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Exposure to first-person shooter videogames is associated with multisensory temporal precision and migraine incidence

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ABSTRACT

Adaptive interactions with the environment require optimal integration and segregation of sensory information. Yet, temporal misalignments in the presentation of visual and auditory stimuli may generate illusory phenomena such as the sound-induced flash illusion, in which a single flash paired with multiple auditory stimuli induces the perception of multiple illusory flashes. This phenomenon has been shown to be robust and resistant to feedback training. According to a Bayesian account, this is due to a statistically optimal combination of the signals operated by the nervous system. From this perspective, individual susceptibility to the illusion might be moulded through prolonged experience. For example, repeated exposure to the illusion and prolonged training sessions partially impact on the reported illusion.

Therefore, extensive and immersive audio-visual experience, such as first-person shooter videogames, should sharpen individual capacity to correctly integrate multisensory information over time, leading to more veridical perception. We tested this hypothesis by comparing the temporal profile of the sound-induced illusion in a group of expert first-person shooter gamers and a non-players group. In line with the hypotheses, gamers experience significantly narrower windows of illusion (~87 ms) relative to non-players (~105 ms), leading to higher veridical reports in gamers (~68%) relative to non-players (~59%). Moreover, according to recent literature, we tested whether audio-visual intensive training in gamers could be related to the incidence of migraine, and found that its severity may be directly proportioned to the time spent on videogames. Overall, these results suggest that continued training within audio-visual environments such as first-person shooter videogames improves temporal discrimination and sensory integration. This finding may pave the way for future therapeutic strategies based on self-administered multisensory training. On the other hand, the impact of intensive training on visual-related stress disorders, such as migraine incidence, should be taken into account as a risk factor during therapeutic planning.

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1. Introduction

Our perception and interactions with the external world do not consist of isolated sensory events, but rather a rich combination of multisensory experiences. This integration of information across different sensory modalities represents a ubiquitous operation in everyday human behaviors that shapes our perception (Sutherland et al., 2014), improving our ability to interact with the environment adaptively, allowing for enhanced detection (Leo and Noppeney, 2014; Leo et al., 2011; Lovelace et al., 2003; Ramos-Estebanez et al., 2007), more accurate localization (Leo and Noppeney, 2014; Nelson et al., 1998; Wilkinson et al., 1996), and faster reactions (Diederich and Colonius, 2004; Hershenson, 1962;Romei et al., 2007). In addition to these highly adaptive benefits, multisensory integration can also be seen in a host of perceptual illusions. One of the more compelling illusions is the 'sound-induced flash illusion' (SIFI) (Hirst et al., 2020; Keil, 2020; Shams et al., 2000, 2002), that occurs when a single flash is presented along with two or more beeps and observers often report seeing two or more flashes, demonstrating that visual perception can be radically altered by signals of other modalities. Importantly, studies have demonstrated that these interactions between the senses are highly dependent upon the temporal characteristics of the stimuli that are combined, such as their level of synchrony. Indeed, it has been shown that multisensory stimuli presented in close temporal proximity are often integrated into a single, unified percept (Andersen et al., 2004; Bastiaansen et al., 2020; Migliorati et al., 2019; Shams et al., 2000; Stein and Meredith, 1993). This perceptual binding over a given temporal interval is best captured in the construct of a multisensory temporal binding window (TBW); (Colonius and Diederich, 2004; Hairston et al., 2005; Powers et al., 2009). Within this window, the combination of information between two different modalities across a range of stimulus asynchronies results in significant alterations at the neural, behavioral and perceptual responses. In line with this idea is the observation that the closer the temporal proximity between two presented stimuli, the more likely they will be integrated into a single percept. On the other hand, as the temporal interval between the stimuli (i.e., the stimulus onset asynchrony, SOA) increases, the likelihood of multisensory interactions decreases (Chan et al., 2018; Shams et al., 2000; Spence et al., 2003; Vroomen and Keetels, 2010). Interestingly, it has been suggested that the brain uses a mechanism similar to Bayesian inference (Knill and Pouget, 2004; Shams et al., 2005) to decide whether, to what degree, and how (in which direction) to integrate the signals from auditory and visual modalities, and that the SIFI can be considered as an epiphenomenon of a statistically optimal computational strategy. In particular, auditory and visual stimuli appear to be integrated into a single perceptual representation at SOAs from physical simultaneity (i.e., 0 msec apart) up to ~100–150 msec, after which the two stimuli are perceived as distinct (Schneider and Bavelier, 2003; Zampini et al., 2005). Accordingly, this temporal window has been viewed as reflecting the typical temporal window of multisensory integration. However, consistent differences across healthy individuals have been observed (Donohue et al., 2015; Hernández et al., 2019; Stevenson et al., 2012; Setti et al., 2011; Stone et al., 2001) and altered multisensory integration with both reduced and wider audio-visual TBW has been documented in atypical populations such as in individuals with autistic spectrum disorders (Stevenson et al., 2014; van Laarhoven et al., 2019; Wallace and Stevenson, 2014; Yaguchi and Hidaka, 2018; Zhou et al., 2018), dyslexia (Bastien-Toniazzo et al., 2010; Hairston et al., 2005) and schizophrenia (De Gelder et al., 2003, 2005; De Jong et al., 2009; Foucher et al., 2007; Pearl et al., 2009; Ross et al., 2007; Szycik et al., 2009).

In line with a Bayesian account, it has been observed that experience can narrow the TBW, for example, a perceptual training (<5 days) in either a combined or unisensory regimen (Powers et al., 2009; Setti et al., 2014; Stevenson et al., 2013; but see; Powers et al., 2016). However, multisensory training might affect the sensitivity to SIFI differently depending on age and task. Indeed, multisensory abilities have been shown to undergo developmental changes (Hirst et al., 2019), as in older adults training seems to be more effective (Setti et al., 2014) relative to younger ones (Powers et al., 2016). Moreover the training task properties possibly impact the outcome of perceptual learning through different transfer mechanisms (McGovern et al., 2016a, b). On the other hand, certain long-term perceptual–cognitive experiences such as musical (Bidelman, 2016) and bilingual (Bidelman & Heath, 2019) exposure, prove the influence of expertise in shaping multisensory integration profiles.

Similarly to what has been found for musicians (Bidelman, 2016) or bilinguals (Bidelman & Heath, 2019), the current study investigates a novel, not yet tested hypothesis (for recent reviews see Hirst et al., 2020; Keil et al., 2020) that an intensive audiovisual experience, such as videogame playing, can sharpen audio-visual processing and their temporal binding window. Moreover, we tested a related hypothesis that together with positive performance effects, intensive videogame playing may be related to an increased incidence of migraine, a neurological condition determined by altered visual cortex excitability and reduced visual contrast sensitivity (Asher et al., 2018; Aurora et al., 1998, Aurora et al., 2003; Brigo et al., 2013; O'Hare and Hibbard, 2016).

Videogames have an astonishing effect on the player's visual system. In several studies, action videogame players have outperformed the non-players in visual information processing abilities (Riesenhuber, 2004), including selective attention (Belchior et al., 2013; Dye et al., 2009; Green and Bavelier, 2003), visual search efficiency (Castel et al., 2005), visuospatial attention (Clark et al., 2011; Spence and Feng, 2010; West et al., 2008), contrast sensitivity (Li et al., 2011) and visual interference suppression (Hazarika et al., 2018). In particular, action videogame players used to play first-person shooter game (FPSG) which is an action videogame involving first person's perspective in which the player experiences the gaming environment through the eyes of the protagonist. The player controls a character or an avatar of the game which performs multiple tasks at the same time, and this has been found to improve players' ability to simultaneously track multiple moving visual items (Green & Bavelier, 2006), spatial abilities (Quaiser-Pohl, Geiser & Lehmann, 2006) and divided attention abilities (Greenfield, DeWinstanley, Kilpatrick & Kaye, 1994). Player needs to react through mouse, keyboard or joystick resulting in faster hand-eye coordination and quick reflective actions (Griffith et al., 1983). Importantly, videogames are inherently multisensory, with first-person shooter and other action games often having both auditory and visual cues that are relevant to an appropriate behavioral response, also considering that the presence of tactile stimulation via the haptic device (e.g., joystick) offers an additional sensory source to be implemented in some cases (Archambault et al., 2007). In line with the multisensory nature of the game, it has been found that videogame players have a more fine-tuned sense of temporal synchrony that enables a greater ability related to the non-players to notice slight asynchronies between auditory and visual stimuli (Donohue et al., 2015), supporting the notion that temporal integration can be manipulated by prior experiences (Harrar and Harris, 2008; Vroomen et al., 2004).

The aim of this study was twofold. First, we aimed to determine whether extensive videogame experience enhances audio-visual processing and narrows the temporal binding window for combining multisensory cues. To test our hypothesis, we submitted the sound-induced flash illusion (SIFI) to first-person shooter game players (FPSG) and non-players (NP) and parametrically varied the onset asynchrony between the first audio-visual pair and the second auditory stimulus. Since it has been demonstrated that individuals with a narrower TBW have an enhanced capacity to distinguish between asynchronous audio-visual inputs (Stevenson et al., 2012), we predict FPSG to show also a reduced temporal window in which they experience the illusion (TWI) which in turn may account for the reduced overall proneness to the illusion (see Ferri, Venskus, Fotia, Cooke & Romei, 2018).

Second, we aimed at testing the relation between videogame experience and migraine based on their link to visual cortical excitability. Noninvasive brain stimulation techniques, such as the tDCS and tACS, have shown to change the SIFI in healthy volunteers, by modulating the excitability of the primary visual cortex (Bolognini, Rossetti, Casati, Mancini & Vallar, 2011) and the temporal window within which the participants perceive the illusion by manipulating the frequency of the occipital alpha activity (Cecere, Rees & Romei, 2015, an oscillatory activity associated with the level of visual cortex excitability within (Romei et al., 2008) and across participants (Romei, Rihs, Brodbeck & Thut, 2008). These findings, which demonstrated that visual cortical excitability has an impact in the SIFI, are also supported by studies on migraine, a condition associated with pathologic cortical hyperexcitability, that results in reduced multisensory illusion (Brighina et al., 2015). In line with this data, migraine is often associated with the excessive use of digital equipment (Torsheim et al., 2010; Xavier et al., 2015). Therefore, we expect that the visual sensory stress due to the intensive and immersive training of the audio-visual integration system of FPSG may lead to higher visual cortex excitability and consequently, to a higher headache-related disability, which may represent a consequence related to the modulation operated at the level of the cortical substrate associated with reduced temporal windows within which gamers experience the SIFI.

2. Methods

2.1. Participants

An initial online screening on a wide sample of ~400 responders was performed in order to identify participants with different levels of gaming experience. Sample size, with all inclusion and exclusion criteria was established prior to data analysis and we report all manipulation and measures in the study. Based on a priori power analysis considering previous studies (Donohue et al., 2015; Ferri et al., 2018; Hazarika et al., 2018) and returning an estimated sample size of 42 participants (effect size d = .8, alpha = .05, and 80% power), 50 healthy participants agreed to take part in the study. Eight were subsequently excluded because their data did not fit to the model (see Data Analysis). On the basis of the assessment of their prior gaming experiences, twenty-one participants (19 men, mean age ± S.D.: 23.8 y ± 3.1) were assigned to the FPSG group (First-Person Shooter Games), and other 21 participants [12 men, 26.6 y ± 5.5; no age differences between the two groups were found ($t_{40} = 1.94$; $p > .05$)] were assigned to the NP group (Non-Players). Participants filled in a videogame questionnaire that assessed their exposure to First-Person Shooter games, the mean time (in hours) spent playing videogames on a weekly basis and their experience, based on the time spent on the videogame expressed in months and years. The NP group was defined as those participants who had <1 h per week of first-person shooter experience in the past 6 months, as well as having less than 1.5 h per week within the past 6 months of real-time strategy and sports games, while the FPSG group was defined as having a minimum of 10 h per week of first-person shooter experience in the past 6 months (mean hours per week ± S.D.: 19.1 ± 9.4) as suggested in previous works on videogame players (Donohue et al., 2015; Gorbet & Sergio, 2018; Hazarika et al., 2018). For the FPSG participants we additionally collected the weekly amount of time spent on games not including FPSG, and the time since first exposure to FPSG videogames.

