Causal events enter awareness faster than non-causal events

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Philosophers have long argued that causality cannot be directly observed but requires a conscious inference (Hume, 1738) . Albert Michotte however developed numerous visual phenomena in which people seemed to perceive causality akin to primary visual properties like colour or motion (Michotte, 1946) . Michotte claimed that the perception of causality did not require a conscious, deliberate inference, but, working over 70 years ago, he did not have access to the experimental methods to test this claim. Here we employ Continuous Flash Suppression (CFS) – an interocular suppression technique to render stimuli invisible (Tsuchiya & Koch, 2005) – to test whether causal events enter awareness faster than non-causal events. We presented observers with 'causal' and 'non-causal' events, and found consistent evidence that participants become aware of causal events more rapidly than non-causal events. Our results suggest that, whilst causality must be inferred from sensory evidence, this inference might be computed at low levels of perceptual processing, and does not depend on a deliberative conscious evaluation of the stimulus. This work therefore supports Michotte's contention that, like colour or motion, causality is an immediate property of our perception of the world.

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19 **ABSTRACT**

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21 inference (Hume, 1738). Albert Michotte however developed numerous visual phenomena in

22 which people seemed to perceive causality akin to primary visual properties like colour or motion

23 (Michotte, 1946). Michotte claimed that the perception of causality did not require a conscious,

24 deliberate inference, but, working over 70 years ago, he did not have access to the experimental

25 methods to test this claim. Here we employ Continuous Flash Suppression (CFS) – an interocular

26 suppression technique to render stimuli invisible (Tsuchiya & Koch, 2005) – to test whether causal

27 events enter awareness faster than non-causal events. We presented observers with 'causal' and

28 'non-causal' events, and found consistent evidence that participants become aware of causal events

29 more rapidly than non-causal events. Our results suggest that, whilst causality must be inferred

30 from sensory evidence, this inference might be computed at low levels of perceptual processing,

31 and does not depend on a deliberative conscious evaluation of the stimulus. This work therefore

32 supports Michotte's contention that, like colour or motion, causality is an immediate property of

33 our perception of the world.

34

INTRODUCTION

35

36   One of the first lessons we instill in statistics courses is that a *'correlation doesn't equal*

37   *causation'*. Philosophically speaking however, the lesson should go much deeper than that. David

38   Hume famously argued that causality was not something that could be observed at all. Even if we

39   manipulate one variable such that it consistently leads to a certain outcome, we can use reason to

40   infer causality from this contingency, but our senses cannot actually observe the causal interaction

41   (Hume, 1738). Kant goes even further, and argues that causality is not a feature of the world, but

42   is a phenomenon we experience because our minds bring the concept of causality to the world

43   (Kant, 1783). Kant's ideas have received renewed expression in the 'User Interface Theory' which

44   claims that we experience a constructed virtual reality, which has evolved to be useful, rather than

45   veridical (Hoffman, Singh & Prakash, 2015). The 'virtual' nature of our experience of the world

46   is illustrated by the perception of colour, in which it is clear that *'the rays, to speak properly, are*

47   *not colored'* (Newton, 1704), and that colour is not inherent to a particular wavelength. Similarly

48   causality is not inherent to particular contingencies of spatiotemporal dynamics, rather causality is

49   an inference the mind brings to those dynamics.

50   Framed in this way, the key question then becomes: at what stage of mental processing is

51   causality inferred? Albert Michotte famously argued that causality was a perceptual phenomenon,

52   and did not require a deliberate, conscious inference (Michotte, 1946). In the 1940s, Michotte

53   developed a series of ingenious displays which demonstrated that parametric variations in the

54   spatiotemporal attributes of a stimulus could predictably influence whether a causal percept was

55   elicited. In one classic example, Michotte presented observers with a *launching* event in which an

56   object moves toward another stationary object, and stops right in front of it. The second object

57   then immediately starts to move along the same trajectory (Figure 1A). This event almost

58   irresistibly evokes a causal impression, in which the first object appears to cause the motion of the

59   second object. Based on this observation, and a series of meticulous experiments with critical

60   parametric variations, Michotte argued that human observers *perceive* causality, and that causality

61   is akin to a primary visual property such as colour or motion. In the seventy years following his

62   seminal contribution, the discussion on the perceptual versus cognitive basis of causality

63   perception has remained wide open (Weir, 1978; Scholl & Tremoulet, 2000; Wagemans, van Lier

64   & Scholl, 2006; Wolff, 2007; Rips, 2011; Rolfs, Dambacher & Cavanagh, 2013; Arnold et al.,

65   2015). Whilst the demonstrations developed by Michotte do appear compelling, it is hard (if not

impossible) to know whether one's conscious thoughts and intentions –whilst watching the stimuli– shape or influence the way in which we perceive them, particularly given that participants are fully aware of the display, and are primed to think about, and indeed make judgements about causality (Choi & Scholl, 2006).

