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Intentional binding in multisensory event sequences: The role of intentionality, causality, and temporal predictability

The temporal illusion of subjectively experiencing a shorter interval duration between a voluntary action and its produced sensory effect is known as intentional binding (i.e., IB) [Haggard et al., 2002]. The research on IB has mainly focused on the use of abstract events, that lack an inherent causal link between actions and their effects, and, thus, they require the use of adaptation strategies. We proposed the adoption of a more naturalistic approach by using multisensory events that are familiar and learned and, thus, they have inherent causal associations. We hypothesized that this established causal link between the event sequences would lead to an increased IB magnitude without the need for adaptation strategies. We conducted five experiments, where we manipulated the action-effect causal relations, while participants performed a simultaneity judgment task [Cravo et al., 2011]. That is, we presented an audiovisual impact action effect, which could be causally related or not, with a preceding voluntary action and an initial cue. Moreover, we tested for the impact of intentionality by the presence or absence of a voluntary action, while the temporal intervals between the action and effect were fixed or random (i.e., manipulation of temporal predictability). Participant data showed no IB induction for audiovisual abstract (Experiment 1) or naturalistic action effects (Experiment 2). However, an enhanced action-effect causal link from the initial cue up to the effect pair (Experiment 3) for temporally predictable intervals, displayed a robust IB effect. In conflict situations, where the event sequences were either mismatched (unrelated initial cue to action and effect; Experiment 4) or had a mismatched response mapping (different type of voluntary action; Experiment 5), no IB effect was obtained. These findings suggest that IB is bound to an integrated sense of causality, which can be obtained only for causally-linked and temporally predictable sequences of multisensory events. Any disruption in this causal sequence, or absence of voluntary action and temporal action-effect predictability, led to the attenuation of the IB effect.

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Intentional binding in naturalistic multisensory events: The role of semantic relatedness

Previous research have demonstrated that voluntary actions and their sensory effects are perceived closer in time; a phenomenon known as intentional binding (IB). Most up-to-date studies have examined IB employing one-modality action effects, mostly abstract (e.g., Buehner & Humphreys, 2009), yet everyday life actions usually produce multisensory, informationally rich effects. Previous experiments have highlighted the importance of predictable action effects for the occurrence of IB (e.g., Desantis, Hughes, & Wazsak, 2012), however the issue of the outcome's particular characteristics and their effect on the phenomenon has not been decidedly addressed. Recently, Thanopoulos, Psarou, and Vatakis (submitted) used naturalistic multisensory stimuli as action outcomes and showed that IB occurs when voluntary actions and their effects hold an inherent causal link from everyday experience, sparing the use of adaptation strategies. However, given the use of a multisensory effect, the induction of IB may be affected by potential crossmodal binding rivalries (Kostaki & Vatakis, 2016). In particular, the unity assumption (i.e., an observer's belief that some stimuli "go together"; Welch & Warren, 1980) might cause temporal stimulus shifts in order to reinforce a unified percept, which can interact with the temporal shift towards the action, as predicted by IB. Thus, in the present study, we attempted to investigate whether strongly unified multisensory action effects can diminish the IB phenomenon. We presented naturalistic multisensory stimuli as action outcomes on an IB paradigm and chose to vary the temporal parameters and semantic content of the presentations (Vatakis & Spence, 2007). Specifically, we used an simultaneity judgment task, with the auditory and visual stimuli serving as effects of a voluntary action and manipulated the semantic congruency between the streams of each modality. We predicted that congruent stimuli would be strongly unified, often acting against their temporal misplacement towards the action, while this would not be the case for incongruent stimuli. Our results will help shed light, for the first time, on the effect of action outcome characteristics on the IB phenomenon.