All participants were naïve to the purpose of the experiment and gave their informed written consent before being tested. The experimental procedures were approved by the University of Bologna Bioethics committee and were in accordance with the 1964 Declaration of Helsinki. The methods carried out in this study are in accordance with approved guidelines.

No part of the study procedures and analyses were pre-registered prior to the research being conducted.

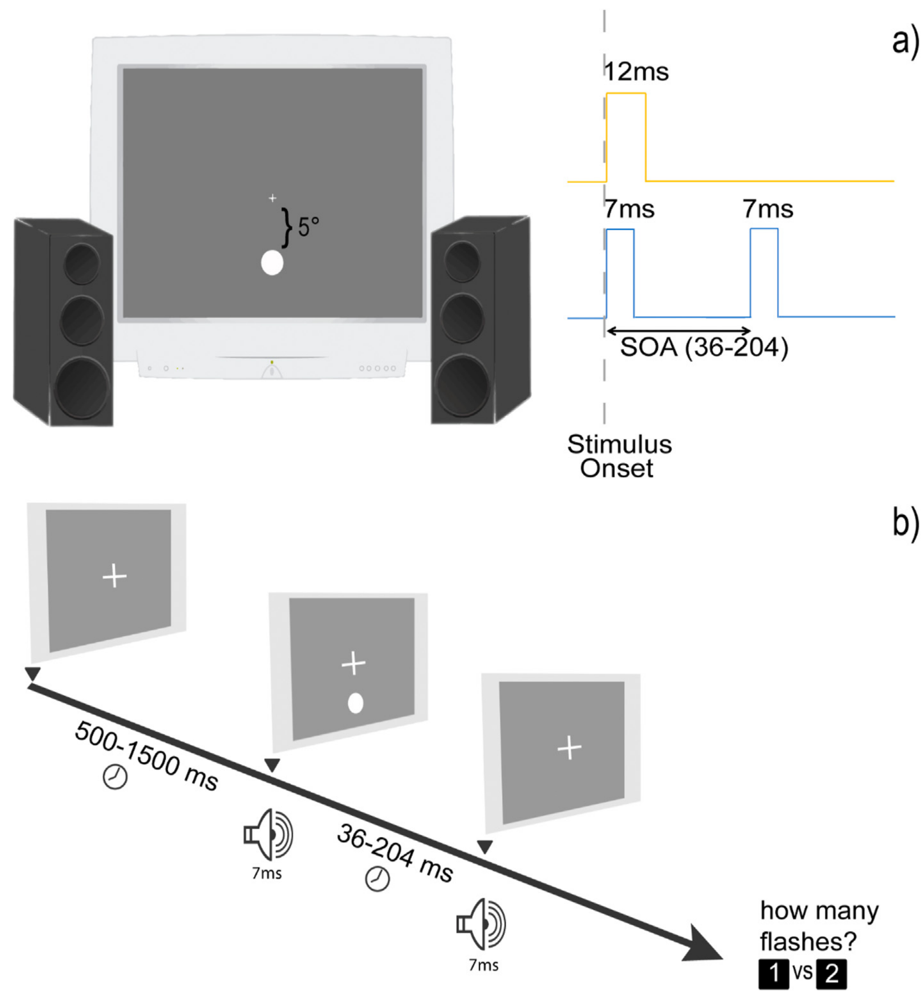

Fig. 1 – a) Experimental setup in the sound-induced flash illusion. A white flash is presented below a fixation cross outside of the foveal area on a neutral background. Simultaneously, two auditory beeps are presented. The duration of the visual stimulus is 12 ms, the auditory stimuli have a duration of 7 ms. b) Schematics of the experimental paradigm. For each trial, participants were instructed to fix a white fixation cross in the middle of a grey screen lasting for a period randomly ranging between 500 and 1500 ms. Subsequently, they were presented with one (and always one) visual flash accompanied by two (and always two) brief auditory stimuli. The onset of the first beep was always temporally coincident with the onset of the visual flash, whereas the onset of the second beep could be presented at 15 different delays, with onset ranging between 36 and 204 ms in 12 ms steps from the first auditory stimulus onset. Participants were explicitly asked to report whether they perceived one versus two visual flashes.

2.2. *Experimental setup*

Stimuli were presented on a 17' CRT display (Cathode Ray Tube, CRT, refresh rate 85 Hz) in a dimly lit room. Participants sat in a comfortable chair in front of the monitor, at 57 cm viewing distance. Two small stereo PC speakers were placed on either side of the monitor and horizontally aligned with visual stimuli (Fig. 1a). Stimulus presentation and behavioral response recording were controlled by a PC running E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). In a few participants ($n = 6$ FPSG and $n = 6$ NP) stimulus presentation and behavioural response recording were controlled through a Matlab custom-made script. Stimulus presentation, script codes, analyses codes and behavioural responses are available at (https://osf.io/5h76y/). Un-speeded manual two-choice responses were collected using a standard keyboard.

2.3. *Stimuli and task*

Stimuli and procedure were adapted from previous studies (Cecere et al., 2015; Cooke, Poch, Gillmeister, Costantini & Romei, 2019; Ferri et al., 2018; Shams et al., 2002). In all trials, both visual and auditory stimuli were presented. On each trial the visual stimulus consisted of a solid white circle subtending 2° of visual angle. The auditory stimulus was a stereo, sinusoidal pure tone (frequency: 3.5 kHz; sampling rate: 44.1 kHz) of 7 ms duration. Each trial started with the display of a white fixation cross (.7 visual degrees) centered on a uniform grey background. After a random time-lag (500–1500 ms), the visual stimulus was briefly flashed for 12 ms, at 5 visual degrees eccentricity below fixation. On each trial, the single flash was always accompanied by two beeps: the first beep was always temporally aligned i.e., synchronous with the flash whereas the second beep followed the first one with a random delay, chosen among 15 possible SOAs (i.e., 36, 48, 60, 72, 84, 96, 108, 120, 132, 144, 156, 168, 180, 192, 204 ms). See Fig. 1b for the spatial configurational and the temporal profile of the stimuli. In a two-alternative forced-choice paradigm, participants reported after each stimulus display whether they perceived one or two flashes by pressing the corresponding button on a keyboard (1 with the index finger or 2 with the middle finger, respectively). Each experimental block consisted of 300 trials (20 repetitions for each of the 15 inter-beep delays). Trial presentation was completely randomized. Participants were instructed to pay attention to visual stimuli only and to ignore the sounds, and to weight accuracy over speed when responding. The presentation of the two auditory stimuli together with the single flash was intended to induce the perception of a second illusory visual flash while there was always only one flash. In particular, the shorter the SOA, the stronger the illusion should be (Shams et al., 2002). The range of SOAs used and the sampling interval chosen proved to be optimal for determining the time interval within which the double-flash illusion is perceived to the maximum degree and provides a sufficiently sensitive time window within which any difference in the time of illusion between FPSG gamers and non-players can be detected. Before starting the experimental session, all participants were asked to complete the Italian version of the Migraine Disability Assessment (MIDAS) questionnaire, an established instrument for assessing headache-related disability (D'Amico et al., 2001; Guglielmetti et al., 2020; Stewart et al., 1999).

3. Data analysis

3.1. *Temporal Window of Illusion (TWI)*

Participants' responses from the behavioural task were used to calculate the temporal window within which the illusion was maximally perceived. To this end, the percentage of trials where the illusion (i.e., two flashes) was experienced was first plotted as a function of the SOAs.

We fitted data to a psychometric sigmoid function [$y = a+b/(1+\exp(-(x-c)/d))$; a = lower asymptote; b = upper asymptote; c = inflection point; d = slope]. The obtained SOA (in ms) corresponding to the inflection point (centre) of the fitted sigmoid (i.e., the point of decay of the illusion) was considered as the amplitude of the window within which the illusion was experienced.

For each participant, the value of the inflection point was calculated using MATLAB and Curve Fitting Toolbox (version 2019b, the MathWorks, Natick, MA) with a trust-region method (Helfrich & Zwick, 1996). The overall goodness of fit to the model was also evaluated for both groups by means of average SSE and R-squared values, calculated for every participant. We excluded 8 subjects from the main analysis because their values did not satisfy fitting constrains ($R^2 < .25$, $p > .06$). Independent *t*-tests were performed to compare group means.

3.2. *Overall proneness to the flash-beep illusion*

To determine the general propensity to the illusion, the percentage of "two" responses across all SOAs were computed for each individual (overall proneness to the illusion). This percentage was compared between the FPSG and NP groups, testing the specific hypothesis that participants in the FPSG group are expected to show a reduced overall proneness to the illusion. An independent sample one-tailed *t*-test was used to examine the difference between the total amount of perceived illusion in the gamers and non-players.

3.3. *Weighted proneness to the illusion*

General differences in the overall propensity to the illusion may be a consequence of between-group differences in the TWI. If participants of the gamers group had a restricted TWI compared to individuals who do not play videogames, they could also perceive the illusion in a comparatively smaller number of trials falling within the SOAs characterising their time integration window, ultimately leading to a trivially smaller overall proneness to the illusion. To specifically test this hypothesis, the measure of the SIFI propensity for TWI of each individual was normalized by calculating the percentage of mean illusion perceived in the 3 SOAs preceding the inflection point. In this way, the absolute number of illusions for sensitive SOAs was kept constant among the participants and any differential effect of propensity was now controlled for individual differences in TWI. A *t*-test for independent one-tailed samples was calculated to compare the weighted propensity to the illusion both for FPSG and NP groups.

3.4. *Relationship between weekly game frequency and MIDAS score*

In order to determine whether a higher proportion of headache-related disability results from a greater exposure to intensive training of the audiovisual integration system of the FPSG group, a regression analysis was performed between the number of hours per week spent with FPSG videogames and the raw scores of the MIDAS questionnaire (Stewart, Lipton, Dowson & Sawyer, 2001 using Pearson's parametric correlation.

As migraine data showed a right-tailed skewness ($sk = 2.07$, $SE = .5$), we addressed symmetry violation by using bootstrap algorithms as they do not require bivariate normality assumptions (Bishara & Hittner, 2017), and also performing a log-transformation of raw data to reduce value of skewness (Feng et al., 2014; Hall, 1992).

