Horizontal Gaze Paralysis 1) is a 31-year-old right-handed woman. She shows a slight strabismus and a complete absence of horizontal (both abduction and adduction) ocular movements but normotypical vertical ocular movements. Participants HGP2 (Horizontal Gaze Paralysis 2) is a 43-year-old right-handed woman showing orthotopia in primary position (i.e., her eyes are in the typical central position) with a complete absence of horizontal (both abduction and adduction) ocular movements, but normotypical vertical ocular movements. HGP1 and HGP2 had previously participated in studies assessing the role of facial motor representations on action perception in which they were referred to as participants IMS10 and IMS4, respectively [S2, S3]. Participant VGP (Individual with Vertical Gaze Paralysis) is a right-handed woman with orthopia, normotypical horizontal ocular movements, but completely absent vertical ocular movements. All three participants showed a mild vision loss with best corrected acuities ranging from 5/10 to 8/10; none of them showed any neurological or psychiatric history.

Supplemental Materials and Methods

The experimental investigations were carried out from May 2019 to November 2019 in sessions lasting approximatively 60 minutes. The study was approved by the

biomedical ethics committee of the Cliniques Universitaires Saint-Luc, Brussels, Belgium (Registration # B403201629166) and all participants gave written informed consent prior to the study. During the experiment, participants were seated in front of a computer screen located at a distance of 56 cm. All the experiments were conducted on a PC equipped with a 19-inch LCD screen (resolution 1280x1024; refresh rate 60 Hz). Stimulus presentation and behavioral data collection were programmed using either OpenSesame (Experiment 1 and 2) [S4] or Psychopy (Experiment 3) [S5].

Experiment 1: Target detection task with exogenous cueing of attention

This experiment aimed at measuring exogenous covert shift of attention (ECSA) in the horizontal and vertical orientation in the three individuals with congenital gaze paralysis and the typically developed control participants. It was performed once by HGP 1, by VGP and by the control participants. HGP 2 performed the experiment twice. In a first session, HGP2 performed only the trials in the paralyzed orientation. In the second session, HGP2 performed the experiment in both orientations. We used an adaptation of the classical target detection task [e.g., S6-S7]: Participants had to detect lateralized targets that could appear 100 ms or 300 ms after the presentation of a peripheral cue that did not predict the location of the to be displayed target.

Method and material.

During the experiment, participants sat at a distance of 56 cm from the screen. Head movements were prevented by a chin and forehead stabilizer. Each trial began with the presentation of one central (2.5° x 2.5°) and two peripheral white boxes (size: 2.5° x 2.5°; eccentricity: 6°) arranged either in the horizontal or vertical axis (in separated blocks). A dot was displayed within the central box for the whole trial and participants were asked to always maintain their eyes focused on it. After 1000 ms, the width of the

outline of one of the two peripheral box increased, providing an exogeneous cue. Then, in 80% of the trials a dot appeared in one of the two peripheral boxes 100 or 300 ms after the onset of the cue. The location of the target was not predicted by the position of the cue. Participants had to press a response button as fast as possible whenever a dot appeared in one of the peripheral boxes. Participants had to respond within 1000 ms. A warning signal (i.e., “Error” written in red in French) appeared in the center of the screen if participants pressed the response button when no target was displayed or if they did not respond within 1000 ms. There were 5 blocks of 60 trials per orientation. They were asked to avoid pressing a button if no dot appeared.

Control participants’ eye movements were recorded using an Eyelink 1000 duo desktop-mounted eye tracker (SR Research, Canada; sampling rate of 1000 Hz; average accuracy range 0.25° to 0.5°, gaze tracking range of 32° horizontally and 25° vertically). At the beginning of each block, a standard 9-point protocol was used to calibrate participants' eye-gaze position to a display screen using Eye-Link software

Gaze movements were not recorded for HGP1, VGP and for the first session of HGP2 on the ground that the absence of gaze displacement in the paralyzed orientation was secured by the chin and forehead stabilizer and controlled online by the experimenter. HGP2’s gaze displacement was recorded in the same conditions as the controls in the second experimental session that took place about 4 months after the first session. HGP2 was allowed to move her head for the calibration phase only. This was done so that she could fixate points presented to the left and right of the screen.