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Aging effects on the multisensory perception of the body

Currently there are contrasting evidence on how the character of embodiment and multisensory integration alters with age with only a few studies examining the role of age in multisensory body schema modulations. We, thus, investigated whether the mechanisms that adjust our body schema percept to various incoming sensory information are modulated by age. This was done through the use of two upper limb illusions: the Marble Hand and the Rubber Hand illusion (MHI and RHI, respectively). For MHI, we presented synchronous audio-tactile stimulation to 83 participants that were divided in 3 age groups: minors (0-17), young adults (18-45), and older adults (46-60 years old). The MHI was assessed through a questionnaire developed by Senna et al. (2014). The analysis revealed a limited experience of the MHI irrespective of age. In terms of age, our results showed increased illusory percepts for the minors and young adults as compared to the older adults. No differences between minors and young adults were noted. These results indicate that the audio-tactile update of body material perception is altered through the age span with illusory perception decreasing as we grow older. For the RHI (Botvinick & Cohen, 1998), 210 participants were tested and divided into the same age groups as those in MHI. The data analysis showed that 81% of the participants did experience the illusion but with no significant age-related differences. Utilising Botvinick & Cohen (1998)'s questionnaire, we introduced a qualitative criterion, namely the ratio of the average score of the 3 illusion indicative questions to the average

score of the remaining 6 neutral questions, which resulted in a weak positive correlation between age and ratio and between age group and ratio. Additionally, the participants experienced the illusion differently as a function of age with an increase in score ratio from the 0-17 to the 18-45 age group. These results are consistent with the hypothesis that older adults have a lower experience of embodiment as compared to younger adults and tend to favor visual processing (Costello & Bloesch, 2017). Even though the outcomes of the MHI and RHI aging data may seem contradictory, we suggest that the importance of visual monitoring in the RHI and the absence of it in audio-tactile MHI is the differentiation factor. Overall, there is an influence of age in the multisensory mechanisms of body schema, however more research with larger sample sizes is necessary.

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A behavioural evaluation of inverse effectiveness as a function of stimuli quality and synchrony

One of the most fundamental principles of multisensory integration is that of inverse effectiveness (IE) supporting that maximization of multisensory gain is attained when the unisensory components of an event evoke weak neuronal responses. Previous behavioural investigations of IE have yielded conflicting findings regarding the levels of noise that lead to the maximization of multisensory gain. Furthermore, studies in this field are often limited to the use of speech stimuli and the artificial degradation of the auditory stream. Here, we examined whether IE would be demonstrated behaviorally by implementing naturalistic degradation in both sensory streams of an audiovisual speech event. Specifically, participants were asked to identify three syllables (/ba/, /fa/, /tha/) presented visually, aurally, or audiovisually at different levels of noise and noise combinations. We expected that participants' performance would deteriorate as the noise levels increased for unisensory

conditions, while for audiovisual conditions we expected that multisensory gain would increase as ambiguity in both channels increased as per the predictions of IE. The analysis showed that according to the: a) Contrast index, the gain was minimized when the auditory stream was of the highest noise independent of visual noise for the syllable /ba/, while no differences were noted for /fa/ and /tha/; b) Absolute Difference (in %) index, the combinations of high auditory and low visual noise levels led to a maximum gain for /ba/ and /fa/, while for /tha/, maximum gain was obtained when both streams were of low noise; and c) Multisensory Integration and Absolute Difference indices, the gain was minimized when the auditory stream was of the highest noise for /ba/, but not for /fa/ and /tha/. Therefore, IE was only validated for specific indices and stimuli, and, thus, our findings along with previous studies place the behavioral validation IE in question. Utilizing the high and low gain multisensory combinations of Experiment 1, we examined -for the first time- the interaction of IE with the temporal rule of multisensory integration (i.e., signals presented synchronously or close in time are more likely to be integrated). Specifically, in Exp. 2, the audiovisual speech stimuli from Exp. 1 were presented at different stimulus onset asynchronies and participants had to complete temporal order judgments. The analysis revealed a higher asynchrony tolerance when high gain stimuli were presented as compared to audiovisual pairs of low gain. Taken together, these findings suggest that the magnitude of multisensory gain and the width of the temporal window of integration interact as a function of the effectiveness levels of the auditory and visual streams of the speech event.