Following a similar procedure (Ferri et al., 2018) we tested significance with a bootstrap Bias-Corrected accelerated (BCa) method [2000 resamples; 95% confidence interval; alpha level of .05 (Diciccio & Romano, 1988; Efron & Tibshirani, 1986)], useful in case of bias and skewness of the bootstrap estimates distribution (Chan & Chan, 2004). A standard multiple regression was additionally conducted in order to assess the best predictor of migraine frequency. Here the independent variables included were the hours x week spent on FPSG (time_FPSG), hours x week spent on other videogames (time_nonFPSG), time since first exposure

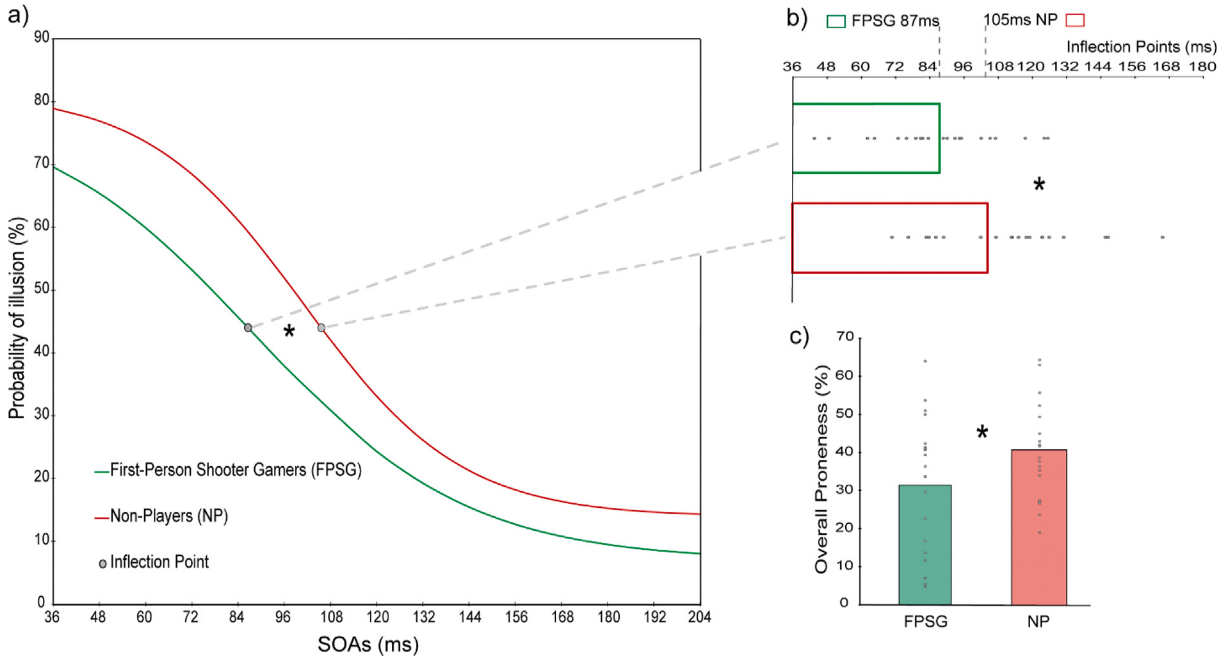

Fig. 2 – Temporal Window of Illusion (TWI) and illusion proneness for FPSG and NP. a) Sigmoid curves representing the average probability of perceiving the illusion plotted as a function of SOA for FPSG (green curve) and NP (red curve) groups. Mean inflection points (grey dots) corresponding to the TWI, are shown in bars (b) corresponding to the mean (in ms) for each group. (c) The proneness to the illusion across all SOAs (Overall Proneness to the Illusion) is reported (in %) for both groups.

to FPSG videogame (game_exp) and the tranformed scores of migraine frequency as a dependent variable.

For completeness, we also compared the incidence of migraine between FPSG and NP. An independent one-tailed t-test was therefore performed on the average migraine frequency over the previous 3 months (according to the Midas items). Considering the relative small sample size for determining migraine incidence (Steiner et al., 2013), we additionally ran a Bayesian implementation of the independent t-test using JASP (JASP Team, Version .13.1), in order to evaluate the relative strengths of evidence for the null versus alternative hypotheses. This allowed us to provide a quantification of the degree to which our data support the null versus the alternative hypothesis (Wagenmakers et al., 2018). We used an informed Bayesian t-test with the informed prior (e.g., t-distribution centered at .35, with a scale of .102 and 3 degrees of freedom) which is representative of the small-to-medium effect commonly observed in biobehavioral sciences (Gronau et al., 2020; Quintana and Williams, 2018).

3.5. *Relationship between TWI, videogaming and migraine: a mediation analysis*

A Mediation analysis (Hayes, 2017; MacKinnon et al., 2007) was implemented to assess the interaction between TWI, videogaming and migraine and test whether and how the weekly time spent on FPSG affected the TWI, by means of migraine incidence. To this aim we included the TWI as an outcome variable, the number of hours per week on FPSG as a predictor and the MIDAS transformed score as a mediator. In other words, we tested the relationship between FPSG gaming and TWI by taking into account the influence of migraine in that relationship. We adopted a model from PROCESS computational tool for SPSS (Hayes, 2012), in order to report the coefficients of the direct effect of time_FPSG on TWI and the indirect effect through migraine frequency. Indirect effect significance was assessed using Sobel test (Sobel, 1982).

4. Results

4.1. *Temporal Window of Illusion*

In line with a role of experience and priors in shaping perception, our primary working hypothesis would predict a shrinking of the temporal window within which the FPSG experience the illusion relative to the NP group. Accordingly, our results revealed for the first time that video gamer individuals showed a significantly reduced TWI (87.75 ms) relative to non-players individuals (105.32 ms) by about 18 ms [independent sample one-tailed t-test: $t(40) = -2.49$; $p = .008$; $d = -.77$ see Fig. 2a,b]. R-squared and SSE mean values (Table 1) returned a comparable goodness of fit for both groups ($R2$, $p = .36$; SSE, $p = .26$).

4.2. *Overall proneness to the flash-beep illusion*

Next, we tested whether the modulation in TWI between groups also led to a different overall proneness to the illusion. According to our hypothesis, shorter TWI should induce FPSG to experience an overall more veridical percept than the NP

Table 1 – Mean values and SEM are depicted for the main dependent variable in the groups of FPSG and NP. Significant differences can be observed between groups for the inflection point and the overall proneness; a tendency towards a significant effect for MIDAS score between the two groups with Bayesian factor moderately in favour of the alternative hypothesis H1 could be observed.

		Inflection Point (ms)	Overall Proneness (%)	Weighted Proneness (%)	SSE	R2	MIDAS_score (%)
FPSG	mean	87.75	31.41	57.26	717.24	.88	5.98
	sem	4.73	3.74	5.25	130.85	.02	1.97
		**	*	n.s.	n.s.	n.s.	n.s.
NP	mean	105.32	40.83	65.32	828.76	.87	3.60
	sem	4.97	2.60	3.26	105.40	.03	1.17

group. Accordingly, we found that video gamer individuals showed more veridical percepts - 1 flash (~68%) relative to non-players (~59%). Independent sample one-tailed *t*-test t(40) = 2.01; *p* = .025; d = .62 (see Fig. 2c for percentage of illusory percept per group).

4.3. *Weighted proneness to the illusion*

When normalising the proneness to the SIFI for the individual TWI, we found that the difference in proneness between the two groups did not reach significance [independent sample one-tailed *t*-test t(40) = −1.27; *p* = .10; d = −.39] (Table 1), confirming that any significant difference observed in the overall proneness to the illusion between the two groups can be explained by the smaller TWI measured in the video gamers group, relative to the control group.

Given that our hypotheses previously tested were partially related, we applied a correction for multiple comparisons based on Holm-Bonferroni method (Aickin & Gensler, 1996) which is a powerful strategy to control for the family-wise error rate (Shaffer, 1995). The sequentially rejective method provided corrected alpha levels (i.e., $\alpha = .016; .025; .05$) which were compared to the p-values obtained for the previous t-tests (i.e., *p* = .008; .025; .10). Significance was confirmed for t-tests performed on TWI and overall proneness to the illusion, with p-values being respectively $\leq .016$ and .025.

4.4. *Relationship between weekly game frequency and MIDAS score*

In line with recent literature reporting a level of comorbidity of video-gaming with migraine reports (Torsheim et al., 2010; Xavier et al., 2015), we tested here whether the time spent on videogames had an impact on migraine reports.

First, we investigated whether the exposure to first-person shooter videogames might alone differentiate groups on the frequency to the migraine report. Results failed to reach significance towards the different incidence of migraine frequency across the two groups (*p* = .16) (see Fig. 3b). This lack of significance could be explained by the fact that our participant samples are smaller relative to comparative epidemiologic studies (e.g., Montagni et al., 2016; Smith et al., 2009; Zapata et al., 2006). Implementation of the Bayesian *t*-test confirms the underpowered sample as it yielded a modest Bayes factor supporting the alternative hypothesis [BF10 = 1.51; posterior median of .346; 95% credible interval: (.092 .590)], relative to the null hypothesis (BF01 = .66). In other words, the modest magnitude of the Bayes factor suggests that the observed data were insensitive to detect an effect, rather that suggesting the absence of the effect (Quintana & Williams, 2018).

However, when specifically inspecting the FPSG group, to test whether the time spent on videogames had an impact on migraine reports, our results showed a statistically significant positive correlation between the number of hours per week that gamers spent at First Person Shooter videogames and the

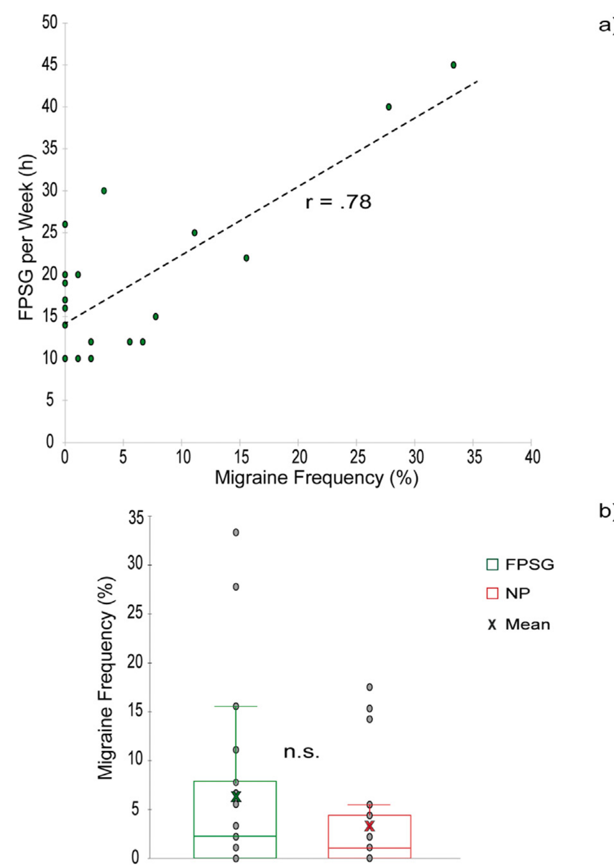

Fig. 3 – Relationship between time spent on FPSG and migraine severity. a) Weekly hours invested in FPSG game for each FSPG participant (green dots) are plotted as a function of their MIDAS score (% over the past 3 months), dashed line represents the regression line. b) Box-plots show distributions of migraine frequency for each participant across both groups.

raw scores of the MIDAS questionnaire [r = .78; p < .001; CIs = (.186 .913) see Fig. 3a]. The positive correlation was also replicated with log-tranformed scores [r = .56; p < .008; CI (.016 .781)]. The multiple regression model was also significant [$R2$ = .435; F(3,20) = 4.36; p = .019]. *Time_FPSG* significantly predicted migraine frequency [β = .558; t = 2.97; p = .008: CI (.009 .052)] compared to *Time_nonFPSG* [β = −.347; t = −1.89; p = .07; CI (-.036 .002)] and *Game_exp* [β = −.077; t = −.409; p = .68; CI (-.214 .144)].