Analysis and results:

Trials were first filtered and excluded if control participants or HGP2 (second session) made a detectable (i.e., amplitude of more than 2°) eye displacement, which

corresponds to 2.39% (317/11100) of the observations. No head movement was detected by the experimenter when HGP1, VGP and HGP2 (first session) performed the experiment. Responses during trials without targets were considered as false alarms (2.52 %; 56/2200). Next, trials with response recorded during the delay or with response time inferior to 100 ms were considered as anticipations and excluded (0.88%; 78/8800). Trials with no response (i.e., participants not pressing the button before the 1000 ms time limit) were discarded (0.45%; 40/8800). Then, we calculated for each participant and each trial category (SOA x Validity) the median absolute deviation around the median (MAD) [S8]; trials were considered as outliers and removed if they were 3 MAD smaller or larger than the individual's median reaction for each category of trials. Altogether these criteria resulted in a total of 9.17% (814/8880) of trials discarded. Prior to any analysis, we correlated the mean response latencies of each control to their percentage of trials in which they responded while they should not (anticipations and response to catch trials). This correlation was not significant which allowed us to rule out speed accuracy trade off (r=-.124, p=.624).

Results of the control group

We first performed a by-subject analysis of the results of the control group. We computed the mean response latencies of valid trials and invalid trials for each participant, axis (horizontal *vs*. vertical), and stimulus onset asynchrony (100 or 300 ms). Typically-developed participants showed, as a group, a significant cueing effect at a SOA of 100 ms for both horizontal (t(14)=5.036, p<.001; 23 ± 17 ms; d=1.3) and vertical (t(14)=6.249, p<.001; 23 ± 14 ms; d=1.61) axes. At a SOA of 300 ms, the cueing effect was not significant for both horizontal (t(14)=2.021, p=.063; 8 ± 15 ms; d=.52) and vertical t(14)=1.974, p=.068; 8 ± 17 ms; d=.51) axes. Comparisons of

horizontal and vertical cueing effects were not significant at either 100 ms (t(14)=.026, p=.98; d<.01) or 300 ms (t(14)=.103, p=.92; d=.03).

Then, we performed by-items analyses of the results of each control participant. Response latencies for each condition (valid and invalid) and orientation (horizontal and vertical) were first inverse-transformed to satisfy the *t*-test's normality assumptions. Then, we compared the inverted response latencies between invalid and valid trials for each axis (horizontal vs. vertical), and stimulus onset asynchrony (100 or 300 ms) in each participant (see Table S1). In the horizontal axis, 11 out of 15 participants showed a significant cueing effect at 100 ms, and 3/15 a significant cueing effect at 300 ms. All but 2 participants showed the effect at either 100 or 300 ms or both. In the vertical axis, 10 out 15 participants showed a significant cueing effect at 100 ms. At 300 ms,5 showed the significant advantage for valid trials and 1 for invalid trials. All but 3 participants showed a significant cueing effect at either 100 ms or 300 ms or both.

Participants with gaze palsy:

We compared response latencies between invalid and valid trials for each axis (horizontal vs vertical), and stimulus onset asynchrony (100 or 300 ms) in each individual with gaze paralysis (see Table S1). These data were inverse-transformed to satisfy the statistic tests' normality assumptions. VGP showed a significant cueing effect of 40 ms in the horizontal axis (p=.041) at 100 ms that decreased at 300 ms (p=.125). In the vertical axis, she did not show a significant advantage for the valid targets at 100 ms (p=.238), but a significant cueing effect of 18 ms emerged later at 300 ms (p=.006). HGP1 showed a significant cueing effects at 100 ms of 19 ms for the horizontal axis (p=.007) and of 39 ms for the vertical axis (p=.005). At 300 ms, she

showed a significant disadvantage of 33 ms for the valid targets for the horizontal axis (p<.001) and of 20 ms for the vertical axis (*p*=.005). HGP2 was tested twice. On the first session, we only tested her on the horizontal axis and she showed a significant cueing effect of 26 ms at 100 ms (*p*=.016) that decreased at 300 ms (*p*=.072). She was tested again 4 months later for both axis and still showed a significant cueing effects at 100 ms of 22 ms for the horizontal axis (*p*=.021) and of 41 ms for the vertical axis (*p*<.001). At 300 ms, there was no significant difference between valid and invalid targets for the horizontal axis (*p*=.301) while there was a weaker but significant cueing effect of 23 ms (*p*=.008) for the vertical axis. Critically, the three participants with gaze paralysis showed a significant exogenous cueing effect in both axes at either 100 ms or 300 ms or both SOAs.