Here we seek to further Michotte's work by exploiting modern experimental methods to ensure participants are not initially conscious of the stimuli presented to them, and importantly never have to make causality judgments on the stimuli. More specifically, in two experiments, we used a modified version of Continuous Flash Suppression (CFS) (Tsuchiya & Koch, 2005; Moors, Wagemans & de-Wit, 2014) that is able to render moving events invisible for extended periods of time, by presenting a dynamic noise pattern to one eye (Figure 1B), suppressing the stimulus presented to the other eye. The particular implementation of CFS employed here is a paradigm also known as the breaking CFS or b-CFS paradigm (Stein, Hebart & Sterzer, 2011). Here, initially suppressed stimuli are gradually increased in contrast during a certain initial time window and then presented at maximal contrast until they "break into" awareness as measured by participants' detection time with respect to a certain stimulus attribute (e.g., its location (left/right or up/down) relative to the fixation cross). We reasoned that if a differential sensitivity to causal and non-causal events is revealed through CFS, this would imply that the visual system differentially processes these events in the absence of a conscious inference. It is important to stress that the "absence of a conscious inference" does not pertain to so-called "unconscious processing" of the causal nature of these events. Rather, it refers to the fact that participants are not required to consciously evaluate the causal nature of the events they are presented with. Although the paradigm employed in this study could be extended to address this question about unconscious processing of causal events, the use of suppression times in principle allows us only to measure any kind of differential sensitivity to the causal nature of the events, be it due to pre-conscious or conscious processing (Stein, Hebart & Sterzer, 2011; Stein & Sterzer, 2014). Note that the use of the so-called "binocular control condition" (Jiang, Costello & He, 2007) does not ameliorate this problem. Therefore, we did not implement such a condition in both experiments reported here.

EXPERIMENT 1

In our first experiment, we presented observers with *launching* (causal) and *passing* (non-causal) events while these were rendered invisible through CFS. The launching event contained

97   two discs, the first disc would start moving towards a second stationary disc, stop right in front of

98   it, at which point the second disc would start moving. The passing event also involved two discs,

99   but the first disc completely overlapped the second disc before the latter started moving (Figure

100 1A) (Scholl & Nakayama, 2002). At trial onset, these events were invisible to participants and they

101 were continuously repeated until participants detected any aspect of the discs emerging through

102 the CFS mask (i.e., observers responded as soon as they saw one or more discs). Importantly, the

103 task was completely unrelated to the causal nature of the events.

104

105   **METHODS**

106 **Participants**. We recruited 24 participants, of which 18 were included in the final analysis. The

107 other 6 participants were excluded because of exclusion criteria defined further below. All had

108 normal or corrected-to-normal vision and participated in return for course credit or a monetary

109 compensation. The study was approved by the local ethics committee of the faculty (the Social

110 and Societal Ethics Committee of the KU Leuven (SMEC) under the approval number G-2014 08

111 033). All participants provided written informed consent prior to the start of the experiment. As

112 we did not have a good intuition about the size of any potential effect, we did not specifically

113 determine our sample size before the start of the experiment. Rather, we decided to collect (what

114 is considered to be) a decent number of participants (~25).

115

116 **Apparatus**. Stimuli were shown on two 19.8-in. Sony Trinitron GDM F500-R (2048 x 1536 pixels

117 at 60 Hz, for each) monitors driven by a DELL Precision T3400 computer with an Intel Core Quad

118 CPU Q9300 2.5 GHz processor running on Windows XP. Binocular presentation was achieved by

119 a custom made stereo set-up. Two CRT monitors, which stood opposite to each other (distance of

120 220 cm), projected to the left and right eye respectively via two mirrors placed at a distance of 110

121 cm from the screen. A head- and chin rest (15 cm from the mirrors) was used to stabilize fixation.

122 The effective viewing distance was 125 cm. Stimulus presentation, timing and keyboard responses

123 were controlled with custom software programmed in Python using the PsychoPy library (Peirce,

124 2007, 2009).

125

126 **Stimuli**. The background of the display in both eyes consisted of a random checkerboard pattern

127 to achieve stable binocular fusion. The individual elements of the checkerboard were 0.34° by

128   0.34°. In both eyes, a grey frame (10° by 10°) where the stimuli were presented was superimposed

129   on the checkerboard pattern. A black (eye dominance measurement) or white (main experiment)

130   fixation cross was presented at the start of each trials for 1 second (size 0.5° by 0.5°). In the eye

131   dominance measurement phase, the target consisted of an arrow (maximal width 4°, maximal

132   height 2°) and the CFS mask consisted of 150 squares with randomly selected sizes between 1°

133   and 2° and a random luminance value. Two grey discs (1° of visual angle) were used to generate

134   the launch and pass events. The starting position of the first disc was located at one of 8 different

135   positions along a virtual circle (2.5° and 3.5° radius for the pass and launch events, respectively)

136   at equally spaced angles (0 – 270°, in steps of 45°). This manipulation of event direction was used

137   to ensure that participants would not adapt to specific event directions over the course of the

138   experiment, and thus to provide sufficient variation with respect to the stimuli that were presented.