In other words, the incidence of migraine-related disability increases proportionally, and selectively, with the increase in the number of hours played at first-person shooter videogames, but not with the time spent over non-FPSG videogames or with the time since first exposure to FPSG videogames.

4.5. *Relationship between TWI, videogaming and MIDAS scores*

In order to elucidate whether there is a relationship between individual TWI, videogaming and migraine we run a mediation analysis.

The model returned a significant direct effect of time_FPSG on TWI (b = 1.28; t = 2.32; p = .032), however the indirect effect through migraine was not significant (b = −.06; z = −.18; p = .86). Indeed, even if the mediator migraine was positively predicted by time_FPSG (b = .030; t = 2.93; p = .008), when assessing the regression model controlling for the mediator and the predictor, migraine was not related to TWI (b = −1.95; t = −.19; p = .85).

5. Discussion

In the present study we asked whether the proneness and temporal sensitivity to the sound-induced flash illusion (SIFI) is clustered as a function of training on first-person shooter videogames (FPSG). To this aim, we tested a group of expert players and contrasted their performance against a group of non-players. The main outcome of the study confirms that FPSG, relative to the NP, show smaller temporal windows within which they experience the illusion and higher veridical reports of one-flash, mostly explained by the higher temporal binding precision of the FPSG.

Secondly, we found that the weekly time spent on videogames positively correlates with the MIDAS score, that is, with headache-related disability (D'Amico et al., 2001) such that the longer the time spent on FPSG videogames, the higher the incidence of migraine reports. Indeed, the amount of weekly hours appears to be the best predictor accounting for migraine incidence, relative to the time spent on other videogames genres or the time since first exposure to FPSG videogames.

However, there not seem to be a relationship between the temporal window within which one experiences the illusion and the incidence of migraine.

Previously, it has been reported that the SIFI is resistant to one session of feedback training (Rosenthal, Shimojo & Shams, 2009), albeit short lasting effects have been documented after one session of neurostimulation (Bolognini et al., 2011) and physical exercise (e.g., O'Brien et al., 2017, 2020).

These findings point to a rather stable and robust effect (Keil, 2020). At first glance, this observation might lead to the assumption that the illusion is a stable trait characterising the individual capacity to integrate information over time which is not susceptible to functional changes and adaptations. However, this robust and yet illusory experience has been suggested to be the result of a Bayesian computation for integrating auditory and visual information operated by our nervous system (Shams et al., 2005) and hence amenable to changes as a function of prolonged exposure to characteristic temporal profiles of audio-visual experiences.

There have been a few attempts actively manipulating within the same group of individuals the illusory percept, leading to some interesting outcomes. For example, it is only after repeated balance training that persistent changes in SIFI have been documented (Merriman et al., 2015). Moreover, the continued exposure to the illusion allows the individual to be more aware of the illusion itself, being able to tell apart an illusory percept from a veridical second flash, without abolishing the perception of the illusion itself (Van Erp et al., 2013). In addition, repeated training sessions over five days aimed at modulating the temporal binding window through a temporal order judgment task exposure has been found to reduce the susceptibility to the SIFI in older adults (Setti et al., 2014), although such effect was quite variable (up to be absent) across participants. Attempts to replicate prolonged training sessions in a wide population are mostly missing or inconsistent with previous findings (Powers et al., 2016).

On the other hand, there has been an increasing interest in the assessment of individual differences accounting for the SIFI ranging from neural correlates (e.g., Balz et al., 2016; Cecere et al., 2015; Cooke et al., 2019; de Haas, Kanai, Jalkanen & Rees, 2012; Mishra et al., 2007) to between-group differences (e.g., Ferri et al., 2018; HaÃŸ et al., 2017; HernÃ¡ndez et al., 2019; Kawakami et al., 2020; Setti et al., 2014).

Group differences in the experience of SIFI provide an intriguing view angle for understanding the impact that nature and nurture have on moulding this robust crossmodal illusory phenomenon. Indeed, between-group differences in the capacity to integrate sensory information over time must rely on the intervention of both natural differences between groups, as those characterised by different phenotypic expressions, and plastic changes in the neural circuits as a function of systematic intervening experiences.

For example, altered SIFI reports have been found in autism (Kawakami et al., 2020), schizophrenia (Haß et al., 2017) and schizotypy alike (Ferri et al., 2018), documenting the impact of phenotypic expressions in perceptual integration. On the other hand, the individual experience may play a role in inducing long-lasting plasticity in audio-visual integration processes as reflected for example in the reduced proneness to the SIFI in professional musicians (Bidelman, 2016). Here, the repeated and prolonged exposure to audio-visual signals intrinsic to the musical training allows for enhanced temporal precision in binding multisensory and sensory-motor information. Such an effect should be dependent on plastic reorganization of neural connections between relevant areas for optimal and adaptive coordination of the acquired musical skill (Herholz & Zatorre, 2012).

Importantly, our results show that in line with the Bayesian account, sensory recalibration due to continued exposure to time-sensitive sensory stimuli tested for a period of at least six months, can lead to enhanced temporal precision able to induce more veridical responses in individuals exposed to self-paced videogame training.

Thus, current findings suggest that extensive and immersive experience in time-sensitive audio-visual settings such as intensive first-person shooter videogames may sharpen individual capacity to correctly integrate audio-visual information over time leading to more veridical non-illusory percept.

In other words, what would determine our subjective experience of integrated versus segregated multisensory information, is not written once and forever as a crystallized mechanism for the perception of the world. Instead, current findings support the view that our perceptual experience is the result of a continuously moulded process, fine-tuned by our past experience. Examples of this mechanism can be seen in studies of serial dependence effects (Cicchini et al., 2018; Kayser & Kayser, 2018) where the presentation of previous trials shows an impact on the response to the next trial. More concretely, our data suggest that sustained videogame experience has narrowed the temporal window for combining multisensory cues, therefore demonstrating enhanced audio-visual processing and less propensity to perceive the sound-induced flash illusion.

These data are in line with the critical role of prolonged perceptual experience in training multisensory discrimination ability (Bidelman, 2016; Donohue et al., 2015; Stevenson et al., 2013). Indeed, just one single session of feedback training does not seem to be enough to modulate the proneness to the SIFI (Rosenthal et al., 2009). Importantly, the relevance of feedback during learning seems to represent a relevant factor for the modulation to occur (Powers et al., 2009). Training-related effects in audio-visual integration are not observed with mere passive stimulus exposure and have only been assessed after one-week post-training (Powers et al., 2009). While continued training under controlled conditions may, in principle, systematically test for the role that variables such as feedback training versus mere passive exposure may have on multisensory processing, testing groups with different exposure to self-paced training such as videogaming, although not systematically controlled for, clearly contains intrinsic feedback information to continued training by direct check on game performance acting both as sensory-motor feedback and motivational cue.

On another note, similar plasticity effects on the SIFI experience as those shown after prolonged training reported in musicians (Bidelman, 2016) and gamers have been observed after just one session of non-invasive brain stimulation both in terms of proneness and TWI modulation (Bolognini et al., 2011; Cecere et al., 2015; Zmigrod & Zmigrod, 2015). For example, Bolognini et al. (2011) showed that modulating visual cortex excitability via cathodal versus anodal tDCS stimulation could inversely impact the susceptibility to the illusion depending on whether they targeted the occipital or the temporal areas. Cecere et al. (2015) showed that it is possible to modulate the temporal window within which participants perceive the illusion by setting the pace of the oscillatory activity in the occipital alpha band via tACS oscillatory entrainment towards slower or faster alpha frequencies (Minami & Amano, 2017).

Interestingly, similar effects in modulating cross-modal perception and shortening the temporal window of the illusion were obtained after one bout of open-skill exercise in older adults due to the temporary arousal associated with increased signal to noise ratio (O'Brien et al., 2017). The same group (O'Brien et al., 2020) has recently partially replicated the results in children. They explored the effect of acute 30-min moderate-intensity exercise (both open and closed skill sports) on multisensory perception in school children, and results demonstrated that both types of activities brought to perceptual benefits (i.e., reduced sensitivity the SIFIo). Again, this suggests that physiological arousal can lead to perceptual benefits. Also, previous findings showed increased sensitivity to the flicker fusion effect after 30 min of cycling (Lambourne et al., 2010). The fact that acute bouts of moderate-intensity exercise influenced the performance of perceptual-cognitive tasks and that such an effect rapidly decays can be explained in terms of arousal theory. However, another study (Merriman et al., 2015) investigated the effect of a prolonged (5-weeks balance) balance training in older adults. Results showed that the training improved balance and postural control in all the participants but improved functional balance correlated with enhanced multisensory processing (tested with SIFI) in the fall-prone older adults suggesting a link between balance control and multisensory interactions.

The effects observed after one single session of neuro-stimulation (Bolognini et al., 2011; Cecere et al., 2015) provide the proof-of-principle that direct modulation of neural activity relevant to the perception of the SIFI causally shapes the SIFI experience itself on the short term. In the case of single session exercise (Lambourne et al., 2010; O'Brien et al, 2017, 2020), short lasting effects are probably related to enhanced arousal which may engage however long-term reorganization following prolonged training (Merriman et al., 2015). Thus, long-lasting effects can be likely achieved only after prolonged exposure to sensory or cortical manipulations (Bidelman, 2016; Merriman et al., 2015). In line with these assumptions, the present study shows that audio-visual interactions may shape cross-sensory sampling over time, by training faster neural processes leading to enhanced temporal binding precision.

In line with our hypothesis and according to previous literature (D'Amico et al., 2001), a second relevant finding is that the weekly time spent on FPSG is associated with the incidence of migraine in the sample of gamers. Interestingly, such effect is selective for the weekly time spent on FPSG games given that the others measures of exposure such as the weekly time over non-FPSG games or the time since first exposure to the FPSG do not account for migraine incidence; thus it appears that the intensive training (>10 hrs per week) into the immersive audio-visual environment of FPSG rather than overall exposure to gaming could account for the incidence of headache-related disability.

The presence of a positive correlation between the number of hours per week that gamers spend on FPSG and a self-report questionnaire measuring headache-related disability is consistent with evidence in literature reporting that video-gaming could be a potential trigger for migraine (Mathers et al., 2009; Neut et al., 2012; Xavier et al., 2015).

One may wonder whether the between group difference observed in the TWI on the one hand and the link between migraine and the weekly time spent on FPSG on the other hand are somehow related. In other words whether there is a relationship between the individual TWI and migraine. Results of the mediation analysis did not provide evidence in support of a link between TWI and migraine. However, considering the multifactorial nature of these phenomena, a direct link between TWI, migraine and time spent on FPSG would be neither obvious, nor predictable. For example, while the weekly time spent on FPSG positively correlates with migraine incidence, TWI may not linearly scale up with the amount of weekly hours spent on it. Indeed, this factor may be confounded by interindividual differences in TWI, independently of videogaming, or on the time since first exposure to FPSG instead. Moreover, there is evidence that proneness to the illusion is altered in participants with migraine (Brighina et al., 2015; Maccora et al., 2019) and related pathological conditions (Cosentino et al., 2015). However, it is not known whether such effect can be accounted for by interindividual differences in TWI or whether they are independent of it.

Here, we found a positive relationship between TWI and the weekly time spent on FPSG, that is, the higher the number of hours spent on FSPG the wider the TWI. This may seem counterintuitive if one assumes that the weekly time spent on videogames may represent the variable accounting for TWI across groups. Alternatively, it may reflect a level of increased sensory noise due to overtraining and fatigue.