Comparison between individuals with gaze palsy and typically-developed controls

Cueing effect was calculated for each participant by subtracting the mean response latency for valid trials from the mean response latency for the invalid trials. We applied the modified t-test [S9] to compare the cueing effect of VGP, HGP1 and HGP2 and of the typically developed group for each axis and SOA (see Table S2). At 100 ms, the cueing effect of the three individuals with gaze palsy did not differ from the mean cueing effect of the typically developed group (all *ps*>.05). There was also no difference of cueing effect at 300 ms between the individuals with gaze palsy and the control group (all *ps*<.05), except a significant smaller cueing effect for HGP1, indicating a stronger reversal of the cueing effect in the horizontal axis (*p*=.01) that was only marginal in the vertical (*p*=.067) axes. This shows that the cueing effects were not only present in each of the individuals with gaze palsy, whatever the axis, but that it did not differ significantly from the effects observed in the typically developed controls.

Comparison between vertical and horizontal cueing

We applied the Bayesian standardized difference test (BSDT) [S10] to test whether the discrepancy of cueing effect between the two axes in the individuals with gaze palsy was significantly different from the discrepancy between the two axes in the control group (see Table S2). At 100 and 300 ms, this discrepancy was not significantly different in the three individuals with gaze paralysis than in the typically-developed controls for both SOAs (all *ps*>.1).

Experiment 2: Overt displacement of attention.

This experiment aimed at measuring the time needed for the participants with congenital horizontal eye paralysis (HGP1 and HGP2) to displace their attention overtly using either eye movements (in the vertical plane) or head movements (in the horizontal plane).

Material and stimuli:

Participants sat in front of a computer screen at a distance of approximately 60 cm. In each trial, participants first saw a visual display composed of one central box (3° x 3°) with a fixation cross (0.1° x 0.1°) at its center and four other boxes (3° x 3°) positioned at 13° below, over, on the right or on the left of the central box. During that phase, participants were asked to fix a central cross. After a variable delay ranging from 1000 to 2000 ms (Mean = 1500; SD = 275), a small circle or a small square (0.2° x 0.2°) appeared in one of the five boxes. Participants were asked to press as fast as possible with their left index finger on the left button of a computer mouse when the target was a circle and with their right index finger on the right button when they saw a square. As the targets were very small, identifying the shape of the target required participants to

displace their gaze towards the targets when they appeared in the periphery. The next trial began immediately after the response was recorded or after 1500 ms if no response was recorded (time limit of 2500 ms). Each shape was presented 15 times at each position in a random order, resulting in 150 trials.

Results:

Analyses were performed separately for trials in which the target appeared at the center of the screen, and horizontal (left and right) orientations and in vertical (up and down) orientations. There was no trial faster than 250 ms. Trials with no response before the time limit and incorrect responses were discarded from response latency analyses (In the center, horizontal and vertical planes: HGP1: 20%, 23% and 18%; HGP2: 3%, 8% and 12%).

The response latency analyses indicated that, in comparison to the time needed to discriminate the two targets at the center of the screen (HGP1: 838 ms; HGP2: 713 ms), participants needed on average 212 (HGP1) and 275 (HGP2) additional ms to displace their eyes and make the same judgment on the vertical plane (HGP1: 1050 ms; HGP2: 988 ms), and on average 302 (HGP1) and 452 (HGP2) additional ms to displace their head and make the same judgment on the horizontal plane (HGP1: 1140 ms; HGP2: 1165 ms). Horizontal head movements were significantly slower than the vertical eye movements (both $ts > 2.5$, both $ps < .01$).

Experiment 3: Target detection task with exogenous cueing of attention and neck abduction.

Experiment 2 relies on an innovating “neck abduction” paradigm to test the possibility that typical ECSA in absence of eye movements may be supported by the programming of head movements. This experiment was performed by HGP2.