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The role of change in interval duration judgements

Temporal judgments belong to a different category of perception due to the fact that there isn't any dedicated sensory system for timing. Thus, the estimation of interval duration requires temporal cues that emerge from transformations of other, non-temporal, perceptual dimensions. Three theories that could account for and predict the role of change in interval duration judgments have been proposed: The change-based account that postulates that the physical or the absolute number of perceived changes that occur within an interval are the cues for its perceived duration (Poynter, 1989). The saliency account emphasizes the apparent aspects of change and considers subjective time dilation as a function of change's perceptual vividness (Herbst, Javadi, van der Meer, & Busch, 2013). Lastly, the neural energy account supports a linear relationship between the neural energy processing requirements of

the stimuli in an interval and its perceived duration (Eagleman & Pariyadath, 2009). Previous research supports that the most crucial temporal cue is the perceived change rather than the physical change, however, it is not clear what is the most important aspect of change perception that affects perceived duration (Herbst et al., 2013). Additionally, it has not been clarified to-date whether higher visual processing demands lead to decreased duration estimates (Brown, 1995; Sgouramani & Vatakis, 2013) or greater selective attention to a stimulus increases its judged duration, irrespectively of the distribution of attentional resources between temporal and non-temporal processing (Mattes & Ulrich, 1998; Tse, Intriligator, Rivest, & Cavanagh, 2004). Hence, we examined which account provides the most appropriate theoretical approach to explain duration judgments of visual stimuli. Change's awareness was considered of special interest to clarify whether duration estimates of intervals in the supra-second range derive from an unconscious metric representation or they are subject to aspects of phenomenal consciousness (Lewis & Miall, 2003; Montemayor, 2017). Our experimental method included a dual task in a flickering paradigm with a change detection task and a temporal reproduction task. We used simple visual geometrical stimuli continuously undergoing one transformation, throughout a trial's duration, which was masked due to the flickering presentation. During stimulus presentation, the timing of perceived change was recorded to examine how attentional distribution affects duration estimates. Subsequently, perceptual change's awareness was assessed using a 4 alternative forced choice task to examine whether unconscious change perception can modulate perceived duration. Moreover, we varied stimulus complexity based on the different predictions offered by the three theoretical accounts. If perceived change is the sole temporal cue, the detection of change will dilate subjective duration, irrespective of stimulus complexity, while if phenomenal change weights differentially, change detection in the less complex stimulus, as appearing more saliently, would dilate more the interval duration than the perceived change of the more complex stimulus. In contrast, based on the neural energy account we would expect that the perceived duration would be a function of stimulus complexity. Our experimental results will elucidate how stimulus changes and the allocation of attention to non-temporal processing demands affect perceived duration.

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Learning to read with a simulation of artificial vision: Experienced-related Changes in Performance on a reading task

In the context of developing a visual prosthesis to restore sight to the blind, it can be useful to examine performance with simulations of artificial vision in order to guide device design. Accordingly, various psychophysical tasks have been administered for measuring performance of normal, sighted subjects and examining the trajectory of improvement over time. Learning effects have been found with eccentric reading for human subjects and with letter recognition tasks for both humans and in non-human primates when there is frequent engagement with the task involved. However, practice with using phosphene vision to perform a more complex task such as reading meaningful sentences, has yet to be evaluated in humans. With the current study, part of a larger project of developing a thalamic visual prosthesis, we sought to examine the beneficial effect of longitudinal learning to read with a simulation of artificial sight. Specifically, we investigated how six normal, sighted subjects adapted to phosphene vision by examining their performance in reading simple, novel sentences out loud in 20-minute sessions on a daily or a near-daily basis, over a period of at least eight weeks. English sentences conforming to the MNREAD criteria, were presented on a LCD monitor through a virtual-reality simulation of artificial vision. The simulation included a real-time gaze contingent architecture that reveals more detail at the point of regard, mimicking a thalamic visual prosthesis. We used five font sizes (logMAR 1.0-1.4) and three