139   The starting position of the second disc was always in the centre of the virtual circle. The centre

140   of the virtual circle was jittered on each trial (in a range of +- 0.5° horizontally and vertically). The

141   discs moved at a speed of 5°/s. As the duration for the launch event would be shorter compared to

142   the pass event for a fixed trajectory length, we adjusted for this by increasing the total distance

143   travelled for the launch event by 1°. We adjusted the length of the trajectory, rather than the speed

144   at which the discs moved as this could induce saliency differences between the events to which we

145   know CFS is sensitive (Moors, Wagemans & de-Wit, 2014). The first disc always appeared from

146   behind a virtual occluder and the second disc would disappear behind a virtual occluder as the

147   event sequence ended after 1000 ms. To ensure a continuous flow of events, 100 ms after the first

148   event sequence, the event initiated again in the reverse order. That is, what previously was the

149   second disc now would appear from behind a virtual occluder, approach what previously was the

150   first disc, and this disc would disappear again behind a virtual occluder. This event loop continued

151   until the participant's response. In the case of a launch, the first disc always stopped just before

152   the second disc after which the second disc started moving, yielding a percept of the first disc

153   causing the movement of the second disc. For a pass event, the first disc stopped when it fully

154   overlapped with the second disc after which the second disc started moving, yielding a percept of

155   the first disc passing over the second disc and completing its trajectory.

156   The CFS mask (8° x 8°) consisted of 104 moving squares (Moors, Wagemans & de-Wit,

157   2014) with a random luminance value and size (uniform range 0.2 to 2°), moving at a speed

158   between 3°/s and 7°/s (randomly determined for each element using a uniform range). The mask

159   elements would be partially occluded if they moved outside of the 10° x 10° frame. If they

160   disappeared completely from behind one side of the frame, they would be moved behind the

161   opposite side of the frame continuing on the same trajectory.

162

163   **Procedure**. In the first part of the experiment, participants' eye dominance was measured

164   according to the procedure outlined by Yang et al. (Yang, Blake & McDonald, 2010). Here, on

165   each trial, a CFS mask was presented to one eye while an arrow pointing either to the left or the

166   right was presented to the other eye and gradually increased in contrast. Upon breakthrough of the

167   arrow stimulus, the participant had to indicate its direction as quickly as possible. Eye dominance

168   was then determined by comparing the mean suppression times for both eyes, and the eye for

169   which the CFS mask elicited the longest mean suppression times was taken as the dominant eye.

170   In all subsequent parts of the experiment, the CFS mask was presented to this eye.

171   In the main part of the experiment, participants were presented on each trial with a moving

172   CFS mask in one eye and a launch or pass event in the other eye (presented in one of eight

173   directions). The discs started at 3% contrast at the beginning of the trial and the contrast was

174   increased by 3% after each iteration of the event sequence. The participants' task was to indicate

175   as quickly as possible when they perceived one or more discs that became visible among the

176   moving squares. We included catch trials in which no event was presented. These catch trials self-

177   terminated after 10 seconds, upon which a new trial was initiated. Experimental trials were always

178   presented until breakthrough. Participants were told before the start of the experiment that trials

179   could sometimes self-terminate, and that this was a characteristic of the experiment to ensure trials

180   would not take too long to complete. Before starting the main experiment, participants completed

181   a practice block to become acquainted with the task.

182   **Design**. The experiment consisted of a 2 x 8 within-subjects design with the factors event type

183   (launch vs. pass) and event direction (eight different, evenly spaced, directions). Participants

184   completed 192 experimental trials in total. 48 catch trials were included. All conditions were

185   randomized across trials. The practice block consisted of 16 trials.

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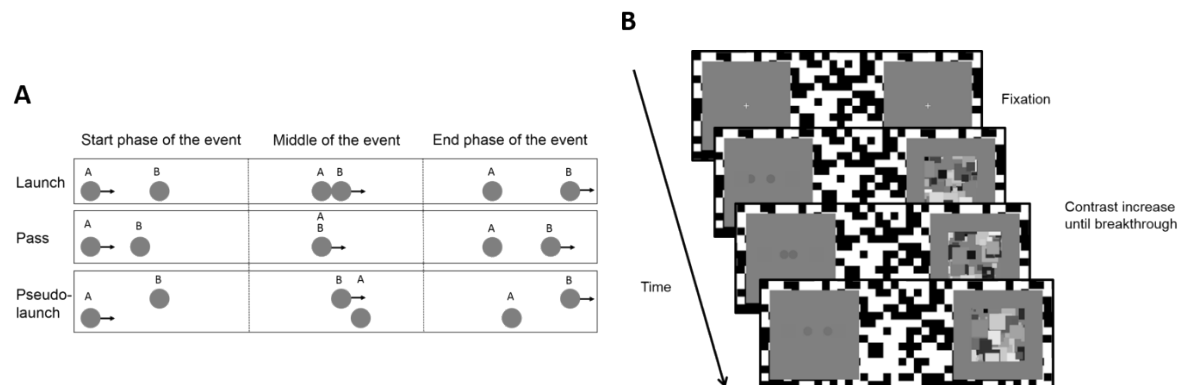
188   Figure 1. (A) Events used in both experiments. In the launch event (Experiments 1 and 2), a disc