Thus one could speculate that, at least for our sample, the specific temporal integration profile of gamers compared to naïves cannot be explained by the relatively recent exposure to FPSG and perhaps it could be traced back in early exposure temporal windows. Early prolonged training may influence audio-visual integration temporal properties until reaching a pleateaou, while further training may maintain such temporal profile, also considering a history of thousands of hours of experience in video games at the time of testing (Bediou et al., 2018; Dale et al., 2020), while many hours of FPSG per week may result in a detrimental overtraining for temporal precision. But crucially, our results are in line with and contribute to a growing literature reporting that extensive expertise involving multisensory environments such as musicians (Bidelman, 2016; Lee & Noppeney, 2011); bilinguals (Bidelman & Heath, 2019) and now for the first time in a sample of first person shooter gamers significantly modulate the SIFI experience, showing that training environments such as action videogame play may actually foster brain plasticity (Bavelier et al., 2012). Importantly, here we add that the effect shown is specific for the temporal dimension modulating this illusory percept.

Videogame players exhibit several visual advantages relative to non-players (Riesenhuber, 2004). Several studies point to increased selective attention (Belchior et al., 2013; Dye et al., 2009; Green & Bavelier, 2003), enhanced visual search abilities (Castel et al., 2005; Wu & Spence, 2013), visuospatial attention (Clark et al., 2011; Green & Bavelier, 2006; Spence & Feng, 2010; West et al., 2008) and contrast sensitivity (Li, Polat, Makous & Bavelier, 2009). Furthermore, a recent experimental study on children with dyslexia has shown the improvement of their reading skills and attention, through a training of only 12 h with action video games (Franceschini et al., 2013). Moreover, the study of (Li et al., 2011) carried out in a sample of adults with amblyopia showed a substantial improvement in a wide range of fundamental visual functions after an extensive videogame training (i.e., 2 h per day, for 40–80 h in total). Thus, in line with this literature and according to our results it is possible to speculate that a regular (but possibly non-intensive) training that prompts temporal sharpening of audio-visual integration processes such as the one observed in musical training or through first-person shooter videogames can be implemented as a promising rehabilitation strategy in the treatment and management of conditions characterised by altered multisensory processes. Such alterations have been found in a number of conditions such as dyslexia, schizotypy and schizophrenia, cognitive decline and ageing in which disproportionally enlarged multisensory integration windows have been reported (Chan et al., 2015; Ferri et al., 2018; Haβ et al., 2017; McGovern et al., 2014; Wallace & Stevenson, 2014).

Some limitation should be taken into consideration when interpreting the current results.

First, it should be noted that no control conditions were included presenting either unisensory or multisensory trials other than the illusory ones we have implemented here. Therefore, we cannot exclude a priori alternative explanations for our results in the different between groups susceptibility to be determined by a specific difference in one sensory domain rather than in multisensory interaction processes or even by a perceptual or decision bias. While the probability that a reduced proneness can be related to a lower efficacy in auditory sensory discrimination for the FPSG group appears very unlikely (Green et al., 2010; Oei & Patterson, 2015), a better visual temporal resolution per se may have played a role in differentiating the performance of the two groups (Li et al., 2006, 2009, 2010). However, gamers have been shown to report cognitive enhancement through several types of tasks (Chopin et al., 2019; Dale et al., 2020), including the multisensory domain Donohue et al., 2010) and the general capacity at extracting audio-visual information (Buckley, Codina, Bhardwaj & Pascalis, 2010; Green et al., 2010). Here we favour the view that gamers have a better efficiency in sensory integration possibly determined by an optimized Bayesian inference mechanism (Green et al., 2007, 2010; Shams, 2012; Ursino et al., 2014). For what concerns decision bias interpretations, we found that between group differences in the proneness to perceive the illusion were abolished when correcting for the individual TWI. A decision bias account would have been better described by a general shift in the illusion report independently of SOA. Instead this finding would favour the interpretation that the effect is specifically determined by the temporal characteristics of the multisensory integration process rather than by a decision bias. Future research should attempt to replicate these findings by carefully including control conditions to ensure replicability of the phenomenon and interpretability of the mechanisms leading to these effects. Not only this will be able to tease apart unisensory from multisensory contribution to the effect found here, but it would also allow determining whether the effect is genuinely sensory in nature rather than being the result of a decision bias.

Another limitation of the study is the relatively small number of participants. While no power analysis could be explicitly conducted to test differences in SIFI between FPSG and NP, the large difference observed in Bidelman et al., (2016) and a comparable number of illusory trials between these studies would suggest that the comparison is adequately powered. Also, a power analysis was not conducted to test for differences between the two groups in migraine and the Bayes factor moderately supports the alternative hypothesis, suggesting that the failure to reach significance was mostly due to the underpowered sample rather than explained by the absence of an effect (Quintana & Williams, 2018). Finally, alternative explanations to the one we have proposed cannot be excluded a priori, such as for example performing high-attention demanding tasks for a prolonged period, or prolonged exposure to full-field swinging display or merely sleep deprivation (Kelman, 2007) derived from extensive game playing may account alternatively for the incidence of migraine in this population. Moreover, the absence of a comprehensive collection of information on the type of recreational activities related to the use of a screen represents another limit and we may not have been able to study in detail the intercurrent effects in this group. However, a few analyses were performed that could exclude time spent on other types of videogames or time since first exposure to FPSG videogames to predict migraine incidence. It should be considered that contemporary individuals recruited as gamers have a usually long gaming history, compared to the gamer's profile of just two decades ago (Dale et al., 2020). Thus, assessing long-term exposure is not simple and surveys which investigate the past years activities seems to be quite unreliable and would have not helped our conclusion.

For the future, it will be useful to increase the sample of participants (Smith et al., 2009; Torsheim et al., 2010; Xavier et al., 2015) and to collect information, through questionnaires, on the habits of the participants to the use of screens for recreational activities or study purposes, as the relationship between screen time exposure and migraine is recognized (Demir & Sümer, 2019; Malkki, 2016; Montagni et al., 2016).

6. Conclusions

A reduced temporal window of integration, leading to a more veridical perception of visual stimulus quantity, seems to characterize people with extensive experience at first-person videogame shooting. This is possibly due to their daily practice in time-sensitive fast-paced multisensory stimuli. Bayesian mechanisms may be at play for multisensory stimuli to be appropriately integrated or segregated in time to adapt and succeed with the shooter performance functionally. On the other hand, excessive weekly time exposure to first-person videogame shooting may represent a trigger for individuals being at higher risk of developing migraine symptoms.

Author contributions

V.R. and P.DL. developed the study concept; V.R. P.DL. A.T. and S.B. contributed to the study design; P.DL. and S.S. performed testing and data collection; P.DL performed the data analysis; V.R. and S.B. wrote the first draft of the manuscript; all authors contributed to and approved the final version of the manuscript for submission.

Open practices

The study in this article earned Open Materials and Open Data badges for transparent practices. Materials and data for the study are available at https://osf.io/5h76y/.

Declaration of competing interest

The authors declare no conflict of interest.

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REFERENCES

Aickin, M., & Gensler, H. (1996). Adjusting for multiple testing when reporting research results: The Bonferroni vs Holm methods. *American Journal of Public Health, 86*(5), 726–728. http://dx.doi.org/10.2105/AJPH.86.5.726

Andersen, T. S., Tiippana, K., & Sams, M. (2004). Factors influencing audiovisual fission and fusion illusions. *Cognitive Brain Research, 21*(3), 301–308. http://dx.doi.org/10.1016/j.cogbrainres.2004.06.004

Archambault, D., Ossmann, R., Gaudy, T., & Miesenberger, K. (2007). Computer games and visually impaired people. *Upgrade, 8*(2), 43–53.

Asher, J., O'Hare, L., Romei, V., & Hibbard, P. (2018). Typical lateral interactions, but increased contrast sensitivity, in migraine-with-Aura. *Vision, 2*(1), 7. http://dx.doi.org/10.3390/vision2010007

Aurora, S. K., Ahmad, B. K., Welch, K. M. A., Bhardhwaj, P., & Ramadan, N. M. (1998). Transcranial magnetic stimulation confirms hyperexcitability of occipital cortex in migraine. *Neurology, 50*(4), 1111–1114. http://dx.doi.org/10.1212/WNL.50.4.1111

Aurora, S. K., Welch, K. M. A., & Al-Sayed, F. (2003). The threshold for phosphenes is lower in migraine. *Cephalalgia: an International Journal of Headache, 23*(4), 258–263. http://dx.doi.org/10.1046/j.1468-2982.2003.00471.x

Balz, J., Keil, J., Roa Romero, Y., Mekle, R., Schubert, F., Aydin, S., Ittermann, B., Gallinat, J., & Senkowski, D. (2016). GABA concentration in superior temporal sulcus predicts gamma power and perception in the sound-induced flash illusion. *Neuroimage, 125*, 724–730. http://dx.doi.org/10.1016/j.neuroimage.2015.10.087

Bastiaansen, M., Berberyan, H., Stekelenburg, J. J., Schoffelen, J. M., & Vroomen, J. (2020). Are alpha oscillations instrumental in multisensory synchrony perception? *Brain Research, 1734*, 14674. http://dx.doi.org/10.1016/j.brainres.2020.146744

Bastien-Toniazzo, M., Stroumza, A., & Cavé, C. (2010). Audio-visual perception and integration in developmental dyslexia: An exploratory study using the McGurk effect. *Current Psychology Letters, 25*(3, 2009). http://dx.doi.org/10.4000/cpl.4928

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35*(1), 391–416. http://dx.doi.org/10.1146/annurev-neuro-060909-152832

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychological Bulletin, 144*(1), 77–110. http://dx.doi.org/10.1037/bul0000130

Belchior, P., Marsiske, M., Sisco, S. M., Yam, A., Bavelier, D., Ball, K., & Mann, W. C. (2013). Video game training to improve selective visual attention in older adults. *Computers in Human Behavior, 29*(4), 1318–1324. http://dx.doi.org/10.1016/j.chb.2013.01.034

Bidelman, G. M. (2016). Musicians have enhanced audiovisual multisensory binding: Experience-dependent effects in the double-flash illusion. *Experimental Brain Research, 234*(10), 3037–3047. http://dx.doi.org/10.1007/s00221-016-4705-6

Bidelman, G. M., & Heath, S. T. (2019). Enhanced temporal binding of audiovisual information in the bilingual brain. *Bilingualism, 22*(4), 752–762. http://dx.doi.org/10.1017/S1366728918000408

Bishara, A. J., & Hittner, J. B. (2017). Confidence intervals for correlations when data are not normal. *Behavior Research Methods, 49*(1), 294–309. http://dx.doi.org/10.3758/s13428-016-0702-8

Bolognini, N., Rossetti, A., Casati, C., Mancini, F., & Vallar, G. (2011). Neuromodulation of multisensory perception: A tDCS study of the sound-induced flash illusion. *Neuropsychologia, 49*(2), 231–237. http://dx.doi.org/10.1016/j.neuropsychologia.2010.11.015

Brighina, F., Bolognini, N., Cosentino, G., Maccora, S., Paladino, P., Baschi, R., Vallar, G., & Fierro, B. (2015). Visual cortex hyperexcitability in migraine in response to sound-induced flash illusions. *Neurology, 84*(20), 2057–2061. http://dx.doi.org/10.1212/WNL.0000000000001584

Brigo, F., Storti, M., Tezzon, F., Manganotti, P., & Nardone, R. (2012). Primary visual cortex excitability in migraine: a systematic review with meta-analysis. *Neurological Sciences, 34*(6), 819–830. http://dx.doi.org/10.1007/s10072-012-1274-8