Methods and materials:

Experiment 3 was identical to Experiment 1 with the following exceptions. We only administered the horizontal version of the task with 6 blocks of 60 trials. HGP2 was seated with her shoulders strapped against the back of a chair. Her non-preferred eye was patched (right). Then we asked her to rotate her head at approximatively 70° to the left. Her head was then immobilized by a chin rest and a helmet (see Figure 1B). She faced the screen so that the midline of her face was in front of the center of the screen. In this position, targets located on the left of the screen were out of reach of a neck movement while those located on the right side of the screen were reachable if she could move. This set up was used as an equivalence of the eye-abduction paradigm in which targets are located out of the oculomotor range of the participants (Craighero, Nascimben, & Fadiga, 2004; Smith, Rorden, & Schenk, 2012).

Results:

HGP made no false alarms on trials without targets. One trial was removed because of an anticipation (response time shorter than 100 ms) and another one because she did not respond within 1000 ms. We then applied the same methodology to remove outliers as in Experiment 1. We compared reaction times between the remaining invalid and valid trials for reachable and unreachable targets and stimulus onset asynchrony (100 or 300 ms) (see Table S1). These data were inverse-transformed to satisfy the statistic tests' normality assumptions. HGP2 showed a significant cueing effect for both Reachable and Unreachable targets at both SOAs (all ps<.02).

Table S1: Individual scores for Experiment 1 & 3 as a function of the target location. Bold values highlight significant cueing effect.

Target location	**Participant**	**SOA (ms)**									
		100						**300**			
		Invalid (SD)		Valid (SD)		Cueing Effect	p-val	Invalid (SD)		Valid (SD)		Cueing Effect	p-val
							Experiment 1						
Horizontal	TD1	406	(60)	371	(60)	**34**	**.001**	384	(74)	374	(58)	10	.320
	TD2	369	(60)	330	(42)	**39**	**<.001**	337	(49)	331	(63)	6	.178
	TD3	394	(66)	353	(62)	**40**	**<.001**	347	(49)	345	(55)	2	.332
	TD4	342	(43)	341	(32)	0	.490	324	(45)	316	(44)	8	.164
	TD5	437	(85)	384	(35)	**54**	**<.001**	386	(62)	383	(73)	3	.291
	TD6	373	(53)	373	(66)	0	.385	348	(50)	321	(40)	**27**	**.003**
	TD7	400	(63)	398	(84)	2	.249	396	(84)	352	(74)	**44**	**.002**
	TD8	378	(51)	374	(53)	4	.306	353	(61)	364	(67)	-11	.228
	TD9	360	(55)	337	(46)	**24**	**.010**	325	(42)	317	(47)	7	.132
	TD10	291	(42)	276	(34)	**15**	**.032**	276	(57)	276	(45)	0	.482
	TD11	318	(42)	278	(39)	**40**	**<.001**	291	(36)	300	(38)	-9	.098
	TD12	358	(35)	345	(50)	**14**	**.017**	342	(41)	337	(55)	4	.170
	TD13	338	(35)	320	(50)	**18**	**.005**	291	(37)	288	(28)	3	.416
	TD14	434	(76)	389	(66)	**44**	**.001**	411	(85)	417	(100)	-6	.488
	TD15	359	(43)	342	(50)	**17**	**.016**	332	(43)	301	(38)	**31**	**<.001**
	VGP	441	(114)	401	(90)	**40**	**.041**	399	(94)	372	(89)	27	.125
	HGP1	363	(43)	344	(73)	**19**	**.007**	308	(34)	341	(49)	**-33**	**<.001**
	HGP2 1st	427	(70)	401	(78)	**26**	**.016**	409	(77)	389	(66)	21	.072
	HGP2 2nd	457	(76)	430	(67)	**22**	**.021**	415	(66)	414	(41)	1	.301
Vertical	TD1	380	(41)	359	(51)	**20**	**.005**	337	(42)	352	(74)	-14	.270
	TD2	346	(44)	316	(33)	**30**	**<.001**	318	(38)	306	(31)	**13**	**.033**
	TD3	357	(68)	360	(83)	-3	.416	345	(37)	338	(63)	7	.082
	TD4	318	(29)	300	(46)	**18**	**.002**	287	(28)	308	(43)	**-21**	**.002**
	TD5	417	(63)	403	(74)	14	.082	372	(52)	350	(41)	**22**	**.018**