189   starts moving toward a stationary disc, stops right in front of it, and the stationary disc then starts

190   moving. In the pass event (Experiments 1 and 2), a disc starts moving toward a stationary disc,

191   stops when it fully overlaps with the stationary disc, and the stationary disc then starts moving. In

192   the pseudo-launch event (Experiment 2), a disc starts moving toward a stationary disc, and stops

193   after passing by the side of the stationary disc, after which the stationary disc starts moving. (B)

194   Trial sequence used in the experiments. After a fixation period (1 second), the moving CFS mask

195   was presented to the dominant eye and the (non-) causal event to the other eye. The disc events

196   repeated and gradually increased in contrast until observers detected any part of the discs. In the

197   second frame, the first disc is not drawn as a full disc because it appears from behind the virtual

198   occluder.

199

200

201   **Data-analysis.** All analyses were conducted in R 3.2.0, a statistical programming language (R

202   Core Team, 2014). All statistical tests were performed in the Bayesian framework relying on

203   model selection through Bayes Factors, using the R BayesFactor package (version 0.9.12-2)

204   (Morey & Rouder, 2015). In short, the Bayes Factor quantifies how consistent the data are with

205   the predictions of one statistical model relative to those of another and therefore provides an

206   intuitive measure to quantify the degree of belief in one statistical model over another (e.g., a

207   model with and without a main effect of event type). All fitted models were ANOVA-style models

208   including random intercepts for participants, and the default settings for the priors (medium prior

209   scale for fixed effects and nuisance prior scale for the participant random effect). We used the

210   variables "event type" (launch vs. pass) and "event direction" (the 8 directions were recoded into

211   horizontal vs. vertical vs. oblique) as predictors in the analysis. As a guideline to interpret the

212   resulting Bayes Factors, we use the classification proposed by Jeffreys (Jeffreys, 1961) in that

213   Bayes Factors from 3 onwards constitute substantial evidence for one model over the other. The

214   data for Experiments 1 and 2 are available at https://figshare.com/s/cb4521afc14ced461fdc.

215

RESULTS AND DISCUSSION

216

217   All participants that responded on more than 5 (~10%) catch trials were removed from the

218   data (*n* = 2). Furthermore, because we wanted to analyse suppression times that were recorded

219   after the first appearance of an event (which was after 500 ms), we excluded all trials in which the

220   suppression time was shorter than 800 ms (i.e., we took a minimal response time of 300 ms and

221   added that to the time point at which the discs interacted to determine the threshold). This ranged

222   from deleting no trials to 25% of trials (*M* = 4.2, *SD* = 7.3). If more than 10% of the participants'

223   data needed to be removed due to this, we removed the participant from the analysis (*n* = 4).

224   Additionally, we defined outliers as suppression times that deviated more than three standard

225   deviations from the participants' mean suppression time and removed these observations. This

226   ranged from deleting no trials to 2% of trials (*M* = 1.1, *SD* = 0.55). Please note that including

227   outliers, or including the participants that did not perform well on the catch trials or responded too

228   fast on more than 10% of trials, does not change the outcome of the analyses. We refer to the

229   Supplementary Materials for an analysis in which we assess the robustness of the results based on

230   all combinations of exclusion criteria (exclusion based on percentage responses on catch trials,

231   exclusion based on percentage too fast trials, exclusion of outliers). Due to their positive skewness,

232   suppression times were logarithmically transformed at the participant level, before subjecting them

233   to any analysis.

234   The results indicated that launch events (*M* = 3.86 s, *SD* = 1.50) entered awareness faster

235   than pass events (*M* = 4.14 s, *SD* = 1.57) (BF > 100 for a model including an effect of event versus

236   an empty model containing only random participant variability), for nearly every observer (Figure

237   2). Table 1 summarizes the results of the Bayes Factor analysis. As can be derived from the Table,

238   a main effect of event direction was also observed. This main effect was mostly due horizontal

239   event directions (*M* = 3.70 s, *SD* = 1.37) entering awareness faster compared to the vertical (*M* =

240   4.09 s, *SD* = 1.69) and oblique (*M* = 4.11 s, *SD* = 1.56) directions.