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), 548–556. http://dx.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. http://dx.doi.org/10.1016/j.actpsy.2005.02.004

Cecere, R., Rees, G., & Romei, V. (2015). Individual differences in alpha frequency drive crossmodal illusory perception. *Current Biology, 25*(2), 231–235. http://dx.doi.org/10.1016/j.cub.2014.11.034

Chan, J. S., Connolly, S. K., & Setti, A. (2018). The number of stimulus-onset asynchronies affects the perception of the sound-induced flash illusion in young and older adults. *Multisensory Research, 31*(3–4), 175–190. http://dx.doi.org/10.1163/22134808-00002605

Chan, J., Kaiser, J., Brandl, M., Matura, S., Prvulovic, D., Hogan, M., & Naumer, M. (2015). Expanded temporal binding windows in people with mild cognitive impairment. *Current Alzheimer Research, 12*(1), 61–68. http://dx.doi.org/10.2174/1567205012666141218124744

Chan, W., & Chan, D. W. L. (2004). Bootstrap standard error and confidence intervals for the correlation corrected for range restriction: A simulation study. *Psychological Methods, 9*(3), 369–385. http://dx.doi.org/10.1037/1082-989X.9.3.369

Chopin, A., Bediou, B., & Bavelier, D. (2019). Altering perception: the case of action video gaming. *Current Opinion in Psychology, 29*, 168–173. http://dx.doi.org/10.1016/j.copsyc.2019.03.004

Cicchini, G. M., Mikellidou, K., & Burr, D. C. (2018). The functional role of serial dependence. *Proceedings of the Royal Society B: Biological Sciences, 285*(1890). http://dx.doi.org/10.1098/rspb.2018.1722, 20181722.

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica, 136*(1), 67–72. http://dx.doi.org/10.1016/j.actpsy.2010.10.003

Colonius, H., & Diederich, A. (2004). Multisensory interaction in saccadic reaction time: A time-window-of- integration model. *Journal of Cognitive Neuroscience, 16*(6), 1000–1009. http://dx.doi.org/10.1162/0898929041502733

Cooke, J., Poch, C., Gillmeister, H., Costantini, M., & Romei, V. (2019). Oscillatory properties of functional connections between sensory areas mediate cross-modal illusory perception. *Journal of Neuroscience, 39*(29), 5711–5718. http://dx.doi.org/10.1523/JNEUROSCI.3184-18.2019

Cosentino, G., Talamanca, S., Aprile, M., Maccora, S., Baschi, R., Pilati, L., Di Marco, S., Fierro, B., & Brighina, F. (2015). O047. The sound-induced flash illusions reveal visual cortex hyperexcitability in cluster headache. *Journal of Headache and Pain, 16*(S1), 1–2. http://dx.doi.org/10.1186/1129-2377-16-S1-A92

Dale, G., Joessel, A., Bavelier, D., & Green, S. (2020). Annals of the New York academy of sciences A new look at the cognitive neuroscience of video game play. *Annals of the New York Academy of Sciences*. http://dx.doi.org/10.1111/nyas.14295

De Gelder, B., Vroomen, J., Annen, L., Masthof, E., & Hodiamont, P. (2003). Audio-visual integration in schizophrenia. *Schizophrenia Research, 59*(2–3), 211–218. http://dx.doi.org/10.1016/s0920-9964(01)00344-9

De Gelder, B., Vroomen, J., De Jong, S. J., Masthoff, E. D., Trompenaars, F. J., & Hodiamont, P. (2005). Multisensory integration of emotional faces and voices in schizophrenics. *Schizophrenia Research, 72*(2–3), 195–203. http://dx.doi.org/10.1016/j.schres.2004.02.013

de Haas, B., Kanai, R., Jalkanen, L., & Rees, G. (2012). Grey matter volume in early human visual cortex predicts proneness to the sound-induced flash illusion. *Proceedings of the Royal Society B: Biological Sciences, 279*(1749), 4955–4961. http://dx.doi.org/10.1098/rspb.2012.2132

De Jong, J. J., Hodiamont, P. P. G., Van den Stock, J., & De Gelder, B. (2009). Audiovisual emotion recognition in schizophrenia: Reduced integration of facial and vocal affect. *Schizophrenia Research, 107*(2–3), 286–293. http://dx.doi.org/10.1016/j.schres.2008.10.001

Demir, Y. P., & Sümer, M. M. (2019). Effects of smartphone overuse on headache, sleep and quality of life in migraine patients. *Independent Researcher in Health Sciences Neurosciences, 24*(2), 115–121. http://dx.doi.org/10.17712/nsj.2019.2.20180037

Diciccio, T. J., & Romano, J. P. (1988). A review of bootstrap confidence intervals. *Journal of the Royal Statistical Society: Series*

B (Methodological), 50(3), 338–354. http://dx.doi.org/10.1111/j.2517-6161.1988.tb01732.x

Diederich, A., & Colonius, H. (2004). Bimodal and trimodal multisensory enhancement: Effects of stimulus onset and intensity on reaction time. *Perception and Psychophysics, 66*(8), 1388–1404. http://dx.doi.org/10.3758/BF03195006

Donohue, S. E., Green, J. J., & Woldorff, M. G. (2015). The effects of attention on the temporal integration of multisensory stimuli. *Frontiers in Integrative Neuroscience, 9*, 1–14. http://dx.doi.org/10.3389/fnint.2015.00032

Donohue, S. E., Woldorff, M. G., & Mitroff, S. R. (2010). Video game players show more precise multisensory temporal processing abilities. *Attention, Perception, & Psychophysics, 72*(4), 1120–1129. http://dx.doi.org/10.3758/APP.72.4.1120

D'Amico, D., Mosconi, P., Genco, S., Usai, S., Prudenzano, A., Grazzi, L., Leone, M., Puca, F., & G, B. (2001). The migraine disability assessment (MIDAS) questionnaire: Translation and reliability of the Italian version. *Cephalalgia: an International Journal of Headache, 21*(10), 947–952. http://dx.doi.org/10.1046/j.0333-1024.2001.00277.x

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia, 47*(8–9), 1780–1789. http://dx.doi.org/10.1016/J.NEUROPSYCHOLOGIA.2009.02.002

Efron, B., & Tibshirani, R. (1986). Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science, 1*(1), 54–75. http://dx.doi.org/10.1214/SS/1177013815

Feng, C., Wang, H., Lu, N., Chen, T., He, H., Lu, Y., & Tu, X. M. (2014). Log-transformation and its implications for data analysis. *Shanghai Archives of Psychiatry, 26*(2), 105–109. http://dx.doi.org/10.3969/j.issn.1002-0829.2014.02.009

Ferri, F., Venskus, A., Fotia, F., Cooke, J., & Romei, V. (2018). Higher proneness to multisensory illusions is driven by reduced temporal sensitivity in people with high schizotypal traits. *Consciousness and Cognition, 65*, 263–270. http://dx.doi.org/10.1016/j.concog.2018.09.006

Foucher, J. R., Lacambre, M., Pham, B. T., Giersch, A., & Elliott, M. A. (2007). Low time resolution in schizophrenia. Lengthened windows of simultaneity for visual, auditory and bimodal stimuli. *Schizophrenia Research, 97*(1–3), 118–127. http://dx.doi.org/10.1016/j.schres.2007.08.013

Franceschini, S., Gori, S., Ruffino, M., Viola, S., Molteni, M., & Facoetti, A. (2013). Action video games make dyslexic children read better. *Current Biology, 23*(6), 462–466. http://dx.doi.org/10.1016/j.cub.2013.01.044

Gorbet, D. J., & Sergio, L. E. (2018). Move faster, think later: Women who play action video games have quicker visually-guided responses with later onset visuomotor-related brain activity. *Plos One, 13*(1), 1–26. http://dx.doi.org/10.1371/journal.pone.0189110

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534–537. http://dx.doi.org/10.1038/nature01647

Green, C. S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology, 20*(17), 1573–1579. http://dx.doi.org/10.1016/j.cub.2010.07.040

Greenfield, P. M., DeWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology, 15*(1), 105–123. http://dx.doi.org/10.1016/0193-3973(94)90008-6

Green, C. S., & Bavelier, D. (2006). Enumeration versus multiple object tracking: The case of action video game players. *Cognition, 101*(1), 217–245. http://dx.doi.org/10.1016/j.cognition.2005.10.004

Green, C. S., Pouget, A., & Bavelier, D. (2007). Action videogame playing improves bayesian inference for perceptual decision-making. *Journal of Vision, 7*(9). http://dx.doi.org/10.1167/7.9.42

Griffith, J. L., Voloschin, P., Gibb, G. D., & Bailey, J. R. (1983). Differences in eye-hand motor coordination of video-game users and non-users. *Perceptual and Motor Skills, 57*(1), 155–158. http://dx.doi.org/10.2466/pms.1983.57.1.155

Gronau, Q. F., Ly, A., & Wagenmakers, E. J. (2020). Informed bayesian t-tests. *American Statistician, 74*(2), 137–143. http://dx.doi.org/10.1080/00031305.2018.1562983

Guglielmetti, M., Raggi, A., Ornello, R., Sacco, S., D'Amico, D., Leonardi, M., & Martelletti, P. (2020). The clinical and public health implications and risks of widening the definition of chronic migraine. *Cephalalgia: an International Journal of Headache, 40*(4), 407–410. http://dx.doi.org/10.1177/0333102419895777

Hairston, W. D., Burdette, J. H., Flowers, D. L., Wood, F. B., & Wallace, M. T. (2005). Altered temporal profile of visual-auditory multisensory interactions in dyslexia. *Experimental Brain Research, 166*(3–4), 474–480. http://dx.doi.org/10.1007/s00221-005-2387-6

Hall, P. (1992). On the removal of skewness by transformation. *Journal of the Royal Statistical Society: Series B (Methodological), 54*(1), 221–228. http://dx.doi.org/10.1111/j.2517-6161.1992.tb01876.x

Hayes, A. F. (2012). Process: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling [White paper]. Retrieved from http://www.afhayes.com/public/process2012.pdf.

Haß, K., Sinke, C., Reese, T., Roy, M., Wiswede, D., Dillo, W., … Szycik, G. R. (2017). Enlarged temporal integration window in schizophrenia indicated by the double-flash illusion. *Cognitive Neuropsychiatry, 22*(2), 145–158. http://dx.doi.org/10.1080/13546805.2017.1287693

Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford publications.