	TD6	397	(86)	358	(48)	39	.064	361	(50)	357	(54)	4	.291
	TD7	379	(79)	347	(73)	**32**	**.010**	353	(75)	334	(81)	19	.064
	TD8	367	(55)	345	(52)	**22**	**.012**	338	(71)	335	(62)	3	.486
	TD9	338	(42)	347	(54)	-8	.255	304	(44)	315	(50)	-12	.116
	TD10	284	(41)	254	(34)	**30**	**<.001**	259	(33)	256	(31)	3	.365
	TD11	312	(51)	284	(33)	**29**	**.003**	305	(37)	285	(30)	**20**	**.003**
	TD12	366	(58)	335	(45)	**32**	**.002**	338	(49)	334	(46)	4	.339
	TD13	358	(42)	313	(38)	**45**	**<.001**	309	(41)	293	(32)	**16**	**.018**
	TD14	393	(59)	363	(79)	**30**	**.009**	379	(51)	333	(58)	**46**	**<.001**
	TD15	328	(42)	311	(40)	18	.162	289	(29)	270	(33)	**18**	**<.001**
	VGP	368	(76)	368	(59)	0	.238	370	(36)	352	(39)	**18**	**.006**
	HGP1	350	(71)	311	(58)	**39**	**.005**	306	(41)	326	(39)	**-20**	**.005**
	HGP2 2nd	490	(60)	449	(73)	**41**	**<.001**	439	(49)	416	(70)	**23**	**.008**
							Experiment 3						
Reachable	HGP2	434	(51)	405	(42)	**29**	**.012**	376	(36)	352	(40)	**24**	**.003**
Unreachable	HGP2	421	(41)	389	(52)	**32**	**.001**	391	(49)	361	(53)	**30**	**.004**

Table S2: P-values of the modified t-tests used to compare the cueing effects of the individuals with congenital gaze paralysis to those of the typically-developed controls in the horizontal and vertical axes and the probability that the discrepancy between the horizontal and vertical cueing effects for a member of the typically developed population would be greater than that of the case (BSDT). Bold values indicate significant p-values.

	SOA (ms)					
	100			300		
	Horizontal	Vertical	Discrepancy	Horizontal	Vertical	Discrepancy
VGP	.175	.067	.128	.120	.289	.653
HGP1	.412	.144	.414	**.010**	.067	.500
HGP2	.478	.117	.426	.329	.204	.372

Supplemental References

S1. Carta, A., Mora, P., Neri, A., Favilla, S., & Sadun, A. A. (2011). Ophthalmologic and systemic features in Möbius syndrome: An Italian case series. *Ophthalmology, 118*(9), 1518-1523. https://doi.org/10.1016/j.ophtha.2011.01.023

S2. Vannuscorps, G., Andres, M., & Caramazza, A. (2020). Efficient recognition of facial expressions does not require motor simulation. Elife, 9, e54687. DOI: 10.7554/eLife.54687

S3. Vannuscorps, G., Andres, M., Carneiro Pereira, S., Rombaux, E. & Caramazzza, A. (2020). Typical lipreading and audiovisual speech perception without motor simulation. BioRxiv. doi: https://doi.org/10.1101/2020.06.03.131813

S4. Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior research methods, 44*(2), 314-324. https://doi.org/10.3758/s13428-011-0168-7

S5. Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of neuroscience methods, 162*(1-2), 8-13. https://doi.org/10.1016/j.jneumeth.2006.11.017

S6. Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. Attention and performance X: Control of language processes, 32, 531-556.

S7. Smith, D. T., Rorden, C., & Jackson, S. R. (2004). Exogenous orienting of attention depends upon the ability to execute eye movements. Current Biology, 14(9), 792-795. https://doi.org/10.1016/j.cub.2004.04.035

S8. Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology, 49*(4), 764-766. https://doi.org/10.1016/j.jesp.2013.03.013

S9. Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist, 12*(4), 482-486. https://doi.org/10.1076/clin.12.4.482.7241

S10. Crawford, J. R., & Garthwaite, P. H. (2007). Comparison of a single case to a control or normative sample in neuropsychology: Development of a Bayesian approach. *Cognitive Neuropsychology, 24*(4), 343-372. https://doi.org/10.1080/02643290701290146

Author contributions

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