241   Table 1. Bayes Factor analysis of Experiment 1.

Model	Bayes Factor	Error
Condition + Direction	1	0
Condition * Direction	37	0.03
All other models	> 100	NA

242   *Note.* All Bayes Factor were computed with the best fitting model (top row) in the numerator and

243   the model under consideration in the denominator. All reported Bayes Factors thus can be

244   interpreted as how much more consistent the data are with the predictions made by the best fitting

245   model compared to the model under consideration.

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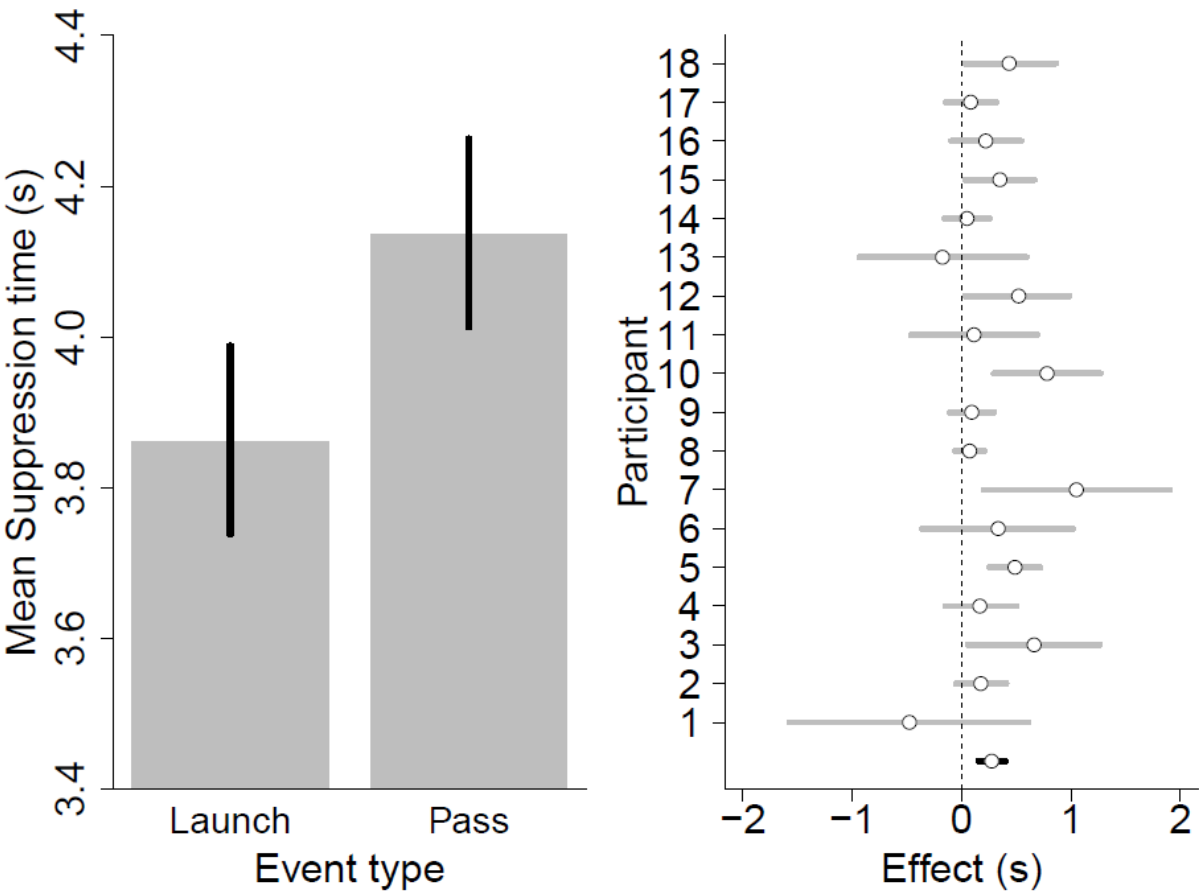
248   Figure 2. Results of Experiment 1. (left) Bar plot depicting mean suppression times for both event

249   types. Errors bars are 95% within-subject confidence intervals. (right) Plot depicting the effect of

250   event type for each observer separately (gray) and across all observers (black, difference between

251   the bars in the left figure).. Dots depict the mean difference between suppression times from pass

252 and launch events, where positive values indicate that launch events entered awareness faster
253 compared to pass events. Lines indicate 95% bootstrapped confidence intervals (based on 10000
254 bootstrap samples). Almost all dots lie to the right of a zero difference, indicating that launch
255 events enter awareness faster than pass events for nearly every observer.