center-weighted phosphene patterns (2000, 1000, 500 phosphenes) to display the text, and included a non-phosphenized view (*i.e.*, normally displayed text) as a control condition. We found that subjects improved their reading accuracy (fraction of words read correctly) in all conditions and training lead to an increase of reading speed (number of correctly read words per minute) that was equivalent to doubling of available phosphenes for each pattern. Most interestingly, the hardest condition (smallest font size through 500 phosphenes), proved highly usable after training while the same pattern did not provide functional reading at the beginning. Consistent with experience-driven neuroplastic changes, we also found that gaps in training tended to lead to temporary decreases in reading speed, but, surprisingly, not reading accuracy. Taken together, our findings suggest that a pattern with 500 phosphenes (130 in central vision) can provide functional reading, an essential activity of daily living. Our results are important for the clinical design of a thalamic prosthesis and as well as post-implant rehabilitation strategies.

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Investigating the Relationship between Face Recognition Ability and False Memories from Misinformation in the Context of Individual Differences

The main purpose of the present, ongoing, study is the investigation of the relationship between Face Recognition Ability (FRA) and False Memories from Misinformation (FMfM), by also emphasizing on the possible effect of individual differences on the above-mentioned variables. More specifically, we investigate how FRA can possibly predict an individual's vulnerability to misinformation and thus, result to the emergence of False Memories, by adopting the 'Classic Misinformation Paradigm'. Our secondary goal is to further investigate and understand how individual differences (i.e. gender, age, educational level) and the exposure time to complex visual stimuli could possibly influence the individuals' identification and further, result to FMfM. Based on findings of previous, similar, studies we hypothesized that individuals with lower FRA will be more prone to experience FMfM. For the investigation of the above hypothesis, up to this point, a sample of 100 participants have been recruited and randomly allocated to one of two experimental groups (control [N=50] and experimental [N=50]). Furthermore, a cognitive battery constructed by the researchers was

used to measure FRA and the amount of False Memories experienced by the participants during the experimental procedure, which consisted of four different stages: In the first stage, participants were requested to pay attention and watch to a brief presentation of pictures/frames depicting a short scene from a movie. In the second stage, participants were asked to recognize the faces presented to them in the first stage of the experimental procedure, in a Face Recognition Cognitive Test. Next, in the third stage of the experiment participants were asked to listen to a series of brief pre-recorded narrations, either depicting the exact events that were presented to them in the first stage of the experiment, or providing them with misinformation cues, depending on the group that they were allocated to (experimental group=misinformation, control group=no misinformation). Finally, in the fourth stage of the experiment, participants were asked to respond to two different types of questionnaires in order to investigate the degree and the source (i.e. pictures, narrations, both) of False Memories that the individuals experienced during the experimental procedure, respectively. Furthermore, up to this point, our results have not indicated a significant relationship between FRA and FMfM. Our second statistical analysis indicated a statistically significant relationship between FRA and a variable we defined as Resistance to Misinformation (RtM), which might indicate that higher FRA and the Recognition of Misinformation (RoM) can be related. Additionally, there was a significant relationship found between the demographic variables such as educational level and: a) FRA, b) overall memory score and c) FMfM. Our results also have not indicated a statistically significant relationship between gender and: a) FRA and b) FMfM. However, our results might have been influenced by several limitations of the present, ongoing study, such as, the small number of participants with a higher educational level and/or the presence of familiar faces in the Face Recognition task, and/or the small number of participants in the experimental group, as well. It was also found that women showed higher overall memory scores than men. Finally, it should be noted that due to the limited age-range of the participants in the present study, the variable of age was not included in the statistical analysis at this time.