Harrar, V., & Harris, L. R. (2008). The effect of exposure to asynchronous audio, visual, and tactile stimulus combinations on the perception of simultaneity. *Experimental Brain Research, 186*(4), 517–524. http://dx.doi.org/10.1007/s00221-007-1253-0

Hazarika, J., Kant, P., Dasgupta, R., & Laskar, S. H. (2018). Neural modulation in action video game players during inhibitory control function: An EEG study using discrete wavelet transform. *Biomedical Signal Processing and Control, 45*, 144–150. http://dx.doi.org/10.1016/j.bspc.2018.05.023

Helfrich, H. P., & Zwick, D. (1996). A trust region algorithm for parametric curve and surface fitting. *Journal of Computational and Applied Mathematics, 73*(1–2), 119–134. http://dx.doi.org/10.1016/0377-0427(96)00039-8

Herholz, S. C., & Zatorre, R. J. (2012). Musical Training as a Framework for Brain Plasticity: Behavior, Function, and Structure. *Neuron, 76*(3), 486–502. http://dx.doi.org/10.1016/j.neuron.2012.10.011

Hernández, B., Setti, A., Kenny, R. A., & Newell, F. N. (2019). Individual differences in ageing, cognitive status, and sex on susceptibility to the sound-induced flash illusion: A large-scale study. *Psychology and Aging, 34*(7), 978–990. http://dx.doi.org/10.1037/pag0000396

Hershenson, M. (1962). Reaction time as a measure of intersensory facilitation. *Journal of Experimental Psychology, 63*(3), 289–293. http://dx.doi.org/10.1037/h0039516

Hirst, R. J., McGovern, D. P., Setti, A., Shams, L., & Newell, F. N. (2020). What you see is what you hear: Twenty years of research using the Sound-Induced Flash illusion. *Neuroscience and Biobehavioral Reviews, 118*, 759–774. http://dx.doi.org/10.1016/j.neubiorev.2020.09.006

Hirst, R. J., Setti, A., Kenny, R. A., & Newell, F. N. (2019). Age-related sensory decline mediates the Sound-Induced Flash Illusion: Evidence for reliability weighting models of multisensory perception. *Scientific Reports, 9*(1), 1–12. http://dx.doi.org/10.1038/s41598-019-55901-5

Kawakami, S., Uono, S., Otsuka, S., Yoshimura, S., Zhao, S., & Toichi, M. (2020). Atypical Multisensory Integration and the Temporal Binding Window in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders, 50*(11), 3944–3956. http://dx.doi.org/10.1007/s10803-020-04452-0

Kayser, S. J., & Kayser, C. (2018). Trial by trial dependencies in multisensory perception and their correlates in dynamic brain activity. *Scientific Reports, 8*(1), 1–11. http://dx.doi.org/10.1038/s41598-018-22137-8

Keil, J. (2020). Double flash illusions: Current findings and future directions. *Frontiers in Neuroscience*. http://dx.doi.org/10.3389/fnins.2020.00298

Kelman, L. (2007). The triggers or precipitants of the acute migraine attack. *Cephalalgia: an International Journal of Headache, 27*(5), 394–402. http://dx.doi.org/10.1111/j.1468-2982.2007.01303.x

Knill, D. C., & Pouget, A. (2004). The Bayesian brain: The role of uncertainty in neural coding and computation. *Trends in Neurosciences, 27*(12), 712–719. http://dx.doi.org/10.1016/j.tins.2004.10.007

Lambourne, K., Audiffren, M., & Tomporowski, P. D. (2010). Effects of acute exercise on sensory and executive processing tasks. *Medicine and Science in Sports and Exercise, 42*(7), 1396–1402. http://dx.doi.org/10.1249/MSS.0b013e3181cbee11

Lee, H. L., & Noppeney, U. (2011). Long-term music training tunes how the brain temporally binds signals from multiple senses. *Proceedings of the National Academy of Sciences of the United States of America, 108*(51), E1441–E1450. http://dx.doi.org/10.1073/pnas.1115267108

Leo, F., & Noppeney, U. (2014). Conditioned sounds enhance visual processing. *Plos One, 9*(9), Article e106860. http://dx.doi.org/10.1371/journal.pone.0106860

Leo, F., Romei, V., Freeman, E., Ladavas, E., & Driver, J. (2011). Looming sounds enhance orientation sensitivity for visual stimuli on the same side as such sounds. *Experimental Brain Research, 213*(2–3), 193–201. http://dx.doi.org/10.1007/s00221-011-2742-8

Li, R., Polat, U., Makous, W., & Bavelier, D. (2006). Temporal resolution of visual processing in action video game players. *Journal of Vision, 6*(6). http://dx.doi.org/10.1167/6.6.1008, 1008–1008.

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience, 12*(5), 549–551. http://dx.doi.org/10.1038/nn.2296

Li, R., Polat, U., Scalzo, F., & Bavelier, D. (2010). Reducing backward masking through action game training. *Journal of Vision, 10*(14). http://dx.doi.org/10.1167/10.14.33, 33–33.

Li, R. W., Ngo, C., Nguyen, J., & Levi, D. M. (2011). Video-game play induces plasticity in the visual system of adults with amblyopia. *Plos Biology, 9*(8). http://dx.doi.org/10.1371/journal.pbio.1001135

Lovelace, C. T., Stein, B. E., & Wallace, M. T. (2003). An irrelevant light enhances auditory detection in humans: A psychophysical analysis of multisensory integration in stimulus detection. *Cognitive Brain Research, 17*(2), 447–453. http://dx.doi.org/10.1016/S0926-6410(03)00160-5

Maccora, S., Giglia, G., Bolognini, N., Cosentino, G., Gangitano, M., Salemi, G., & Brighina, F. (2019). Cathodal occipital tDCS is unable to modulate the sound induced flash illusion in migraine. *Frontiers in Human Neuroscience, 13*, 247. http://dx.doi.org/10.3389/fnhum.2019.00247

MacKinnon, D. P., Fairchild, A. J., & Fritz, M. S. (2007). Mediation analysis. *Annual Review of Psychology, 58*(1), 593–614. http://dx.doi.org/10.1146/annurev.psych.58.110405.085542

Malkki, H. (2016). Long screen time exposure could increase the risk of migraine. *Nature Reviews Neurology, 12*(1), 4. http://dx.doi.org/10.1038/nrneurol.2015.238

Mathers, M., Canterford, L., Olds, T., Hesketh, K., Ridley, K., & Wake, M. (2009). Electronic media use and adolescent health and well-being: Cross-sectional community study. *Academic Pediatrics, 9*(5), 307–314. http://dx.doi.org/10.1016/j.acap.2009.04.003

McGovern, D. P., Astle, A. T., Clavin, S. L., & Newell, F. N. (2016a). Task-specific transfer of perceptual learning across sensory modalities. *Current Biology, 26*(1), R20–R21. http://dx.doi.org/10.1016/j.cub.2015.11.048

McGovern, D. P., Roudaia, E., Newell, F. N., & Roach, N. W. (2016b). Perceptual learning shapes multisensory causal inference via two distinct mechanisms. *Scientific Reports, 6*(1), 1–11. http://dx.doi.org/10.1038/srep24673

McGovern, D. P., Roudaia, E., Stapleton, J., McGinnity, T. M., & Newell, F. N. (2014). The sound-induced flash illusion reveals dissociable age-related effects in multisensory integration. *Frontiers in Aging Neuroscience, 6*. http://dx.doi.org/10.3389/fnagi.2014.00250

Merriman, N. A., Whyatt, C., Setti, A., Craig, C., & Newell, F. N. (2015). Successful balance training is associated with improved multisensory function in fall-prone older adults. *Computers in Human Behavior, 45*, 192–203. http://dx.doi.org/10.1016/j.chb.2014.12.017

Migliorati, D., Zappasodi, F., Perrucci, M. G., Donno, B., Northoff, G., Romei, V., & Costantini, M. (2019). Individual alpha frequency predicts perceived visuotactile simultaneity. *Journal of Cognitive Neuroscience, 32*(1), 1–11. http://dx.doi.org/10.1162/jocn_a_01464

Minami, S., & Amano, K. (2017). Illusory jitter perceived at the frequency of alpha oscillations. *Current Biology, 27*, 2344–2351. http://dx.doi.org/10.1016/j.cub.2017.06.033. e4.

Mishra, J., Martinez, A., Sejnowski, T. J., & Hillyard, S. A. (2007). Early cross-modal interactions in auditory and visual cortex underlie a sound-induced visual illusion. *Journal of Neuroscience, 27*(15), 4120–4131. http://dx.doi.org/10.1523/JNEUROSCI.4912-06.2007

Montagni, I., Guichard, E., Carpenet, C., Tzourio, C., & Kurth, T. (2016). Screen time exposure and reporting of headaches in young adults: A cross-sectional study. *Cephalalgia: an International Journal of Headache, 36*(11), 1020–1027. http://dx.doi.org/10.1177/0333102415620286

Nelson, W. T., Hettinger, L. J., Cunningham, J. A., Brickman, B. J., Haas, M. W., & McKinley, R. L. (1998). Effects of localized auditory information on visual target detection performance using a helmet-mounted display. *Human Factors, 40*(3), 452–460. http://dx.doi.org/10.1518/001872098779591304

Oei, A. C., & Patterson, M. D. (2015). Enhancing perceptual and attentional skills requires common demands between the action video games and transfer tasks. *Frontiers in Psychology, 6*(FEB), 113. http://dx.doi.org/10.3389/fpsyg.2015.00113

Neut, D., Fily, A., Cuvellier, J. C., & Vallée, L. (2012). The prevalence of triggers in paediatric migraine: A questionnaire study in 102 children and adolescents. *Journal of Headache and Pain, 13*(1), 61–65. http://dx.doi.org/10.1007/s10194-011-0397-2

O'Brien, J., Ottoboni, G., Tessari, A., & Setti, A. (2017). One bout of open skill exercise improves cross-modal perception and immediate memory in healthy older adults who habitually exercise. *Plos One, 12*(6). http://dx.doi.org/10.1371/journal.pone.0178739

O'Brien, J., Ottoboni, G., Tessari, A., & Setti, A. (2020). Multisensory perception, verbal, visuo-spatial, and motor working memory modulation after a single open- or closed-skill exercise session in children. *BioRxiv*. http://dx.doi.org/10.1101/2020.01.29.924563, 2020.01.29.924563.

O'Hare, L., & Hibbard, P. B. (2016). Visual processing in migraine. *Cephalalgia, 36*(11), 1057–1076. http://dx.doi.org/10.1177/0333102415618952

Pearl, D., Yodashkin-Porat, D., Katz, N., Valevski, A., Aizenberg, D., Sigler, M., Weizman, A., & Kikinzon, L. (2009). Differences in audiovisual integration, as measured by McGurk phenomenon, among adult and adolescent patients with schizophrenia and age-matched healthy control groups. *Comprehensive Psychiatry, 50*(2), 186–192. http://dx.doi.org/10.1016/j.comppsych.2008.06.004

Powers, A. R., Hillock, A. R., & Wallace, M. T. (2009). Perceptual training narrows the temporal window of multisensory binding. *Journal of Neuroscience, 29*(39), 12265–12274. http://dx.doi.org/10.1523/JNEUROSCI.3501-09.2009

Powers, A. R., Hillock-Dunn, A., & Wallace, M. T. (2016). Generalization of multisensory perceptual learning. *Scientific Reports, 6*(1), 1–9. http://dx.doi.org/10.1038/srep23374

Quaiser-Pohl, C., Geiser, C., & Lehmann, W. (2006). The relationship between computer-game preference, gender, and mental-rotation ability. *Personality and Individual Differences, 40*(3), 609–619. http://dx.doi.org/10.1016/j.paid.2005.07.015

Quintana, D. S., & Williams, D. R. (2018). Bayesian alternatives for common null-hypothesis significance tests in psychiatry: A non-technical guide using JASP. *BMC Psychiatry, 18*(1), 1–8. http://dx.doi.org/10.1186/s12888-018-1761-4

Ramos-Estebanez, C., Merabet, L. B., Machii, K., Fregni, F., Thut, G., Wagner, T. A., … Pascual-Leone, A. (2007). Visual phosphene perception modulated by subthreshold crossmodal sensory stimulation. *Journal of Neuroscience, 27*(15), 4178–4181. http://dx.doi.org/10.1523/JNEUROSCI.5468-06.2007

Riesenhuber, M. (2004). An action video game modifies visual processing. *Trends in Neurosciences, 27*(2), 72–74. http://dx.doi.org/10.1016/J.TINS.2003.11.004