256 These results indicate that the visual system is sensitive to the causal structure of events in
257 such a way that this sensitivity influences the pace at which these events enter awareness, when
258 they are initially rendered invisible. Whilst this difference could reside in the potential to interpret
259 one event as causal, the launch and pass events differ in a number of other ways, amongst which
260 an aspect we refer to as the local motion contrast. That is, although pass events were drawn such
261 that the first disc stopped when it completely overlapped with the second disc prompting the
262 motion of the second disc, perceptually these events consist of a continuous motion signal. In
263 contrast, launch events contain sharp motion on- and offsets. Indeed, it is known that low-level
264 differences in contrast, spatial frequency, or orientation sometimes drive observed differences
265 between suppression times (Gray et al., 2013; Moors et al., 2016b). In our second experiment, we
266 sought to replicate the difference found in the first experiment in an independent sample, and
267 included an additional control condition for the difference in the local motion contrast between the
268 launch and pass event. This additional control condition (referred to as a "pseudo-launch" event)
269 was exactly the same as the launch event (in terms of stimulus energy), except for the starting
270 position of the first disc, which was shifted such that it would stop after passing by the side of the
271 second stationary disc. This means that the secondary disc would only start moving after the first
272 disc had stopped in a location where it could not logically have caused the motion of the second
273 (Figure 1A), while the event contains the same number of sharp motion on- and offsets.

EXPERIMENT 2

METHODS

276 **Participants.** We recruited 27 new participants, of which 17 were included in the final analysis.
277 One participant failed to complete the full experiment, and 9 others were excluded because of the
278 exclusion criteria used during data analysis. All participants had normal or corrected-to-normal
279 vision and participated in return for course credit or a monetary compensation. The study was
280 approved by the local ethics committee of the faculty (the Social and Societal Ethics Committee

281   of the KU Leuven (SMEC) under the approval number G-2014 08 033). All participants provided

282   written informed consent prior to the start of the experiment. Because the effect observed in

283   Experiment 1 appeared quite strong (according to the Bayes factor analysis), we decided to collect

284   a similar number of participants in Experiment 2.

285   **Apparatus.** The experimental set-up was exactly the same as in Experiment 1.

286   **Stimuli.** The stimuli were exactly the same as in Experiment 1, except for the pseudo-launch event

287   described here. The pseudo-launch event was modified from the sequence of the launch event. A

288   pseudo-launch event was generated by shifting the starting position of the first disc upward or

289   downward (relative to the second disc, orthogonal to the direction of motion of the disc) by the

290   size of the disc. The starting position of the first disc was also shifted forwards 2 times the size of

291   the disc in the direction in which it would travel, such that during its movement it would pass next

292   to the second disc, and stop just after it had passed by the side of the second disc. The second disc

293   would then move in exactly the same manner in which it moves in the launch event.

294   **Procedure.** The procedure was exactly the same as in Experiment 1.

295   **Design.** The experiment consisted of a 3 x 8 within-subjects design with the factors event type

296   (launch vs. pass vs. pseudo-launch) and event direction (eight different, evenly spaced, directions).

297   Participants completed 192 experimental trials in total. 48 catch trials were included. All

298   conditions were randomized across trials. The practice block consisted of 16 trials.

299   **RESULTS AND DISCUSSION**

300   We used the same data processing pipeline as in Experiment 1. All participants that

301   responded on more than 5 (~10%) catch trials were removed from the data ($n = 5$). All trials in

302   which the suppression time was shorter than 800 ms were also excluded. This ranged from deleting

303   no trials to deleting 60% of trials ($M = 6$, $SD = 12.9$). Five participants exceeded the threshold of

304   more than 10% trials shorter than 800 ms. One of these also fulfilled the criterion to be excluded

305   based on responding to more than 10% of catch trials. Thus, the total number of participants that

306   was removed based on the exclusion criteria was equal to 9. Additionally, we excluded outlying

307   suppression times defined as deviating more than three standard deviations from the participants'

308   mean suppression time. This ranged from deleting no trials to deleting 2.6% of trials ($M = 1.1$, SD

309   = 0.8). Again, including these outlying trials, or including the participants that did not perform

310   well on the catch trials or had too many fast responses, does not change the outcome of the analyses

311   (see Supplementary Materials), and only strengthened the evidence for the pattern of results

312   reported here. Logarithmically transformed suppression times were again the unit of analysis, and

313   event direction was recoded in the same way as in Experiment 1.

314   The results of Experiment 2 replicate the result of the first experiment showing that launch

315   events ($M = 3.58$ s, $SD = 1.21$) entered awareness faster than pass events ($M = 3.82$ s, $SD = 1.34$)

316   (see Figure 3). Critically, launch events also entered awareness faster than pseudo-launch events

317   ($M = 3.75$ s, $SD = 1.21$). Table 2 summarizes the results of the Bayes Factor analysis, which are

318   very much in line with the results of Experiment 1. Indeed, the best fitting model is exactly the

319   same as in Experiment 1. The main effect of event direction was again due to horizontal event

320   directions ($M = 3.42$ s, $SD = 1.04$) breaking suppression faster compared to vertical ($M = 3.94$ s,

321   $SD = 1.44$) and oblique event directions ($M = 3.76$ s, $SD = 1.27$). Furthermore, paired Bayesian t-

322   tests indicated that launch events entered awareness faster than pass events (BF > 100) and pseudo-

323   launch events (BF = 3), while the data appeared to be most consistent with the absence of a

324   suppression time difference for pass and pseudo-launch events (BF < 0.1).

325   Thus, the results of Experiment 2 indicated that the suppression time difference between

326   launch and pass events was confirmed in an independent sample. Furthermore, the addition of the

327   pseudo-launch event revealed that this type of event entered awareness as fast as pass events did

328   rather than launch events. This indicates that the local motion contrast was not exclusively

329   determining the suppression time difference observed in Experiment 1, and puts more weight to

330   interpreting the suppression time differences being due to the differences in the causal structures

331   of the events.

332   Table 2. Bayes Factor analysis for Experiment 2.

Model	Bayes Factor	Error
Condition + Direction	1	0
Direction	33	0.024
All other models	> 200	NA

333   *Note.* All Bayes Factor were computed with the best fitting model (top row) in the numerator and

334   the model under consideration in the denominator. All reported Bayes Factors thus can be

335   interpreted as the how much more consistent the data are with the predictions made by the best

336   fitting model compared to the model under consideration.

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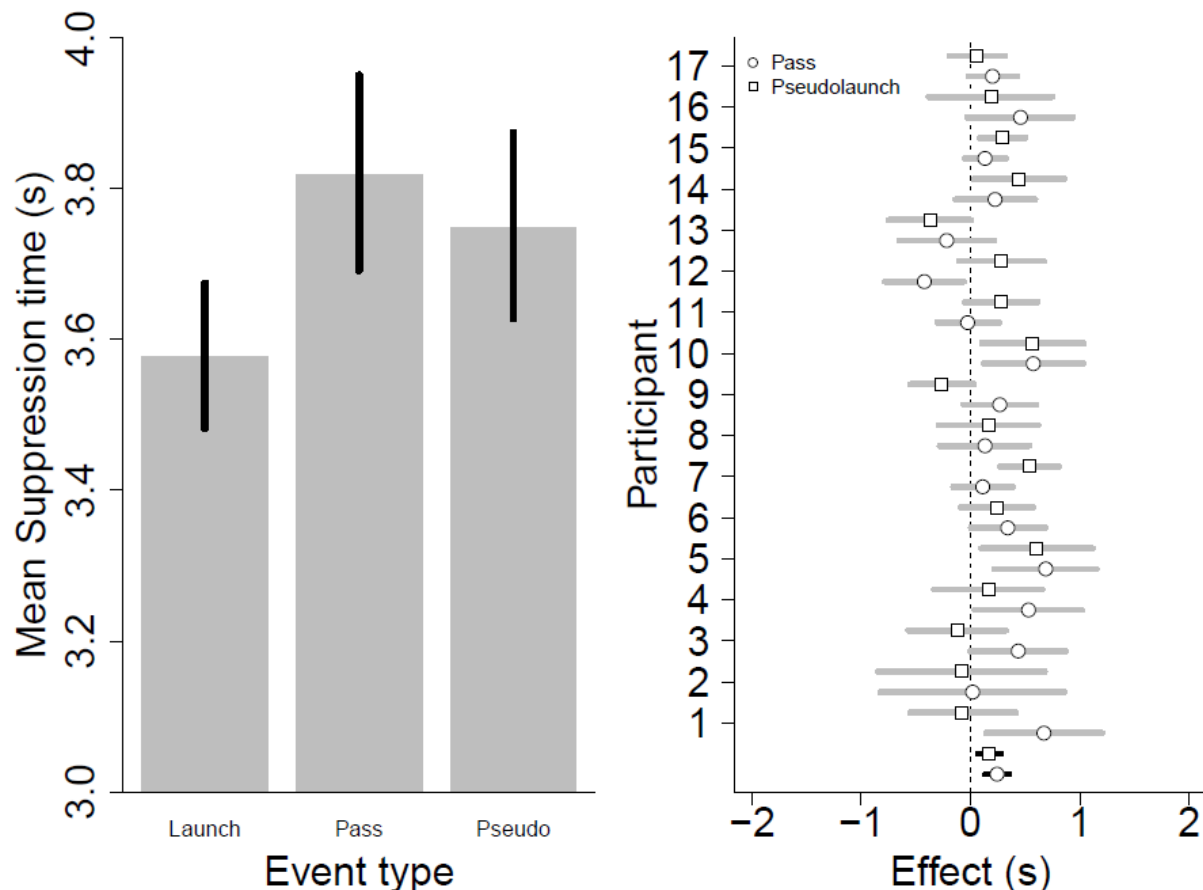
339   Figure 3. Results of Experiment 2. (left) Bar plot depicting mean suppression times for all three

340   event types. Errors bars are 95% within-subject confidence intervals. (right) Plot depicting the

341   effect of event type for each observer separately (gray) and across all observers (black, difference

342   between the bars in the left figure). Dots depict the mean difference between suppression times

343   from pass and launch events, where positive values indicate that launch events entered awareness

344   faster compared to pass events. Squares depict the same information, but now for launch vs.