Romei, V., Brodbeck, V., Michel, C., Amedi, A., Pascual-Leone, A., & Thut, G. (2008). Spontaneous fluctuations in posterior α-band EEG activity reflect variability in excitability of human visual areas. *Cerebral Cortex, 18*(9), 2010–2018. http://dx.doi.org/10.1093/cercor/bhm229

Romei, V., Murray, M. M., Merabet, L. B., & Thut, G. (2007). Occipital transcranial magnetic stimulation has opposing effects on visual and auditory stimulus detection: Implications for multisensory interactions. *Journal of Neuroscience, 27*(43), 11465–11472. http://dx.doi.org/10.1523/JNEUROSCI.2827-07.2007

Romei, V., Rihs, T., Brodbeck, V., & Thut, G. (2008a). Resting electroencephalogram alpha-power over posterior sites indexes baseline visual cortex excitability. *Neuroreport, 19*(2), 203–208. http://dx.doi.org/10.1097/WNR.0b013e3282f454c4

Rosenthal, O., Shimojo, S., & Shams, L. (2009). Sound-induced flash illusion is resistant to feedback training. *Brain Topography, 21*(3–4), 185–192. http://dx.doi.org/10.1007/s10548-009-0090-9

Ross, L. A., Saint-Amour, D., Leavitt, V. M., Molholm, S., Javitt, D. C., & Foxe, J. J. (2007). Impaired multisensory processing in schizophrenia: Deficits in the visual enhancement of speech comprehension under noisy environmental conditions. *Schizophrenia Research, 97*(1–3), 173–183. http://dx.doi.org/10.1016/j.schres.2007.08.008

Schneider, K. A., & Bavelier, D. (2003). Components of visual prior entry. *Cognitive Psychology, 47*(4), 333–366. http://dx.doi.org/10.1016/s0010-0285(03)00035-5

Setti, A., Burke, K. E., Kenny, R. A., & Newell, F. N. (2011). Is inefficient multisensory processing associated with falls in older people? *Experimental Brain Research, 209*(3), 375–384. http://dx.doi.org/10.1007/s00221-011-2560-z

Setti, A., Stapleton, J., Leahy, D., Walsh, C., Kenny, R. A., & Newell, F. N. (2014). Improving the efficiency of multisensory integration in older adults: Audio-visual temporal discrimination training reduces susceptibility to the sound-induced flash illusion. *Neuropsychologia, 61*(1), 259–268. http://dx.doi.org/10.1016/j.neuropsychologia.2014.06.027

Shaffer, J. P. (1995). Multiple hypothesis testing. *Annual Review of Psychology, 46*(1), 561–584. http://dx.doi.org/10.1146/annurev.ps.46.020195.003021

Shams, L. (2012). Early integration and bayesian causal inference in multisensory perception. *The Neural Bases of Multisensory Processes*, 217–232. http://dx.doi.org/10.1201/9781439812174-16

Shams, L., Kamitani, Y., & Shimojo, S. (2000). What you see is what you hear. *Nature, 408*(6814). http://dx.doi.org/10.1038/35048669, 788–788.

Shams, L., Kamitani, Y., & Shimojo, S. (2002). Visual illusion induced by sound. *Cognitive Brain Research, 14*(1), 147–152. http://dx.doi.org/10.1016/S0926-6410(02)00069-1

Shams, L., Ma, W. J., & Beierholm, U. (2005). Sound-induced flash illusion as an optimal percept. *Neuroreport, 16*(17), 1923–1927. http://dx.doi.org/10.1097/01.wnr.0000187634.68504.bb

Smith, L., Louw, Q., Crous, L., & Grimmer-Somers, K. (2009). Prevalence of neck pain and headaches: Impact of computer use and other associative factors. *Cephalalgia: an International Journal of Headache, 29*(2), 250–257. http://dx.doi.org/10.1111/j.1468-2982.2008.01714.x

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological Methodology, 13*, 290. http://dx.doi.org/10.2307/270723

Spence, C., Baddeley, R., Zampini, M., James, R., & Shore, D. I. (2003). Multisensory temporal order judgments: When two locations are better than one. *Perception and Psychophysics, 65*(2), 318–328. http://dx.doi.org/10.3758/BF03194803

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

Stein, B. E., & Meredith, M. A. (1993). In M. Cambridge (Ed.), *The merging of the senses*. The MIT Press.

Steiner, T. J., Stovner, L. J., Al Jumah, M., Birbeck, G. L., Gururaj, G., Jensen, R., … Chatterji, S. (2013). Improving quality in population surveys of headache prevalence, burden and cost: Key methodological considerations. *The Journal of Headache and Pain, 14*(1), 87. http://dx.doi.org/10.1186/1129-2377-14-87

Stevenson, R. A., Siemann, J. K., Schneider, B. C., Eberly, H. E., Woynaroski, T. G., Camarata, S. M., & Wallace, M. T. (2014). Multisensory temporal integration in autism spectrum disorders. *Journal of Neuroscience, 34*(3), 691–697. http://dx.doi.org/10.1523/JNEUROSCI.3615-13.2014

Stevenson, R. A., Wilson, M. M., Powers, A. R., & Wallace, M. T. (2013). The effects of visual training on multisensory temporal processing. *Experimental Brain Research, 225*(4), 479–489. http://dx.doi.org/10.1007/s00221-012-3387-y

Stewart, W. F., Lipton, R. B., Dowson, A. J., & Sawyer, J. (2001). Development and testing of the migraine disability assessment (MIDAS) questionnaire to assess headache-related disability. *Neurology, 56*, 20–28. http://dx.doi.org/10.1212/wnl.56.suppl_1.s20

Stevenson, R. A., Zemtsov, R. K., & Wallace, M. T. (2012). Individual differences in the multisensory temporal binding window predict susceptibility to audiovisual illusions. *Journal of Experimental Psychology: Human Perception and Performance, 38*(6), 1517–1529. http://dx.doi.org/10.1037/a0027339

Stewart, W. F., Lipton, R. B., Whyte, J., Dowson, A., Kolodner, K., Liberman, J. N., & Sawyer, J. (1999). An international study to assess reliability of the Migraine Disability Assessment (MIDAS) score. *Neurology, 53*(5), 988–994. http://dx.doi.org/10.1212/wnl.53.5.988

Stone, J. V., Hunkin, N. M., Porrill, J., Wood, R., Keeler, V., Beanland, M., … Porter, N. R. (2001). When is now? Perception of simultaneity. *Proceedings of the Royal Society B: Biological Sciences, 268*(1462), 31–38. http://dx.doi.org/10.1098/rspb.2000.1326

Sutherland, C. A. M., Thut, G., & Romei, V. (2014). Hearing brighter: Changing in-depth visual perception through looming sounds. *Cognition, 132*(3), 312–323. http://dx.doi.org/10.1016/j.cognition.2014.04.011

Szycik, G. R., Münte, T. F., Dillo, W., Mohammadi, B., Samii, A., Emrich, H. M., & Dietrich, D. E. (2009). Audiovisual integration of speech is disturbed in schizophrenia: An fMRI study. *Schizophrenia Research, 110*(1–3), 111–118. http://dx.doi.org/10.1016/j.schres.2009.03.003

Torsheim, T., Eriksson, L., Schnohr, C. W., Hansen, F., Bjarnason, T., & Välimaa, R. (2010). Screen-based activities and physical complaints among adolescents from the Nordic countries. *BMC Public Health, 10*(1), 324. http://dx.doi.org/10.1186/1471-2458-10-324

Ursino, M., Cuppini, C., & Magosso, E. (2014). Neurocomputational approaches to modelling multisensory integration in the brain: A review. *Neural Networks, 60*, 141–165. http://dx.doi.org/10.1016/j.neunet.2014.08.003

Van Erp, J. B. F., Philippi, T. G., & Werkhoven, P. (2013). Observers can reliably identify illusory flashes in the illusory flash paradigm. *Experimental Brain Research, 226*(1), 73–79. http://dx.doi.org/10.1007/s00221-013-3413-8

van Laarhoven, T., Stekelenburg, J. J., & Vroomen, J. (2019). Increased sub-clinical levels of autistic traits are associated with reduced multisensory integration of audiovisual speech. *Scientific Reports, 9*(1), 1–11. http://dx.doi.org/10.1038/s41598-019-46084-0

Vroomen, J., & Keetels, M. (2010). Perception of intersensory synchrony: A tutorial review. *Attention, Perception & Psychophysics, 72*(4), 871–884. http://dx.doi.org/10.3758/APP.72.4.871

Vroomen, J., Keetels, M., De Gelder, B., & Bertelson, P. (2004). Recalibration of temporal order perception by exposure to audio-visual asynchrony. *Cognitive Brain Research, 22*(1), 32–35. http://dx.doi.org/10.1016/j.cogbrainres.2004.07.003

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E. J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., et al. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review, 25*(1), 58–76. http://dx.doi.org/10.3758/s13423-017-1323-7

Wallace, M. T., & Stevenson, R. A. (2014). And its dysregulation in developmental disabilities. *Neuropsychologia, 64*, 105–123. http://dx.doi.org/10.1016/j.neuropsychologia.2014.08.005

West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision, 8*(16), 1–9. http://dx.doi.org/10.1167/8.16.13

Wilkinson, L. K., Meredith, M. A., & Stein, B. E. (1996). The role of anterior ectosylvian cortex in cross-modality orientation and approach behavior. *Experimental Brain Research, 112*(1), 1–10. http://dx.doi.org/10.1007/BF00227172

Wu, S., & Spence, I. (2013). Playing shooter and driving videogames improves top-down guidance in visual search. *Attention, Perception, and Psychophysics, 75*(4), 673–686. http://dx.doi.org/10.3758/s13414-013-0440-2

Xavier, M. K. A., Pitangui, A. C. R., Silva, G. R. R., de Oliveira, V. M. A., Beltrão, N. B., & de Araújo, R. C. (2015). Prevalence of headache in adolescents and association with use of computer and videogames. *Ciencia e Saude Coletiva, 20*(11), 3477–3486. http://dx.doi.org/10.1590/1413-812320152011.19272014

Yaguchi, A., & Hidaka, S. (2018). Distinct autistic traits are differentially associated with the width of the multisensory temporal binding window. *Multisensory Research, 31*(6), 523–536. http://dx.doi.org/10.1163/22134808-00002612

Zampini, M., Guest, S., Shore, D. I., & Spence, C. (2005). Audio-visual simultaneity judgments. *Perception and Psychophysics, 67*(3), 531–544. http://dx.doi.org/10.3758/BF03193329

Zapata, A. L., Moraes, A. J. P., Leone, C., Doria-Filho, U., & Silva, C. A. A. (2006). Pain and musculoskeletal pain syndromes related to computer and video game use in adolescents. *European Journal of Pediatrics, 165*(6), 408–414. http://dx.doi.org/10.1007/s00431-005-0018-7

Zhou, H. Y., Cai, X. L., Weigl, M., Bang, P., Cheung, E. F. C., & Chan, R. C. K. (2018). Multisensory temporal binding window in autism spectrum disorders and schizophrenia spectrum disorders: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews, 86*, 66–76. http://dx.doi.org/10.1016/j.neubiorev.2017.12.013

Zmigrod, S., & Zmigrod, L. (2015). Zapping the gap: Reducing the multisensory temporal binding window by means of transcranial direct current stimulation (tDCS). *Consciousness and Cognition, 35*, 143–149. http://dx.doi.org/10.1016/j.concog.2015.05.012