345   pseudolaunch events. Lines indicate 95% bootstrapped confidence intervals (based on 10000

346   bootstrap samples). Most of the data points lie to the right of a zero difference, indicating that

347   launch events enter awareness faster than pass or pseudolaunch events.

348   **DISCUSSION AND CONCLUSION**

349   The results of Experiments 1 and 2 both suggest that the human visual system shows
350   differential sensitivity to events that are more or less able to elicit causal percepts. This suggests
351   that whilst our senses clearly cannot directly register the *'... connexion betwixt causes and effects'*
352   (Hume, 1738), the ability to compute a difference between events that are more or less likely to
353   elicit causal percepts occurs independent of observers having to explicitly report their percept of
354   the event.. This result is very consistent with Michotte's claim that *'there is actual perception of*
355   *causality, in the same sense that there is perception of shapes, movements (il y a veritablement*
356   *perception de la causalité, au meme titre qu'il y a perception de formes, de mouvements)'*
357   (Michotte, 1946). In other words, just as we do not have to consciously infer that something is
358   'round' or 'fast', it seems we do not have to consciously reflect for the visual system to compute
359   the difference between events that more or less likely to elicit causal percepts. This conclusion had
360   been suggested by Michotte's work, but these previous demonstrations and experiments were
361   always limited by the fact that participants were aware of the stimuli, primed to think about them,
362   and make judgements in terms of causality (Choi & Scholl, 2006), a term not even mentioned to
363   participants during the experiments.

364   As such, our results provide additional evidence for the claim that the causal structure of
365   events is encoded as a basic and elemental feature by the visual system. Indeed, along these lines,
366   a recent study showed that it is possible to measure adaptation aftereffects after prolonged exposure
367   to launch events. Furthermore, this adaptation aftereffect was retinotopically specific lending
368   further support to the notion that the aftereffect is perceptual in nature and that neuronal
369   populations might exist that are dedicated to the encoding of causal events (Rolfs, Dambacher &
370   Cavanagh, 2013) – but see Arnold et al. (2015) for contrasting views on this finding. Second,
371   neuroimaging studies have provided evidence that the neural signature associated with the
372   causality of events is independent from attending these events or not or having to explicitly judge
373   the causality of the events, suggesting that the causal structure of events is a basic feature encoded
374   by the visual system (Blakemore et al., 2001; Fugelsang et al., 2005; Roser et al., 2005). Third, the
375   perception of causality develops already very early in infancy (Saxe & Carey, 2006). Last,
376   similarity judgments of launching events that vary in their spatial and temporal properties (i.e.,
377   spatial and temporal gaps between both objects) indicate that the classic launching stimulus is
378   easiest to discriminate from other launching stimuli, highlighting its distinctive nature during
379   visual processing (Young & Sutherland, 2009).

380   Our results can also be framed to be informative about what is processed during perceptual

381   suppression induced by CFS. That is, although initial b-CFS studies seemed to provide very strong

382   evidence for elaborate and complex unconscious processing of the suppressed stimulus (Jiang,

383   Costello & He, 2007; Mudrik et al., 2011; Sklar et al., 2012), evidence has been accruing that

384   processing of a stimulus rendered invisible through CFS is largely restricted to basic visual features

385   such as orientation, spatial frequency, color, curvature, contrast energy, and spatial coherence

386   (Gray et al., 2013; Hedger, Adams & Garner, 2015; Moors et al., 2016a,b; Moors, Wagemans &

387   de-Wit, 2016). Furthermore, neural processing of the invisible stimulus has been shown to be

388   largely restricted to early visual areas (Hesselmann & Malach, 2011; Yuval-Greenberg & Heeger,

389   2013; Fogelson et al., 2014). Together with the neuroimaging evidence on the perception of causal

390   events, we speculate that the observed advantage for causal events could stem from early levels of

391   visual processing, basically extracting the features of the retinal stimulation and organizing them,

392   before deliberately making sense of them.

393   On a more cautionary note, whilst we can say that the visual system appears to display a

394   heightened sensitivity to events that are known to be more or less able to elicit causal percepts, we

395   cannot definitively prove that this is because the visual system has made an inference that one

396   event is causal and one not. It could be that early visual processing identifies some spatiotemporal

397   properties as a 'proto-causal' representation, which requires further elaboration before a truly

398   causal inference is made. With this limitation in mind however, we argue that this result provides

399   evidence that further strengthens Michotte's claim that causality, like shape or motion, is a basic

400   feature of our perception.

401
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404

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